# ELECTRICAL MEASUREMENTS.

## ELECTROMAGNETIC MEASUREMENTS.

**2457.** A current of electricity is not a material substance, and, therefore, has no *dimensions* (length, area, or weight) by which it might be measured. *A current of electricity must, therefore, be measured by the effects which it produces.*

**2458.** These effects manifest themselves as follows :

*When a current of electricity is flowing in a conductor, the energy expended in overcoming the resistance of the conductor manifests itself as* **heat.** The amount of this energy is equal to the square of the current times the resistance (see Art. **2341**); therefore, the heat generated in a circuit will be proportional to the square of the current if the resistance be constant, or to the resistance if the current be constant.

*When a current of electricity flows through a conducting liquid, the liquid is decomposed.* This decomposition is due to a chemical action of the current, known as **electrolysis,** and is distinct from the heating effect. The decomposition either liberates a certain amount of gas or deposits one or more of the elements of the liquid upon one of the electrodes. *The amount of liquid decomposed is directly proportional to the quantity* (coulombs) *of current;* hence, the rate of decomposition, or the amount of liquid decomposed per unit of time, is proportional to the strength of the current in amperes.

*When a current of electricity flows through a conductor, a field of magnetic force is set up around the conductor which*

*tends to produce a relative motion in any other magnetic field in the vicinity;* as, for instance, that emanating from a magnet pole. The force acting on such a pole will be directly proportional to the strength of the current, to the length of the conductor, to the strength of the magnet pole, and inversely proportional to the square of the distance between the conductor and the magnet pole.

An instrument which measures a current by its electromagnetic effect is called a **galvanometer.**

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## THEORY OF THE GALVANOMETER.

**2459.** As the units of electrical measurements are based upon the so-called "absolute" or "C. G. S." system (see Art. **2254**), measurements of current by means of electrolytic effect can be made only when the effect of unit current has been previously determined. By the electromagnetic action the absolute value of a current may be derived as follows :

As stated in Art. **2458,** the force exerted on a unit pole by a neighboring current is proportional to the strength of the current, to the length of the conductor, to the strength of the pole, and inversely proportional to the square of the distance from the conductor to the unit pole.

Then, to exert unit force on the unit pole, it is necessary to employ unit current, and a conductor of unit length, that is, one centimeter long, which must be bent to an arc of unit (one centimeter) radius, in order that each part of the conductor be at unit distance from the unit pole.

Under these conditions, a current of one C. G. S. unit flowing through the conductor will act on a unit pole at the center of the arc to which the conductor is bent with a force of one *dyne.* Thus the absolute value of one C. G. S. unit of current may be determined.

**2460.** When a magnetic pole is placed near another magnetic pole, the attraction (or repulsion) of the two poles is proportional to the product of the strengths of the two

poles, and inversely proportional to the square of the distance between them ; so, two equal magnetic poles, which, when placed at a unit distance (one centimeter) apart, exert a force of attraction or repulsion on one another of *one dyne*, are said to be of *unit strength.*

**2461.** In Art. **2272** it was pointed out that the C. G. S. unit of current is ten times greater than the practical unit, the latter being more convenient to use. Similarly in Arts. **2282** and **2303** the C. G. S. and practical values of the units of resistance and electromotive force were given.

It would be very difficult to construct apparatus that would fulfil the conditions given in Art. **2459.** It is much easier to use a conductor bent into a complete circle, and as the effect of changing various dimensions is known from the relations given in Art. **2459,** a formula may be constructed which will give the effect on a magnet pole of a current flowing through a conductor of any length bent to any radius.

Let $r$ represent the radius in centimeters to which the conductor is bent; now, if the conductor be of sufficient length to be bent into a coil of more than one turn having a radius $r$, the length of *each turn* of the bent conductor is $\pi d = 2\pi r$ centimeters, and the *total length* of the conductor $= 2\pi r t$ centimeters, where $t$ represents the number of turns that the conductor makes when bent into the coil. The distance between the conductor and the center of the coil is obviously equal to $r$ centimeters; then the force that a current of 1 C. G. S. unit flowing through the coil would exert on a unit magnet pole placed at the center of the coil $= \frac{2\pi r t}{r^2}$ dynes, being directly proportional to the length of the conductor, and inversely proportional to the square of the distance between the magnet pole and the conductor. (Art. **2458.**)

This force being also directly proportional to the strength of the current, a current of $A$ C. G. S. units will exert a

force of $A \times \frac{2\pi r t}{r^2}$ dynes; or, representing the force exerted on the magnet pole in dynes by $f$,

$$f = \frac{2\pi A r t}{r^2}.$$

Dividing both terms of the fraction by $r$,

$$f = \frac{2\pi A t}{r}, \qquad \textbf{(448.)}$$

which is the formula required.

**2462.** It is not convenient to directly measure the force exerted on a unit pole by a current circulating in a coiled conductor.

If, however, any magnet pole can be influenced by a known constant force in one direction, then, by exerting upon it another force, due to a current circulating in a coil, but acting in a different direction, the resultant of the two forces may be accurately determined and the value of the second force measured.

This known constant force is furnished by the earth itself, which is a magnet of such enormous size that for short distances the direction of its lines of force may be considered as perfectly parallel. The actual direction of the earth's field is not horizontal, but at an angle to the horizontal, so the actual field may be said to be made up of two components—a horizontal and a vertical component. The horizontal component is most frequently made use of in measurements, as in this case. A small bar magnet placed across the earth's field of force will have equal and opposite forces acting on its poles or ends, since the lines of force act in a parallel direction ; this results in turning the magnet about its center, if the magnet is free to move, until the forces act in a direct line with the center, when it can no longer move. This is illustrated by the magnet in the common compass. The force of the earth's field tends to keep the magnet parallel to the lines of force of the earth's field, and, consequently, the magnet points *north* and *south*.

**2463.** Fig. 980 illustrates this action. The direction of the earth's field of force is represented by the line *a b*. A bar magnet, *N S*, placed across this line at an angle with it will have equal and opposite forces acting upon the poles *N* and *S*, as shown by the arrows. These forces may be considered as parallel to the line *a b*; so, if the magnet be free to turn about its center, these forces will bring it to a state of rest when the line *a b* passes through the magnet from *N* to *S*.

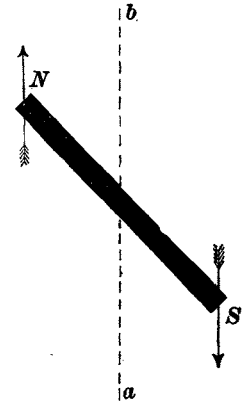

FIG. 980.

If the magnet *N S* be acted upon by another force at an angle with *a b*, the magnet will come to rest at a point where the two forces balance.

In Fig. 981 the magnet *N S* is acted upon by the earth's field along the line *a b*, the direction of the force on the *N* pole of the magnet being along the line *d N*, and that on the *S* pole along the line *c S*, as indicated by the arrow-heads. In addition, another force is acting along the line *x y*, at right angles to *a b*, the direction of the force on the *N* pole being along the line *c N*, and on the *S* pole being along the line *d S*, as indicated by the arrows. Under the influence of these two forces the magnet is deflected into the position shown, where it remains at rest, making the angle *m*° with the line *a b*.

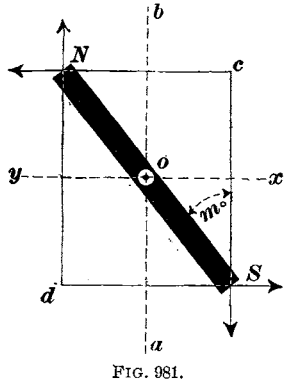

FIG. 981.

Calling the horizontal component of the strength of the earth's field *H*, the strength of the force acting along the line *x y*, *f*, and the strength of each pole of the magnet *N S*, *p*, then the forces acting on the *N* pole of the magnet are equal to $H \times p$ in the direction *d N*, and $f \times p$ in the

direction $c\,N$; the forces acting on the $S$ pole are equal to $H \times p$ in the direction $S\,c$, and $f \times p$ in the direction $d\ S$. The force $H \times p$ acting in the opposite directions on the two poles of the magnet form a couple tending to rotate the magnet about its center $o$. The moment of this couple is equal to one of the forces multiplied by the perpendicular distance between their lines of action. (See Art. **906.**) That is, the moment of the couple produced by the force $H\,p$ is equal to $H\,p \times c\ N$, and its direction is right-handed. Similarly, the force $f\,p$ produces a couple which tends to produce left-handed rotation of the magnet, and the moment of this couple is $f\,p \times S\,c$. Since the magnet is in equilibrium, that is, at rest, these two moments are equal, and

$$f\,p \times S\,c = H\,p \times c\,N, \text{ or } f \times S\,c = H \times c\,N.$$

Since this last equation does not contain $p$, it follows that the deflection of the magnet *is independent of the strength of the magnet.*

Since $f \times S\,c = H \times c\,N$, $f = H\frac{c\,N}{S\,c}$.

In Art. **754,** rule **5,** it is stated that the tangent of an angle is equal to the side opposite divided by the side adjacent.

In Fig. 981, $c\,N$ is the side opposite the angle $m°$, and $S\,c$ the side adjacent. Therefore, $\frac{c\,N}{S\,c}$ is the tangent of the angle $m°$, and the force $f$ is given by the formula

$$f = H \times \tan m°. \qquad \textbf{(449.)}$$

$H$ being constant, $f$ varies as the *tangent of the angle through which the magnet is deflected.* An instrument which measures current on this principle is called a **tangent galvanometer.**

**2464.** The horizontal component ($H$) of the earth's field has been accurately measured at various places, and the following table gives the values for some well-known localities:

## TABLE 84.

15 **HORIZONTAL COMPONENT OF THE EARTH'S MAGNETISM.**

| Locality. | Value of Component. Lines of Force per Square Centimeter. |
|---|---|
| London, England..... | .180 |
| Paris..... | .188 |
| Berlin..... | .178 |
| Rome..... | .240 |
| Montreal..... | .147 |
| Niagara..... | .167 |
| Halifax..... | .159 |
| Boston..... | .170 |
| New York..... | .184 |
| Philadelphia..... | .194 |
| Washington..... | .200 |
| Chicago..... | .184 |
| Cleveland..... | .184 |
| San Francisco..... | .255 |

### TANGENT GALVANOMETER.

**2465.** It is necessary that the lines of force that influence the magnet be practically parallel within the range covered by the swing of the magnet. With the earth's field this is the case, as has been pointed out in Art. **2462**; but with a coiled conductor, this only holds true of a very small space relative to the diameter of the coil, at the center of the coil. A tangent galvanometer must, therefore, have a magnet of short length as compared with the diameter of the coil.

A magnet $\frac{3}{4}$ in. long can be used with a coil of 8 in. diameter with accurate results.

The deflections of a magnet as short as this could scarcely

be read directly. A very thin light pointer is, therefore, attached to the magnet, usually at right angles to it, which extends out over a scale upon which the deflections may be read.

Fig. 982 gives a top view of a simple tangent galvanometer in which $N\ S$ is the coil of wire and $P$ is the pointer attached to the permanent magnet $M$. Two scales are shown,

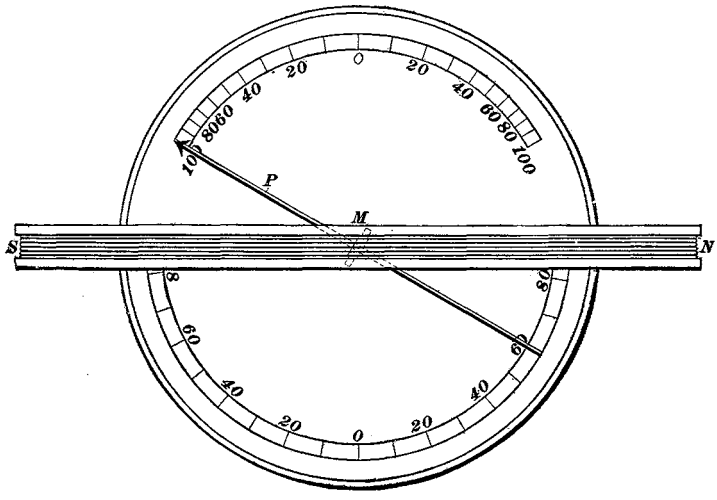


FIG. 982.

one on each side of the coil. One is divided into degrees, and the divisions on the other are proportional to the tangents of the angles represented by the divisions on the degree scale.

**2466.** In order that a variety of current strengths may be measured with the same instrument, it is customary to wind the coil in two or more parts, of varying number of turns and size of wire. The terminals of these parts of the coil are led out to binding-posts, *b*, *b*, *b*, *b*, Fig. 983, on the base of the instrument, so that either one or all the parts of the coil may be used. Even this method of winding does not give much range to the instrument. Another way of regulating its indications is to vary the *effective* earth's

field, which may be accomplished by placing a permanent bar magnet, called a **controlling magnet,** in the plane of the coil and parallel to it.

Fig. 983 shows a tangent galvanometer, with an adjustable controlling magnet *m*. If this controlling magnet be so placed that its *N* pole corresponds in direction with the *N* pole of the magnet of the instrument, its field will be added to the earth's field, so that a given current will give a smaller deflection than if the controlling magnet were removed. If the polarity of the controlling magnet be reversed, the opposite effect will result, and the instrument will give a deflection with a very small current.

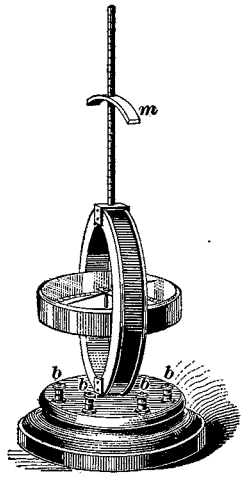

FIG. 983.

**2467.** Controlling magnets are used on many forms of galvanometers; there is a difficulty, known as **drift,** which attends their use, especially when used to make the galvanometer very sensitive. This difficulty is due to the fact that the direction of the earth's field is continually changing slightly, and its effect is to make the zero-point of the instrument vary from time to time. This effect may be shown by the diagram in Fig. 984. In (*a*), *n o* represents the direction and magnitude of the force due to the earth's field, and *n m* the direction and magnitude of the force due to the controlling magnet. The resultant *n s* is then the direction which the magnet of the instrument would assume. Now if the direction of the earth's field change through a slight angle to the position shown in (*b*), the resultant is then the line $n_1 s_1$, and its direction is at an angle

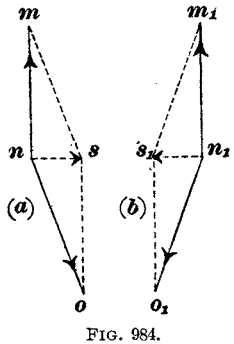

FIG. 984.

of nearly 180° to the resultant $n\,s$. If the controlling magnet had not been used, there would have been a slight "drift," but the use of the controlling magnet to lessen the effective field very much magnifies the effect of any change in the direction of the earth's field.

**2468.** When a controlling magnet is used, it is necessary to find the deflection that a certain known current will produce, as the actual value of $H$ is no longer known. Knowing the deflection with a given current, other currents may be measured, as the galvanometer is still governed by the same law, and formula **449** may be changed to read

$$C = K \tan m^\circ, \qquad \textbf{(450.)}$$

where $C$ = current in amperes and $K$ = a constant, called the *galvanometer constant*, by which the tangent of the angle of deflection must be multiplied to get the value of the current flowing. This process of finding the constant of a galvanometer or other measuring instrument by comparing it with a known standard is called **calibration.**

The formula for the value of $f$ with this form of tangent galvanometer is the same as before, viz., $f = H \tan m^\circ$, but the value of $H$ is now the intensity of the earth's field *plus* or *minus* (according to its polarity) the intensity of the field due to the controlling magnet. After having found the *galvanometer constant*, this value of $H$ may be calculated.

**2469.** The following examples illustrate the application of the formulas of the tangent galvanometer:

EXAMPLE.—What will be the force in dynes exerted on a unit magnet pole placed at the center of a coiled conductor of three turns bent to a circle of 12 cm. radius, by a current of 2 C. G. S. units?

SOLUTION.—Use formula **448,** $f = \dfrac{2\pi A t}{r}$.

$2\pi = 6.2832$; $A = 2$; $t = 3$; $A t = 6$; $r = 12$.

Then, $f = \dfrac{6.2832 \times 6}{12} = \dfrac{37.6992}{12} = 3.1416$ dynes. Ans.

EXAMPLE.—A tangent galvanometer has the following dimensions: Mean diameter of coil, $7\frac{1}{2}$ in.; number turns first section, 3; number turns second section, 1. If this instrument is set up in Boston, and a

current of 2 amperes* is sent through the first section of the coil, what will be the deflection of the magnet in degrees?

SOLUTION.—Use formula **448**, $f = \frac{2\pi A t}{r}$.

Diameter of coil = 7⅞ in. = 20 cm.; turns = 3; amperes = 2; C. G. S. units = .2.

Therefore, $f = \frac{2 \times 3.1416 \times .2 \times 3}{10} = \frac{3.76992}{10} = .376992$ dyne due to coil.

Also, from formula **449**, $f = H \times \tan m°$.

Transposing, $\tan m° = \frac{f}{H}$. $H = .170$. (Table 84.)

Therefore, $\tan m° = \frac{.376992}{.170} = 2.2176$.

Referring to the table of Natural Tangents, the tangent of the angle 65° 46′ is 2.2134. This is as nearly correct as the deflection could be read on the scale. Ans. 65° 46′, nearly.

**2470.** EXAMPLE.—Another galvanometer is constructed exactly like that referred to in Art. **2469**, but with a controlling magnet attached to increase its range. The two galvanometers are connected together by wires, so that the *second section* of the coil of the *first galvanometer* (called No. 1) is in series with the *first section* of the galvanometer with the controlling magnet (called No. 2). On sending a current through the two instruments, the deflection of No. 1 is 52°, while the deflection of No. 2 is but 38°. (*a*) What current is passing through the galvanometers, and (*b*) what is the value of the galvanometer constant of No. 2, if the experiment is made in Philadelphia?

SOLUTION.—(*a*) Consider No. 1 only.

From formula **449**, $f = H \tan m°$.

As $H = .194$, $m° = 52°$, and $\tan m° = 1.28$, nearly,

$$f = .194 \times 1.28 = .24832.$$

Also, from formula **448**, $f = \frac{2\pi A t}{r}$, or $\frac{2\pi A t}{r} = .24832$; hence, $\frac{6.2832 \times A \times 1}{10} = .24832$; $.62832\,A = .24832$, and $A = .3952$ C. G. S. units of current.

As $A$ equals C. G. S. units, this result must be multiplied by 10 to give practical units = 3.952 amperes. Ans.

(*b*) In No. 2 the current is 3.952 amperes and the tangent of the angle of deflection = tan 38° = .7813, nearly; substituting in formula

* Whenever the word *ampere* is used alone, the practical unit (one-tenth of the C. G. S. unit) is understood. The C. G. S. unit, when used, is called the *C. G. S. unit.*

**450,** $C = K \tan m°$ ; $C = 3.952$, and $\tan m° = .7813$, $3.952 = K \times .7813$, or $\frac{3.952}{.7813} = K = 5.058$. Ans.

REMARK.—This value of $K$ is only good for the first section of the galvanometer coil, which consists of three turns. If the value of $H$ in formula **449,** $f = H \tan m°$, be calculated for this galvanometer, then changes may be made in the number of turns of the coil used, without recalculating a galvanometer constant, if the controlling magnet be unchanged.

In the example above given, the value of $f$ in No. 2 is obviously three times that in No. 1, as the same current passes through three times the length of wire. Therefore, $f = 3 \times .24832 = .74496$, and $\tan m° = \tan 38° = .7813$, nearly. As $\frac{f}{\tan m°} = H$, then, $\frac{.74496}{.7813} = H = .9535$.

This value of $H$ represents the combined value of the field due to the earth and that due to the controlling magnet. As will be seen, the intensity of this field is nearly five times that of the earth alone; so galvanometer No. 2 may be used to measure currents of about five times the strength that No. 1 will measure under the same conditions.

### EXAMPLES FOR PRACTICE.

**2471.** 1. A coil of wire is wound 20 cm. in diameter and consists of 5 turns. Through this coil a current of 12 amperes is passed. What will be the force exerted on a unit magnet pole at the center of the coil? Ans. 3.77 dynes.

2. Using the same galvanometer, a current of 5 amperes is passed through the second section of the coil. (*a*) What will be the deflection in degrees? (*b*) What would be the deflection if the instrument were in Washington instead of Boston? (*c*) What current would a deflection of 46° indicate, using the first section of the coil and taking the measurement in Chicago?

Ans. { (*a*) 61° 35′, nearly. (*b*) 57° 31′, nearly. (*c*) 1.009 amperes nearly.

3. A galvanometer with a coil 12 in. diameter having 12 turns of wire gives a deflection of 42° when a certain current is passed through, the instrument being set up in Montreal. What is the value of this current in amperes? Ans. .267 ampere.

### SINE GALVANOMETER.

**2472.** Another form of galvanometer, shown in Fig. 985, employs much the same principle as the tangent galvanometer, except that its coil $C$ is movable about a vertical axis.

This instrument being set up with the plane of its coil in the earth's magnetic meridian, and the pointer (which, as in the tangent galvanometer, is usually fixed at right angles to the magnet) at zero, a current is sent through the coil by means of the wires $W$, which deflects the magnet. The coil is then turned in the same direction that the magnet is deflected, until in such a position that the magnet comes to rest with the plane of the coil coinciding with the direction of the magnet. This point is usually determined by a mark on a part of the support of the coil, which must be made to register with the pointer attached to the magnet. The angle through which the coil has been turned is read by a vernier from a scale of degrees $S$ attached to the base of the instrument, *and the sine of this angle multiplied by the proper constant gives the current flowing in the coil*, whence the name.

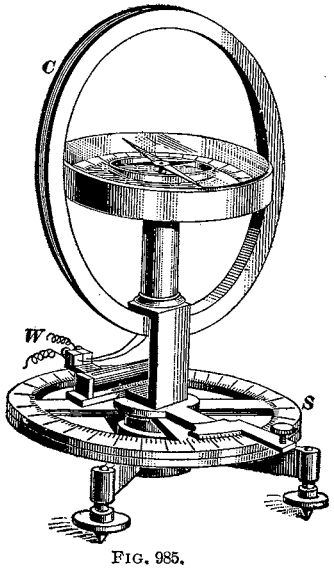

FIG. 985.

**2473.** The theory of the sine galvanometer may be demonstrated as follows:

In Fig. 986, $NS$ is a magnet which is acted on by the earth's field along the line $a\,b$, the direction of the force on the $N$ pole being represented by the line $Nc$. Another force is also acting on the magnet at right angles to its axis $NS$, along the line $xy$. This force acts on the $N$ pole in the direction represented by the line $N\,d$. As the forces acting on the $S$ pole are equal to those acting on the $N$ pole, only the latter need be considered.

As before, call the horizontal component of the strength of the earth's field $H$, the strength of the force acting along the line $xy$, $f$, and the strength of the pole of the magnet, $p$.

Let the line $Nc$ represent the amount and direction of the force $Hp$ due to the earth's field, and the line $Nd$ the amount and direction of the other force; then, by completing the parallelogram of forces (see Art. **875**) the resultant of the two, $Ne$, is found.

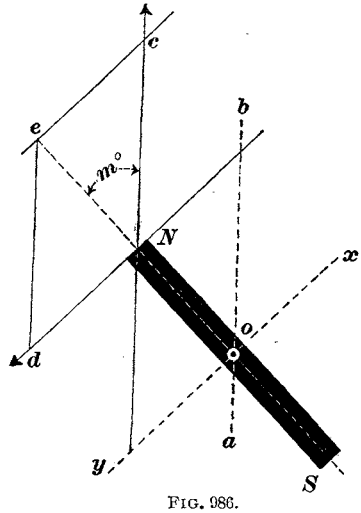

FIG. 986.

This resultant $Ne$ represents the direction and amount of the single force that would deflect the magnet to the position shown, where it makes the angle $m°$ with the line $Nc$, which is parallel to $a\,b$.

It is evident that the lengths $Nc$ and $Nd$ can represent $H$ and $f$, respectively, since they have been assumed to represent those amounts each multiplied by the constant $p$. Then, as $Nd = c\,e$ and $Nd = f$, $f = c\,e$. From Art. **754**, rule **2**, $c\,e = Nc \sin m°$; hence, as $f = c\,e$ and $H = Nc$,

$$f = H \sin m°. \qquad \textbf{(451.)}$$

NOTE.—This principle may also be demonstrated by the use of couples, as in the case of the tangent galvanometer, and it is recommended that the student work out that demonstration himself.

The value of $f$ may be obtained in the same manner as for the tangent galvanometer.

If a magnet be used whose length is nearly equal to the inside diameter of the coil, the current will still be proportional to the sine of the angle of deflection of the needle, as the axis of the needle is always at right angles to the lines of force of the coil, but the value of $f$ will no longer be correct if calculated from formula **448**, as the force acting on the magnet poles is not uniform throughout the area

enclosed by the coil, but is greater near the coil than towards the center, and formula **448** gives the force at the center only.

The sine galvanometer is not as convenient an instrument to use as the tangent galvanometer, as the coil must be carefully adjusted to the correct position to get accurate results instead of taking the reading directly from the position of the pointer, but it is more accurate than ordinary forms of tangent galvanometers.

### REFLECTING TANGENT GALVANOMETER.

**2474.** If the needle of a tangent galvanometer be suspended by a fiber of raw silk or other similar material without twist, and if a beam of light reflected from a small mirror attached to the needle be used for a pointer, very accurate measurements of the deflection can be obtained.

An instrument so constructed is known as a **reflecting tangent galvanometer.** It is usual in this case to set up a suitably divided *straight* scale some distance from, and parallel to, the normal (zero) position of the mirror. The lamp giving the light is located behind the scale, in which is a small slit or hole through which the necessarily small beam of light passes, being reflected from the mirror back to the scale.

Since the reflected beam of light makes the same angle *with the mirror* that the original beam does, but on the opposite side of a perpendicular to the mirror, the angle between the original beam and the reflected beam will be equal to *twice the angle of deflection of the mirror.* Allowance for this fact, also for the fact that a *straight* scale is used, must be made in calculating the constant of a reflecting tangent galvanometer.

It is usual in this class of instruments to make the magnet of a number of small magnets, made from short bits of steel needles or pieces of watch-spring, and arrange one-half of the magnets with their poles opposing the remainder, which makes the magnet **astatic;** that is, the earth's field has almost no directive force on the magnetic system

of the instrument. By using a strong controlling magnet, the instrument is made almost independent of the earth's field, and thus errors or drift due to variations in the horizontal component of the earth's magnetism are rendered of little effect.

**2475.** When the magnetic system and mirror are thus constructed and suspended by a long fiber, considerable difficulty in reading may be met with, owing to the length of time required for the needle to come to rest after being deflected. This is corrected by **damping** the moving parts of the instrument, which may be effected by suspending from the needle a small fan of very light construction, which, by reason of the friction of the air on the blades of the fan as it moves, causes the needle to swing more slowly and come to rest at once.

This damping effect is an important feature of most measuring instruments. Other methods than that given above are used, one of which is to enclose the moving magnetic needle in a cavity in a block of copper; movement of the needle then sets up little eddy currents in the copper block, which retard the movement of the needle, giving the desired damping effect.

In the D'Arsonval galvanometer, described in the following article, the damping of the moving coil is effected by winding that coil on a bobbin of thin copper or other nonmagnetic metal. The movement of this bobbin with the coil through the field generates eddy currents in the bobbin itself, which currents produce the required damping effect.

### THE D'ARSONVAL GALVANOMETER.

**2476.** Another electromagnetic measuring instrument which is quite extensively used is the **D'Arsonval galvanometer,** which derives its name from its inventor, a French physicist. Its principle is slightly different from most of the other forms of galvanometers in that the magnet is large and stationary, and the coil is small and movable. It consists of a large permanent horseshoe magnet, between the poles of which is suspended a coil of wire.

Current is led to the coil by means of the suspension, and this current in the coil causes the coil to rotate about its axis, the tendency of the coil being to place itself at right angles to the lines of force. This tendency is opposed by the suspension, which may be a spring or an elastic wire or fiber. A pointer may be attached to the coil to indicate its deflection, though usually a mirror is used, a reflected beam of light from which forms the pointer, as in the reflecting tangent galvanometer. In many forms of this instrument a soft iron core is supported between the poles of the magnet, a space being left between the core and the magnet in which the coil swings. This core serves to increase the strength of the field in which the coil moves.

By suitably shaping the poles of the magnet, the intensity of the magnetic field in various parts may be so varied that the movement of the beam of light will be directly proportional to the current in the coil. Fig. 987 represents one form of the D'Arsonval galvanometer. In the figure, *PP* is the magnet; *C*, the movable coil; *S*, *S*, fine platinum wires, which suspend the coil *C*; *M*, the mirror, and *I*, the iron core, which is supported from the back in the center of the coil *C*. Connection from the binding-posts *B*, *B* to the coil *C* is made through the platinum suspension wires *S*, *S*. One of the chief advantages of this instrument is the fact that external fields, such as the earth's magnetism, have little effect upon it, so that it requires no controlling magnet or correction for the earth's field, and may be used near dynamos and large masses of iron without being affected.

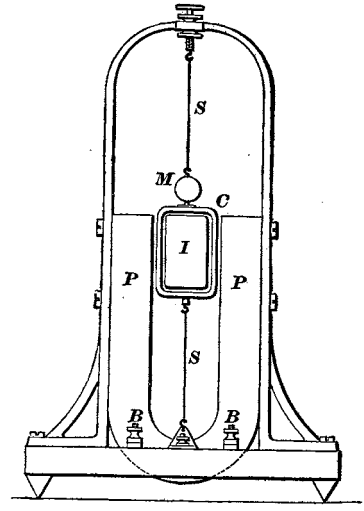


FIG. 987.

Many of the commercial forms of portable instruments are built on the principle of this galvanometer, as will be described.

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### REFLECTING GALVANOMETER.

**2477.** It is often desirable to use an instrument for indicating the presence of very small currents without necessarily measuring their value. For this purpose, the reflecting tangent galvanometer is modified by making the coils of considerably less diameter in proportion to the length of the magnet, and by winding the coil with a great

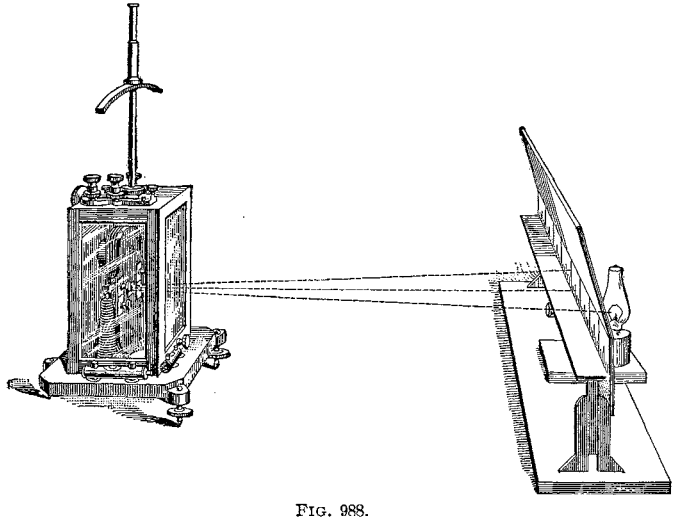

FIG. 988.

many turns of wire, so as to make a very strong field at the center of the coil with a feeble current. The magnetic system is made astatic, but the magnets that point in one direction are hung considerably below those that point in the opposite, and each set of magnets has its own coil; in order that the magnetic system may be suspended in the center of the coils, each coil is wound in two equal parts, and, when mounted, a very small space is left between the parts, through which the fiber which suspends the system passes.

This form of instrument is known as a **reflecting galvanometer.** Fig. 988 shows one form of this instrument. with lamp and scale.

### BALLISTIC GALVANOMETER.

**2478.** A special form of reflecting galvanometer known as a **ballistic galvanometer** is used for measuring transient currents, such as are induced in a conductor if a current in a neighboring conductor be started or stopped, or if a magnet be moved in the vicinity. This form of galvanometer has its magnetic system constructed so as to be of considerable weight, and so arranged as to give the least possible damping effect. If a momentary current pass through the coils of the instrument, the impulse given to the needle does not cause appreciable movement of the magnetic system until after the current has ceased, owing to the inertia of the heavy moving parts, which results in a slow swing of the system after the impulse has ceased; the maximum angle of swing may be read by watching the spot of light, reflected from the mirror attached to the magnetic system, move across a suitably divided scale, and noting the point at which the spot of light ceases to move and begins to swing back. The *quantity* of electricity (the number of coulombs) that pass through the coils of the instrument is proportional to *the sine of one-half the angle of deflection of the needle:*

$$Q = K \sin \frac{m^\circ}{2}. \qquad (452.)$$

The deflection being usually small, the quantity of electricity may be regarded as directly proportional to the angle of deflection. As the use of the mirror and ray of light as a pointer merely doubles the angle of deflection, it will introduce no serious error to consider the quantity of electricity proportional to the swing of the spot of light across the scale, and formula **452** may be modified to read

$$Q = K\,d, \qquad (453.)$$

where $d$ = deflection in scale divisions.

**2479.** Fig. 989 shows one form of ballistic galvanometer in which $C$, $C$, are the two parts of the coil, either of

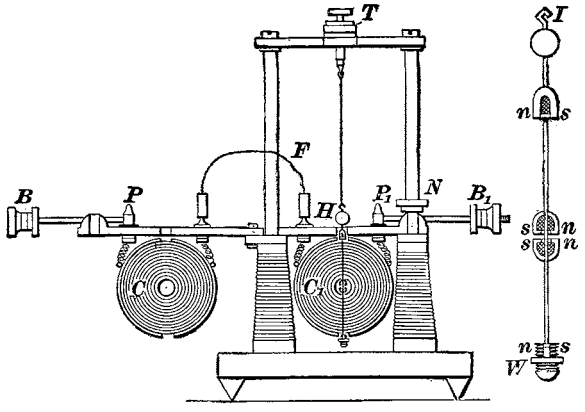


FIG. 989.

which may be swung back, as shown, to examine or remove the magnetic system.

Each coil is supported from a brass strip, both of which are clamped in place by the nut $N$.

Connections to the coils are made from the terminals $P$, $P_1$, the coils being connected together through the flexible cable $F$, which allows either coil to be swung aside without disturbing the connections.

When in use, the instrument is surrounded by a case (not shown) through which the binding-posts $B$, $B_1$ project.

The magnetic system, an enlarged section of which is shown at the right, is suspended by a fine quartz fiber from the torsion head $T$, the magnets and mirror being hooked on to the lower end of the suspension by the hook $I$.

The magnets are thimble-shaped, and filled with lead to give weight. The system is rendered astatic by the arrangement of polarities as shown, the upper and lower magnets being the stronger, and, therefore, directing the system. No external controlling magnet is used with this system, so drift is very nearly eliminated; the sensibility of the system is varied by screwing the small soft iron ring $W$

up or down on the lower magnet. If the ring is screwed up, it *short-circuits* some of the lines from that magnet, thus weakening its effect on the system.

**2480.** One of the principal uses to which the ballistic galvanometer is put is measuring the magnetic qualities of iron.

Samples of the iron to be tested, usually in the form of a ring, are wound throughout their length with insulated wire, so that if a steady current be sent through the wire the ring will be magnetized. If a second coil of wire be wound for a short distance over the first coil, any change in the number of lines of force in the ring will induce an electromotive force in the second coil.

A ring so wound is represented in Fig. 990, where $R$ is

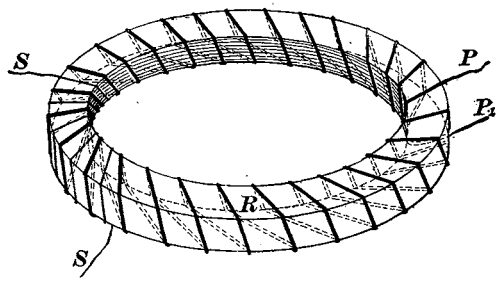


FIG. 990.

the iron ring, $P P_1$ the *primary* or magnetizing coil, $S S$ the *secondary* or induction coil.

*If the coil $S S$ be closed through a circuit of fixed resistance, the number of coulombs of electricity that will flow in this secondary circuit when the number of lines of force passing through that coil is changed will be directly proportional to the amount of change in the number of lines of force.*

This is independent of the *rate of change;* for, assuming that the number of lines of force changes uniformly for one second, and that the turns of the secondary coil are such that 1 volt is generated in that coil, then, if the resistance of the entire secondary circuit is 1 ohm, 1 ampere will flow for 1 second, or as long as the E. M. F. is being generated;

that is, the *quantity* of electricity will be *one coulomb*. Now, if the number of lines of force be changed by the same amount, but in *two* seconds, only $\frac{1}{2}$ volt will be generated in the secondary coil, and only $\frac{1}{2}$ ampere will flow in the secondary circuit, but it will flow for two seconds, and the quantity of electricity will be the same as before.

The same holds true if the rate of change in the number of lines is not uniform, which is usually the case.

**2481.** If known currents be sent through the primary coil $P P_1$, the magnetizing force **H** may be readily calculated. (See formula **430.**) Any change in this magnetizing current will produce a change in the number of lines of force in the iron ring, which will be indicated by a swing of the galvanometer needle, and the amount of this swing will indicate the relative amount of change in the number of lines of force passing through the secondary coil. For calibrating the ballistic galvanometer for magnetic measurements, it is usual to note the swing when a known number of lines of force is made to cut the turns of a coil in the galvanometer circuit. This may be done by preparing a coil of wire wound on a bobbin of considerable size, and arranging it between supports so that it may be rotated through 180°; by placing the coil with its plane at right angles to the direction of either the vertical or the horizontal component of the earth's magnetism, the rotation of the coil will cause its sides to cut the lines of force of the earth's field. If the value of the component be known, the number of lines enclosed by the coil, and, therefore, the number cut by its rotation, can be calculated, the area of the space enclosed by the coil being known. This method, known as the *earth coil method*, is open to the objection that the components of the earth's magnetism vary slightly from time to time.

**2482.** Another method for determining the magnetic properties of iron is shown in Fig. 991, where the apparatus and connections are indicated. The iron to be tested is in the shape of a flat iron ring *I*, upon which is evenly wound a certain known number of turns of insulated wire, the

terminals being $p$ and $p'$. This is called the *primary* or chief coil. The same number of turns of insulated wire are wound on a wooden or other non-magnetic core, with the terminals at $t$ and $t'$. The coil $C$ is called the *calibrating* coil. On the iron ring $I$ and also at the center of the length on the coil $C$ are wound induction-coils, or secondary coils, consisting of a few turns of insulated wire.

As the dimensions of the coil $C$ and the current passing through the coil are measurable, the exact number of lines of force per square inch designated by **H** in air, wood, or other non-magnetic medium, may readily be determined by formula **430.** According to Art. **2478** and formula

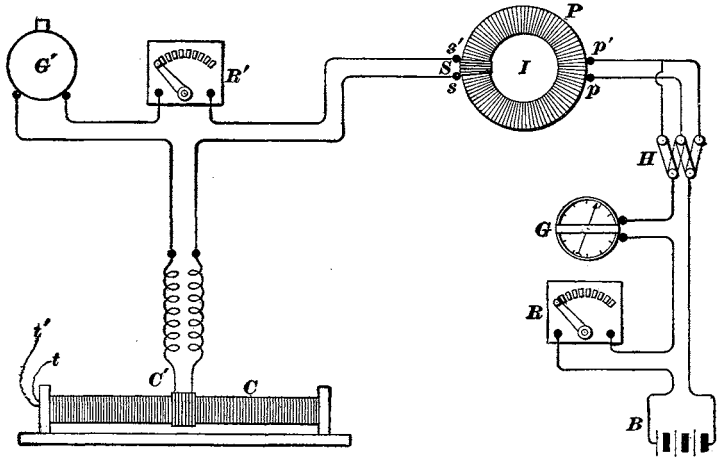


FIG. 991.

**453,** the setting up of a certain number of lines of force in the wooden core of $C$ will cause the needle of the ballistic galvanometer $G'$ to give a certain kick. By varying the make and break currents, the ballistic galvanometer $G'$ may be calibrated, so that the kick of the galvanometer $G'$ being given, the number of lines of force in the coil $C'$, or in any other similar coil, may be determined.

A succession of currents of different values may be sent through the primary coil $P$ of the iron ring $I$, thus producing therein a certain number of lines of force **B,** which

number is indicated by the kick of the needle of the ballistic galvanometer, as previously noted. These results may be tabulated, or else laid out in the form of a magnetization curve, as was explained in Art. **2402.**

**2483.** As the diagram now stands, the calibrating coil is out of circuit, and the primary coil $P$ of the iron ring is being energized by the battery $B$. The energizing current is regulated by the adjustable resistance $R$, and is calculated from the dimensions of the primary circuit or measured by the galvanometer, or low reading ammeter, $G$. The reversing switch $S$ is used to start, stop, or reverse the current in the primary coil $P$. An adjustable resistance $R'$ is also in the secondary, for varying the range of the ballistic galvanometer $G'$, as the values of **H** and **B** are widely different.

In order to calibrate the ballistic galvanometer $G'$, the reversing-switch terminals are disconnected from the coil $P$ by means of the double-throw switch $D$, which then enables connection to be made instead to the terminals $t$, $t'$ of the calibrating coil $C$.

**2484.** The test of the iron may be made in a variety of ways. The two most used are the *step-by-step* and the *reversal* methods.

The **step-by-step** method consists of suddenly increasing or decreasing the magnetizing current in the primary coil by moving the handle of the rheostat $R$. The swing of the galvanometer $G'$ at each step indicates the amount of change in the lines of force corresponding to a change in the magnetizing force. The total number of lines at any point may be determined by adding together the previous *changes*, as observed by the swing of the galvanometer.

**2485.** The **reversal** method is to reverse the current in the primary by throwing the reversing switch $H$. The lines of force will then change from a certain number in one direction down to zero, and then to about the same number in the opposite direction. This change will cause a swing of the galvanometer $G'$, and one-half this swing is taken to represent the number of lines of force in the circuit due to

the magnetizing force that has been reversed. By increasing or decreasing this magnetizing force by successive steps, and reversing each time, the *curve of magnetization* may be obtained.

**2486.** One objection to the step-by-step method is that an error in one of the early observations will be included in the whole series, as they are all added together; but with care in taking the readings, this need not occur. With the method of reversals, however, the *residual magnetism* introduces an error; as, when the magnetizing force is reversed, the lines of force will not also be entirely reversed, so that there will not be as many lines in the circuit after the reversal as before, with the same magnetizing force. In either case, the magnetizing force **H** can be readily calculated from the magnetizing current, and the total induction in the sample of iron may be determined by the galvanometer swings. By this means the value of **B** may be obtained, and the magnetization curve of the particular sample of iron under test may be plotted.

EXAMPLE.—1. Calibrate the ballistic galvanometer $G'$, shown in Fig. 991, for resistance of rheostat $R' = 0$; 500 ohms; 1,000 ohms, the following information being given:

*Data.*—The upper terminals of the reversing switch $S$ were disconnected from the primary coil $P$ and connected to the calibrating coil $C$ by the terminals $t$, $t'$, so that the current from the battery $B$ passed through the calibrating coil $C$, the primary coil $P$ being out of circuit.

The elements of the present *primary circuit* have resistances as follows:

Resistance of primary calibrating coil $C = 3$ ohms.

Internal resistance of battery $B = 1.2$ ohms.

Resistance of rheostat $R$, ten steps of 4 ohms each = 40 ohms.

Resistance of balance of primary circuit, including connections, = 1.1 ohms.

The parts of the secondary circuit have the following resistances:

Resistance of rheostat $R'$, ten steps of 200 ohms each = 2,000 ohms.

Resistance of ballistic galvanometer $G' = 500$ ohms.

Resistance of balance of secondary circuit, including both secondary coils, = 10 ohms.

The battery $B$ has 6 cells, each furnishing a constant E. M. F. of 1.9 volts.

The secondary coil $S$ consists of 120 turns of No. 22 insulated wire.

The calibrating coil $C$ is wound on a wooden rod 30 inches long and 2 inches in diameter, and consists of 1,200 turns of No. 18 insulated wire, wound evenly in two layers.

The secondary calibrating coil $C'$, wound at the center of the length of the primary calibrating coil $C$, has 260 turns of No. 22 wire.

The ballistic galvanometer $G'$ is of the type already described in Art. **2477,** with a scale about 4 feet long, and reads from zero at the center to 225 at each end. *The resistance $R'$ all being cut out, the galvanometer $G'$ gives the scale reading 48.*

SOLUTION.—To calibrate the ballistic galvanometer $G$ means to ascertain the deflection of the galvanometer corresponding to one line of force passing through the secondary coil $S$.

The *current* in the primary calibrating coil $C$, according to Ohm's law, is

$$C = \frac{E}{R} = \frac{6 \times 1.9}{3 + 1.2 + 1.1} = \frac{11.4}{5.3} = 2.15 \text{ amperes.}$$

The number of lines of force per square inch cross-section of the wooden core, by formula **430,**

$$\mathbf{H} = \frac{3.192 \times a\text{-}t}{l} = \frac{3.192 \times 2.15 \times 1,200}{30} = 274.5 \text{ per square inch.}$$

The total number of lines of force in the wooden core $\mathbf{N} = \mathbf{H} \times$ area $= 274.5 \times 3.1416\, r^2 = 274.5 \times 3.1416 = 862.4$ total lines of force in core.

We have now determined the total number of lines of force that passed through the secondary coil $C'$ of 260 turns when the ballistic galvanometer $G'$ moved 48 scale divisions. If there was only one turn in the secondary coil $C'$ instead of 260, the galvanometer $G'$ would have moved only $\frac{48}{260} = .1846$ of a scale division. If only one line of force had been erected, or dissipated, in the coil $C$, and consequently $C'$, instead of 862.4 lines of force, the galvanometer would have moved only $\frac{.1846}{862.4}$, or .000214 of a scale division. But the secondary coil $S$ on the iron ring $I$ has 120 turns. Therefore, when $R' = 0$, one line of force passing through the coil $S$ will throw the galvanometer .000214 division $\times$ 120 = .02568 scale division. Ans.

When $R' = 500$, the total resistance of the secondary circuit is increased from 510 ohms to 1,010 ohms, and the current would be proportionally *decreased.* (See Art. **2480.**) Consequently, the scale reading would be decreased, and one line of force passing through the secondary coil $S$ would cause a deflection of $.02568 \times \frac{510}{510 + 500} = .01297$ scale division. Ans.

When $R' = 2,000$, the scale reading per line of force $= .01297 \times \frac{510}{510 + 2,000} = .005179$ scale division. Ans.

EXAMPLE.—2. (*a*) From the data and information following, work out the magnetomotive force **H** in the primary coil of the iron ring, and the resulting density of lines of force **B**, *using the step-by-step method;* from these results plot a *magnetization curve* on cross-section paper, showing the magnetic qualities or susceptibility of the iron. (*b*) What kind of iron does the sample seem to be?

*Data.*—The circuit connections are exactly shown in Fig. 991, the calibrating coil of the previous example having been replaced in the primary circuit by the primary coil *P* of the flat iron ring *I*. The dimensions of the iron ring are: 5 inches inside diameter, 6½ inches outside diameter, and 1 inch thick. The *primary coil P* is wound evenly over the entire ring *I*, and consists of 800 turns of No. 18 insulated wire, affording a resistance of .8 ohm. The *secondary coil* is made up of 120 turns of No. 22 insulated wire. All the resistance of the rheostat *R'*, 2,000 ohms, is in circuit.

The data given and the results obtained in the previous examples are also available.

The manner of performing the experiment is to turn in the whole resistance of rheostat *R* of 40 ohms, and then close the switch *H*. Noting the swing, the spot of light gradually settles down to zero. The rheostat hand of *R* is suddenly thrown back to the second contact. This cuts out 4 ohms resistance, which allows an additional amount of current to flow through the circuit. The addition of this quantity of current sets up additional lines of force, and the additional lines of force set up a current in the ballistic galvanometer *G'*. The rheostat is moved around the successive steps, and the readings noted as follows:

| Resistances of *R*. | Deflection of Galvanometer *G'*. |
|---|---|
| Ohms. | Divisions. |
| 40 | 220.6 |
| 36 | 11.1 |
| 32 | 12.9 |
| 28 | 7.7 |
| 24 | 14.8 |
| 20 | 13.2 |
| 16 | 16.3 |
| 12 | 19.6 |
| 8 | 26.0 |
| 4 | 30.7 |
| 0 | 40.4 |

SOLUTION.—(*a*) The calculations should be made in tabular form, for the sake of clearness. The following calculations will have to be

made, and a column may properly be assigned for the result of each calculation:

1. The resistance of the primary circuit.
2. The current in the primary circuit.
3. The magnetomotive force **H** of the primary coil (per inch of length of core).
4. The deflection of the ballistic galvanometer $G'$ in scale divisions.
5. The corresponding *change* in the number of lines of force in the iron ring $I$.
6. The total number of lines of force in the iron ring.
7. The density **B** per square inch in the iron.

Column 1 is found by adding the resistances of the elements of the primary circuit, the several values of the adjustable rheostat $R$ having been given in the example; for illustration, the first quantity equals $.8 + 1.2 + 1.1 + 40 = 43.1$ ohms. The rest are found in the same manner.

| 1. Resistance of Primary Circuit. | 2. Current in Primary Circuit. | 3. **H** Magneto-motive Force in Primary Coil. | 4. Deflect. of Galvanom-eter. Divisions. | 5. Change in Number of Lines of Force. | 6. Total Number of Lines of Force. | 7. **B** Lines of Force in Iron, per Square Inch. |
|---|---|---|---|---|---|---|
| 43.1 | .2645 | 37.40 | 220.6 | 42,600 | 42,600 | 56,800 |
| 39.1 | .2916 | 41.20 | 11.1 | 2,144 | 44,744 | 59,630 |
| 35.1 | .3248 | 45.90 | 12.9 | 2,510 | 47,254 | 63,000 |
| 31.1 | .3666 | 51.84 | 7.7 | 1,487 | 48,741 | 65,000 |
| 27.1 | .4207 | 59.50 | 14.8 | 2,858 | 51,599 | 68,800 |
| 23.1 | .4935 | 69.78 | 13.2 | 2,549 | 54,148 | 72,200 |
| 19.1 | .5968 | 84.40 | 16.3 | 3,148 | 57,196 | 76,250 |
| 15.1 | .7550 | 106.8 | 19.6 | 3,785 | 60,981 | 81,300 |
| 11.1 | 1.027 | 145.2 | 26.0 | 5,021 | 66,002 | 88,000 |
| 7.1 | 1.606 | 227.1 | 30.7 | 5,928 | 71,930 | 95,600 |
| 3.1 | 3.677 | 520.0 | 40.4 | 7,801 | 79,731 | 106,300 |

The readings in column 2 are found by dividing the total electromotive force of the cells, 11.4 volts, by the respective resistances given in column 1.

The values of the magnetomotive force in column 3 can be calculated from formula **430**, $\mathbf{H} = \frac{3.192 \times a \cdot t}{l}$, where the number of turns $t = 800$, and the current $a = .2645, .2916, .3248$ ampere, etc.; the length of the magnetic circuit $l$ is determined from the dimensions of the ring, as

follows: The mean diameter of the ring $= \frac{5 + 6\frac{1}{2}}{2} = 5\frac{3}{4}$ inches. Length $l = 5\frac{3}{4} \times 3.1416 = 18.06$ inches.

The deflections of the galvanometer, column 4, are given in the example.

The *change* in the number of lines of force, that is, the additional number of lines of force due to the increases of primary current, noted in column 2, when the resistance of the rheostat $R'$ equals 2,000 ohms, is found by dividing the respective deflections by .005179; for it was shown in example 1, in the last answer, that, when $R' = 2{,}000$ ohms, one line of force causes a deflection of .005179 scale division; therefore, the number of lines of force in the iron is the deflection divided by .005179.

The *total* number of lines of force, column 6, corresponding to the respective magnetic forces tabulated in column 3, are obtained by adding the change in the number of lines of force in column 5 to the total number of lines of force of the reading immediately preceding.

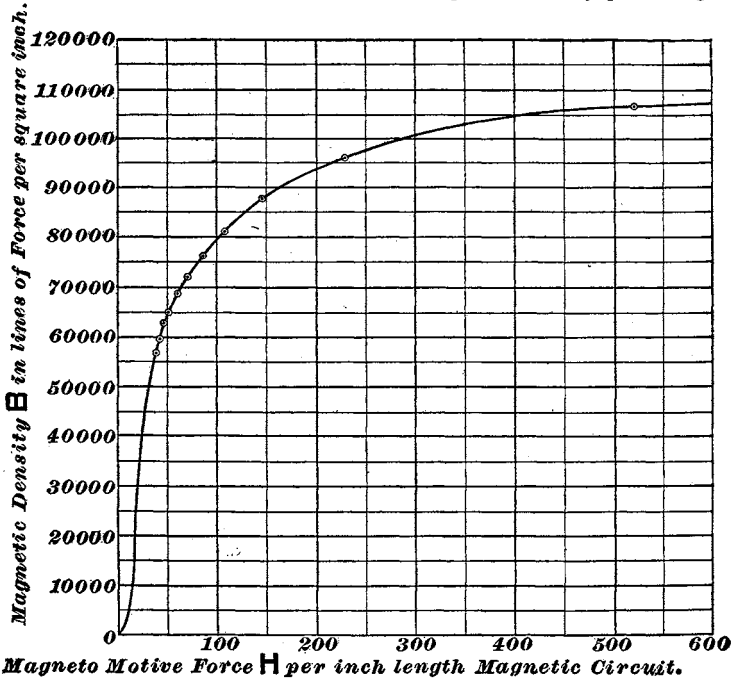


FIG. 992.

The lines of force per square inch **B**, in column 7, are obtained by dividing the total number of lines of force, column 6, by the

cross-sectional area of the iron ring. This area is evidently $\frac{3}{4}$ in. $\times$ 1 in. = .75 square inch.

NOTE.—The student is advised to perform the computations enumerated, to better comprehend the rules and principles involved.

These values of the magnetomotive force **H** and the corresponding density **B** of the lines in the iron are now plotted on a sheet of cross-section paper, and the points so obtained connected by a line forming the *magnetization curve* of the piece of iron under test. This curve is shown in Fig. 992.

SOLUTION.—(*b*) Wrought iron. This is learned by comparing the magnetization curve obtained with the magnetization curves given in Fig. 952.

**2487.** The galvanometers thus far described comprise the principal forms of galvanometers in use. The selection of any one instrument for a test depends upon its particular fitness for that work. All galvanometers, however, are merely current measurers, or, in some cases, current indicators only, and certain features of their use and certain apparatus used with them are common to all.

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## GALVANOMETER SHUNTS.

**2488.** If a resistance be connected in parallel with a galvanometer through which a current is flowing, the current will divide between the two branches of the circuit, as shown in Fig. 993, inversely as the respective resistances of the circuits; and the galvanometer is said to be *shunted* by the resistance. (See Art. **2320.**)

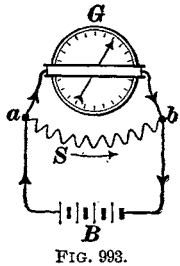

FIG. 993.

The drop in volts in each branch will be the same; that is, $C_s R_s = C_g R_g$, where $C_g$ = current in galvanometer, $C_s$ = current in shunt, $R_g$ = resistance of galvanometer, $R_s$ = resistance of shunt. The total current $C = C_s + C_g$. The fraction of the total current that passes through the galvanometer is found by the formula

$$C_g = \frac{C}{n+1}, \qquad \textbf{(454.)}$$

where $n =$ the resistance of $G$ divided by the resistance of $S = \frac{R_g}{R_s}$.

This results from the equations $C_s R_s = C_g R_g$ and $C = C_s + C_g$ as follows: $n = \frac{R_g}{R_s}$, or $n R_s = R_g$.

Therefore, for $C_s R_s = C_g R_g$, write $C_s R_s = C_g n R_s$, or $C_s = C_g n$; for $C = C_s + C_g$, write $C = C_g n + C_g$, or $C = (n+1)C_g$.

Therefore, $$C_g = \frac{C}{n+1}.$$

Thus, by inserting a known resistance in parallel with a galvanometer, also of known resistance, the total current flowing may be calculated from the current flowing in the galvanometer, as measured by it. A resistance arranged for such use with a galvanometer is known as a **galvanometer shunt.**

This affords a convenient means of increasing the range of a galvanometer, as by inserting the proper shunts, currents of any reasonable multiple of the normal range of the galvanometer may be measured.

Galvanometers are often furnished by the makers with shunts of $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$ of the resistance of the instrument, which increase the range of the instrument 10, 100, or 1,000 times. Applying formula **454,** we obtain for the three different shunts the following currents :

$$\left(C_g = \frac{C}{n+1} = \frac{C}{9+1=10}\right).$$

$$\left(C_g = \frac{C}{n+1} = \frac{C}{99+1=100}\right).$$

$$\left(C_g = \frac{C}{n+1} = \frac{C}{999+1=1{,}000}\right).$$

The value of $n+1$ is, therefore, the amount by which any particular shunt will multiply the range of the instrument, and is called the **multiplying power** of that shunt.

In the foregoing cases the multiplying powers of the shunts are obviously 10, 100, and 1,000, respectively.

**2489.** To find the necessary shunt resistance to make the multiplying power of the shunt any desired amount, *divide the resistance of the galvanometer by the multiplying power less 1;* as the multiplying power $= n + 1$, then, $(n + 1) - 1 = n$, or $R_s = \frac{R_g}{n}$.

It is evident that introducing the shunt into the circuit in parallel with the galvanometer reduces the resistance of that part of the circuit (between $a$ and $b$, Fig. 993). In some delicate measurements it is desirable that this resistance be not altered, and galvanometer shunts are sometimes mounted in connection with a second resistance, known as a **compensating resistance,** which is introduced into the circuit in *series* with the galvanometer and its shunt. This resistance is given such a value that its resistance, plus the *combined resistance* of the galvanometer and its shunt as connected in parallel, is equal to the resistance of the galvanometer alone. The value of this resistance for any particular case may be readily calculated from the formulas for derived circuits. (See Arts. **2320** to **2329.**)

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**EXAMPLES.**

**2490.** 1. If a galvanometer whose resistance is 21 ohms gives a deflection of 40 with a current of 2 amperes, what will be the resistance of the shunt that must be used to cause 16 amperes to give the same deflection?

SOLUTION.—The multiplying power of this shunt is evidently 8; therefore, $8 = n + 1$ and $n = 7$. $R_g = 21$ and $\frac{21}{7} = 3$ ohms. Ans.

2. What must be the value of a *compensating resistance* if used with the galvanometer and its shunt in the above example?

SOLUTION.—Let $R_g =$ the resistance of the galvanometer $= 21$ ohms, and $R_s =$ the resistance of the shunt $= 3$ ohms. By formula **412,** their joint resistance in parallel is, then, $R = \frac{R_g R_s}{R_g + R_s}$.

Substituting the values of $R_g$ and $R_s$, $R = \frac{21 \times 3}{21 + 3} = \frac{63}{24} = 2.625$ ohms.

As the compensating resistance plus the joint resistance of the galvanometer and shunt is equal to the galvanometer resistance, or $R_c + R = R_g$, substituting the values gives $R_c + 2.625 = 21$, or $R_c = 21 - 2.625 = 18.375$ ohms. Ans.

3. What is the resistance of a galvanometer if a shunt of 10 ohms resistance has a multiplying power of 8? Ans. 70 ohms.

## PRECISION IN MEASUREMENTS.

**2491.** Mathematical results can be obtained with absolute accuracy with proper attention, but any *measurements* which can be made are liable to error, that is, it can not be determined that the measurement is absolutely correct. For example, an absolutely rectangular portion of the top of a table 37.5 in. long and 20 in. wide has a surface area of absolutely 750 square inches, no more and no less, but it would be impossible to lay out a surface on a table or anywhere else that would be *known* to have a surface area of *exactly* 750 square inches.

Results from a series of measurements can not be expected to have a greater degree of accuracy than the instruments with which such measurements are made; and, conversely, it is unnecessary labor to use very accurate and sensitive instruments to obtain results which it is only necessary to know approximately.

Again, each of a series of measurements should be made with a degree of precision corresponding to the effect each measurement will have on the final result. For example, if it be desired to find the cubic inches of iron in a bar about 20 feet long and about $\frac{3}{4}$ inch square, by measuring its length and width and thickness, it would be absurd to carefully measure the length to eighths of an inch with a graduated scale, and then to estimate the width and thickness by using the end joint of the thumb as an inch and estimating by the eye the fraction of that distance that would equal the width or thickness of the bar.

In making delicate tests that require a high degree of accuracy, the subject should be carefully studied, and precautions taken to remove as far as possible any source of error; the reading should be repeated several times, and, if possible, repeated with different methods and apparatus. Even then the best that can be said is that the results are as nearly accurate as the apparatus will allow, to the best of one's judgment.

So, in making measurements, electrical or otherwise, care should be taken to make the apparatus, methods of using it,

and the necessary calculations as accurate as the required degree of precision of the final result requires. At the same time unnecessary labor in making one part of the work precise beyond a point where the unavoidable errors in another part would neutralize such precision should be avoided.

**2492.** This leads to the consideration of how many significant figures to retain in the readings, calculations, and results to obtain results within the accuracy of the instruments used. By **significant figures** is meant the number of *digits*, with the exception of the zeros used to indicate the position of the decimal point.

For example, 20467, 28.321, and .00010569 would each have five significant figures. If it were necessary to use but four significant figures, these values would be written 20470, 28.32, or .0001057; that is, if the figure dropped be 5 or greater, the next figure to the left is increased 1; if less than 5, the figure to the left is unchanged. Zeros are sometimes significant figures, as in the example, $25 \times 4 = 100$, which has three significant figures in the answer, 100, as the example has been carried out far enough to show that the value of units and tens is 0 in each case. In the previous example where four significant figures are required, the number 20470 indicates that the actual value of the last figure 0 is known to be within 5 units either way from 0. Whereas, if five significant figures were required, 20470 would indicate that the last number was known to be within .5 unit either way from 0.

The requirements of the calculations and results of observations in this respect are as follows:

(*a*) If any one of the measurements can not be determined within 1%, four significant figures retained in any reading, calculation, or result will give an answer correct within the limits of precision of the measurements.

(*b*) If any one of the measurements can not be determined within less than 0.1%, but can be within 1%, five significant figures are required, and (*c*) if not within 0.01%, but within 0.1%, six significant figures are required.

The degree of precision of the various instruments used in making electrical measurements can be obtained either from careful calibration or from the maker's guarantee, and results obtained from such instruments may be calculated with the allowable degree of accuracy by observing the requirements given.

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## ELECTROCHEMICAL MEASUREMENTS.

**2493.** The decomposition of liquids by the electric current affords a means of measuring the current that requires but little apparatus and gives very precise results. This method is chiefly used for determining galvanometer constants, as it is not usually well suited for the measurement of commercial currents, that is, currents used for lighting, power, etc.

The following constants for the decomposition of water have been accurately determined. A current of 1 ampere flowing for 1 second will decompose .00009324 gram (.0014388 grain) of water. The gas resulting from this decomposition is a mixture composed of .00001036 gram of hydrogen and .00008288 gram of oxygen; so, by measuring the amount of water decomposed by a current in a given time, either by measuring the loss of weight of the water or by measuring the volume of either or both gases given off, the value of the current may be calculated. The latter method is called the *volume method.* Since corrections must be made for temperature, pressure, etc., in determining by their volume the weight of the gases collected, this method involves considerable labor and time. It is usually simpler to use the first mentioned, or *weight method.*

**2494.** In this method the gases resulting from the decomposition of the water are allowed to escape into the air. If they were allowed to pass off directly from the surface of the water, considerable water vapor would pass off with them, and the loss of weight of the water would not be a true measure of the current flowing; these gases are,

therefore, made to pass through a certain apparatus known as a **desiccator,** which consists merely of a glass tube, loosely filled with some substance which will absorb the water vapor while allowing the gases to escape unchanged. The whole apparatus, including desiccator and water, should be weighed, and the difference between the weight before and after the passage of the current will represent the value of the current.

Fig. 994 shows two forms of apparatus for this method of measuring current. The tube $T$ contains the liquid and the (platinum) electrodes, which pass through a cork which has been boiled in paraffin. The tube $t$ is the desiccator, and is loosely filled with asbestos soaked in sulphuric acid. The small tube in the end of the tube $t$, through which the gases pass off, should be closed with a paraffined cork $c$ previous to and just after the passage of the current, to prevent the acid in the tube $t$ absorbing moisture from the air, which would introduce an error.

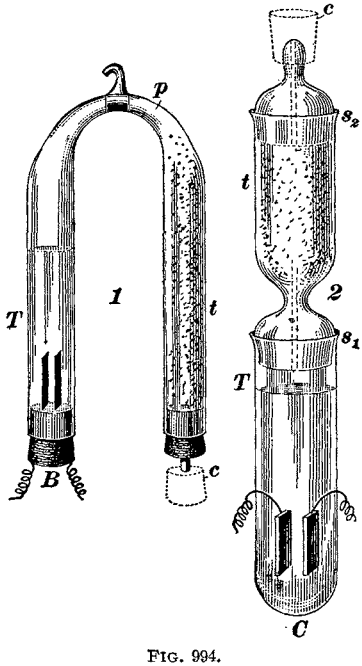


FIG. 994.

The second form of apparatus illustrated is more difficult to make. The joints at $s_1$ and $s_2$ are ground to fit, and wires to the electrodes are sealed into the sides of the tube $T$.

As pure water has an extremely high resistance (one authority gives 7 megohms per cubic centimeter), it is necessary to add some substance to increase its conductivity. For these tests sulphuric acid is used; a small proportion of acid is sufficient.

**2495.** To measure current with this apparatus, the tube $T$ should be filled with acidulated water, and the tube $t$ with asbestos soaked in sulphuric acid. With the cork $c$ in place, carefully weigh the whole apparatus. Then join the terminals of the apparatus to the battery from which the current is to be taken, and removing the cork $c$, note the exact time at which the final connection is made to the battery. It is better to use some form of switch for closing the circuit after all connections have been made. After allowing the current to pass until sufficient water has been decomposed, break the circuit, noting again the exact instant the current ceases to flow, replace the cork $c$ and reweigh the apparatus.

To find the strength of the current that has been passing in amperes:

Let $w_1$ = the original weight of apparatus;
$w_2$ = the weight after the current has passed;
$t$ = time in seconds during which the current flows;
$C$ = strength of current in amperes.

Then, if the weights are taken in *grams*,

$$C = \frac{w_1 - w_2}{.00009324\, t}. \qquad \textbf{(455.)}$$

If the weights are in *grains*,

$$C = \frac{w_1 - w_2}{.0014388\, t}. \qquad \textbf{(456.)}$$

**Rule.**—*To determine the strength of a current by decomposition of water, subtract from the original weight of the apparatus its weight after the current has passed through; divide this result, expressed in grams or grains, by the length of time the current was passing, in seconds, multiplied by the number of grams or grains of water which can be decomposed by 1 ampere in 1 second.*

EXAMPLE.—The original weight of the apparatus was 980.5 grams; the current was passed through for 38 minutes, and the weight was then found to be 979.6 grams; what was the strength of the current in amperes?

SOLUTION.—In this example, $w_1 = 980.5$ grams ; $w_2 = 979.6$ grams 38 minutes = 2,280 seconds = $t$. Then, by formula **455**,

$$C = \frac{980.5 - 979.6}{.00009324 \times 2,280} = \frac{.9}{.2125872} = 4.233+ \text{ amperes.} \quad \text{Ans.}$$

It will now be readily seen that if a galvanometer be connected in series with the apparatus for decomposing the water, and the deflection noted, its galvanometer constant may be easily calculated.

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**EXAMPLES FOR PRACTICE.**

1. If the loss in weight of apparatus be 3.462 grains after a current has passed through for 40 minutes, how many amperes have been passing? Ans. 1.0025 amperes.

2. If .756 ampere is passed through the apparatus for 1 hour, what will be the loss of weight of the apparatus (*a*) in grams? (*b*) in grains?

Ans. { (*a*) .2537+. (*b*) 3.9158+.

NOTE.—In decomposing water, a battery of sufficient number of cells to give about 2 volts should be used. The cells should give a constant current.

**2496.** If a solution of copper sulphate (blue vitriol) be used instead of acidulated water, the decomposition of the liquid by the current will cause a deposit of copper on the negative electrode. The weight of copper deposited in a given time is proportional to the current flowing, and 1 ampere will deposit .0003286 gram of copper in 1 second. Moderate variations in the proportions of copper sulphate in the solution or the temperature do not affect the result appreciably. The above figure is given for a half saturated solution of copper sulphate [that is, about 1 part (by weight) of copper sulphate to 5 parts of water] at a temperature of 73° F. A reduction of temperature to 54° F. would not alter the figure given by more than .03%.

In making measurements of the amount of copper deposited, electrodes of copper should be used, of such size that there shall be from 8 to 15 square inches of surface to be deposited upon for each ampere of current.

When the copper is deposited from the copper sulphate solution, sulphuric acid is set free, which dissolves a portion

of the *positive* plate, forming copper sulphate, thus keeping the amount of copper sulphate in solution practically constant. The positive plate does not lose in weight in direct proportion to the current passing, so in measurements of this description the gain in weight of the negative plate only is measured.

**2497.** Apparatus prepared according to the following description will afford a means of measuring the current, which requires even less apparatus than the weight method of water decomposition, but the precautions therein noted should be taken to insure reliable results.

**Trough.**—The vessel or trough used should be of wood or other insulating material, of sufficient size to allow the square part of the plates to hang entirely below the surface of the liquid.

**2498. Plates.**—It would be best to use three plates, one negative or *gain plate*, suspended between two positive or *loss plates*, which should be of the same shape and material as the gain plate, but somewhat smaller and thicker. The gain plate should be of very thin copper, so that its gain in weight will be enough to make considerable difference between its weights before and after the test.

The plates should be cut approximately square and the corners clipped off. It is rather better to make them circular, but this form is often not as convenient to prepare, and is not at all necessary. From one side of the plate a narrow strip should be left projecting, long enough to bend into a hook by which to hang the plate on the scales or in the liquid.

Three pieces of heavy bare copper wire or rod should be provided, long enough to reach across the top of the trough; on resting these on the edges of the trough a short distance apart, the electrodes may be readily hung from them and the necessary connections made to them from the battery.

The positive plates should be rubbed bright on both sides with fine sandpaper. The negative plate should be

carefully rubbed smooth and bright with very fine sandpaper or emery, taking great care not to touch the part of the bright surface that will be below the surface of the liquid with the bare fingers or any greasy substance. A piece of clean paper or cloth should be used to handle the plate with. After carefully brightening the plate, it should be washed and dried carefully several times, and then accurately weighed.

This preparation of the gain plate should not be made until all the rest of the apparatus is ready, as a long exposure to the air will oxidize the bright surface of the copper.

**2499. Liquid.**—Make the liquid by dissolving 1 part (by weight) of crystals of copper sulphate in 5 parts (by weight) of water, and adding about 1 per cent. of strong sulphuric acid. (One per cent. is about 3 teaspoonfuls to the quart.) This excess of acid serves to dissolve such impurities as may exist in the copper sulphate.

A conducting liquid thus prepared for electrolysis or for use in a battery is known as an *electrolyte*. (See Art. **2238.**) Other salts of metals in solution besides the above may be used as the electrolyte, with corresponding metals as electrodes.

**2500. Battery and Connections.**—A battery of two cells in series will be sufficient if small currents are desired. Cells should be used giving approximately a constant current. If constant-current batteries are not available, use three or four cells of some other type, and insert a resistance which may be varied to keep the current constant. The various forms of cells will be described later. Connections should be made by means of insulated wires, as shown in Fig. 995, where $S$ = switch for making and breaking the circuit; $B$ = battery; $R$ = resistance for keeping the current constant; $G$ = galvanometer; $T$ = trough containing plates and liquid;

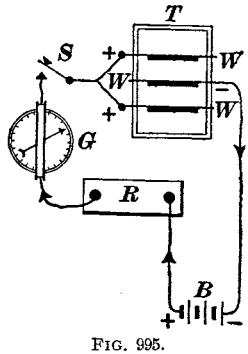

FIG. 995.

$W$, $W$, $W$ = copper wires across top of trough from which plates are hung.

**2501.** After preparing the solution and setting up the apparatus, the positive plates should be hung in place, then the negative plate should be prepared and weighed; as soon as possible hang the negative plate in place; put in sufficient liquid to completely cover the plates; then, close the switch, noting the exact instant when the circuit is made. The deflection of the galvanometer needle should be noted from time to time, and any change in the deflection corrected by changing the resistance $R$. After sufficient time has elapsed, open the switch, again noting the exact time.

As soon as possible, take out the negative plate, wash and dry it carefully several times, and accurately weigh it. Then, find the amperes that have been flowing by the following formulas:

Let $w_1$ = the original weight of gain plate;
$w_2$ = the weight after the current has passed;
$t$ = time in seconds during which the current flows;
$C$ = strength of current in amperes.

Then, if the weights are in grams,

$$C = \frac{w_2 - w_1}{.0003286\ t}. \qquad \textbf{(457.)}$$

If the weights are in grains,

$$C = \frac{w_2 - w_1}{.005068\ t}. \qquad \textbf{(458.)}$$

**Rule.**—*In order to determine the strength of current by measurement of copper deposited, subtract the original weight of the gain plate, in grams, from the weight as found after the experiment; divide this result by the length of time the current was flowing in seconds multiplied by the number of grams of copper which can be deposited by 1 ampere in 1 second.*

After finding the current which has been passing, the galvanometer constant can be found from formulas **448** and **450.**

EXAMPLE.—The positive plate is a sheet of copper about $2\frac{1}{2}$ in. square and about $\frac{1}{32}$ in. thick. After cleaning, it weighs 29.62 grams. The current being allowed to pass for 75 minutes, the plate weighs 31.33 grams. A tangent galvanometer in circuit gave a deflection of 42°. (*a*) How many amperes were passing, and (*b*) what was the galvanometer constant?

SOLUTION.—(*a*) In this example, $w_1 = 29.62$ grams; $w_2 = 31.33$ grams; $t = 75 \times 60 = 4{,}500$ seconds. Then, by formula **457**, the current

$$C = \frac{31.33 - 29.62}{.0003286 \times 4{,}500} = 1.1564 \text{ amperes.} \quad \text{Ans.}$$

(*b*) Use formula **450.**

$$C = K \tan m^\circ.$$

$$\text{Tan } 42^\circ = .9004.$$

Then,
$$\frac{C}{\tan m^\circ} = K;$$

or,
$$\frac{1.1564}{.9004} = K = 1.2843. \quad \text{Ans.}$$

NOTE.—The weight of copper deposited per ampere per second may be taken in grains (Troy) instead of grams, and the result worked out in the same way. 1 gram = 15.432 grains (Troy).

EXAMPLE.—Change the weights in the above example to grains and work out the results.

## MEASUREMENT OF POTENTIAL.

**2502.** If two points between which a difference of potential exists are connected together by a conductor, a current will flow from one to the other, its value depending on the resistance of the conductor and the difference of potential between the two points.

If this conductor be the coil of a galvanometer, it is obvious that the divisions on the scale may be marked to read volts instead of amperes.

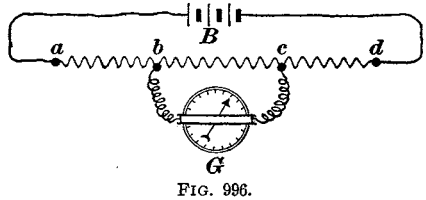

FIG. 996.

In Fig. 996 a current flows from the battery *B* through the resistance *a b c d*. There will, therefore, be a certain fall of potential along *a b c d*, and it may be desired to measure the difference of potential between *b* and *c*.

**2503.** If a galvanometer whose resistance is approximately that of the part of the circuit *b c* is connected to the points *b* and *c*, the current flowing from *a* to *b* will divide at *b*, and a part flow through the galvanometer *G*. The whole current will again flow from *c* to *d*. If the resistance of the galvanometer is known, the current flowing through it, as measured by the deflection of the needle, is also a measure of the difference of potential between *b* and *c*, but this difference of potential is not the same as it was before the galvanometer was connected.

The galvanometer being placed in parallel with a part of the circuit reduces the total resistance of the circuits, and as the distribution of resistance between *a* and *d* is changed, the distribution of the fall of potential will also be changed.

In order, therefore, to measure the difference of potential between *b* and *c*, the instrument used should be so constructed that it will not measurably alter the conditions of the circuit. If the galvanometer *G* in Fig. 996 have a very high resistance as compared with *b c*, so that the current passing through it will be a very small percentage of the total current in the circuit, the conditions will not be altered sufficiently to introduce any serious error.

**2504.** When a difference of potential exists between two points between which no current is flowing, as a battery with no external circuit made, it is usually the case that any considerable current flowing will reduce this difference of potential, owing to the internal resistance of the battery or other generator of the E. M. F.

To measure this difference of potential again requires a galvanometer of such resistance that a very small current will flow through it, in order that the conditions of the circuit shall not be sensibly changed; so that commercial measuring instruments that are constructed on the galvanometer principle are divided into two classes:

1. Instruments of low resistance, so arranged that a considerable current is required to give readable deflections, usually with the scales so marked as to give the deflection

of the needle the proper value in amperes of the current passing through the instrument. These are called **ampere-meters,** or more briefly **ammeters.**

2. Instruments of high resistance, so arranged that very small currents will give readable deflections, and with the scales usually so marked as to give the deflection of the needle the proper value in volts of the difference in potential between the points to which the instrument is connected. Such instruments are called **voltmeters.**

**2505.** Fig. 997 illustrates a method of measuring differences of potential, in which the principle of operation necessitates that *no current* be flowing through the galvanometer *G*. In the figure, *a b c d* is a resistance through which a current is flowing, supplied by the battery *B*. It is desired to measure the difference of potential between *b* and *c*. *S* is a battery of standard cells, the E. M. F. of which is known, arranged so that one or more of the cells in series may be used.

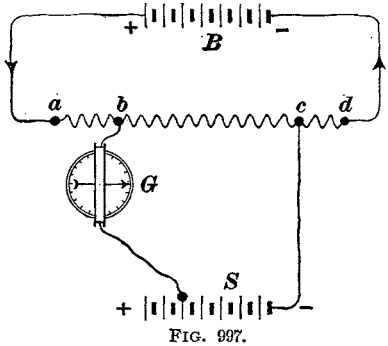

FIG. 997.

If the negative pole of the battery *S* be connected to the same end of *b c* that the negative pole of *B* is connected, and the positive pole of *S* to the other end of *b c*, through the galvanometer *G*, it will be seen that, if the battery *S* had no E. M. F. of its own, the difference of potential between *b* and *c* would tend to drive a current through *S* from *b* to *c*, which would be indicated by the galvanometer. *S* has an E. M. F., however, which, from the way it is connected, opposes the passage of such a current, and if the E. M. F. of *S* exactly equals the drop in volts between *b* and *c*, no current will flow through *S*. To measure the difference of potential between *b* and *c*, it only remains to adjust the number of cells in *S* until the galvanometer *G*

indicates no deflection; then, multiplying the E. M. F. of each cell in $S$ by the number used will give the drop in volts between $b$ and $c$.

As no current flows through the galvanometer, it may be large or small, of high or low resistance, as long as it is sensitive to small currents. Consequently, various current strengths and differences of potential may with this method (called the **zero** method) be measured with a single galvanometer.

## MEASUREMENT OF RESISTANCE.

**2506.** The resistance of a conducting body may be measured in a variety of ways. One of the most common is the **fall of potential** method, which consists of passing a current through the unknown resistance and measuring the amperes flowing and the drop in volts through the resistance. The resistance is calculated from Ohm's law. Fig. 998 shows the arrangement of the apparatus. $a\ b\ c\ d$ is a resistance of which it is desired to know the resistance $b\ c$.

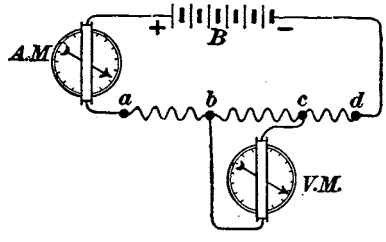


FIG. 998.

A current from the battery $B$ flows through the ammeter $A\ M$ and the resistance. The drop in volts from $b$ to $c$ is measured by the voltmeter $V\ M$.

EXAMPLE.—1. If the current flowing from $a$ to $d$ be 2.2 amperes, and the drop from $b$ to $c$ be 6.25 volts, what is the resistance of the part of the circuit $b\ c$?

SOLUTION.—By formula **410**, $R = \frac{E}{C}$.

$E = 6.25$. $C = 2.2$. $R = \frac{6.25}{2.2} = 2.841$ ohms. Ans.

2. If the current be found to be 21.25 amperes, and the drop in potential 4.6 volts, what is the resistance? Ans. .2165 ohm.

**2507.** This method of measuring resistance is often not convenient, and many times impossible to use. Another

method is to compare the unknown resistance with one or more known resistances in several ways. It may be done by connecting a known and the unknown resistance in series, and, on sending a current through the two, measuring the drop in volts across each. The resistances will be directly proportional to the fall of potential, and the current need not be measured.

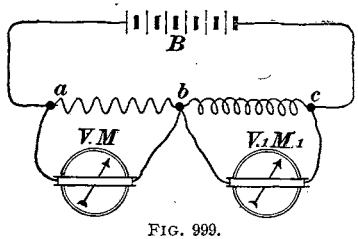

FIG. 999.

In Fig. 999, $B$ is the battery, the current from which flows through the known resistance $a\ b$ and the unknown resistance $b\ c$. Voltmeters $V\ M$ and $V_1\ M_1$ measure the fall of potential across each. The same voltmeter might readily be used for both readings.

EXAMPLE.—1. If the resistance $a\ b$ is known to be 2 ohms, and the drops as measured by $V\ M$ and $V_1\ M_1$ are 4.25 volts in $a\ b$ and 6.12 volts in $b\ c$, what is the resistance of $b\ c$?

SOLUTION.—As the resistances are directly proportional to the drops of potential,

$$4.25 : 6.12 :: 2 : x;$$

or,
$$\frac{2 \times 6.12}{4.25} = x = \frac{12.24}{4.25} = 2.88 \text{ ohms.} \quad \text{Ans.}$$

EXAMPLE.—2. If the drop through the known resistance is 6.28 volts and through the unknown 2.25, what is the unknown resistance if the known is 3.5 ohms? Ans. 1.254 ohms.

**2508.** Another way to attain the same result would be to connect the known and the unknown resistance in parallel, and measure the current in each. The currents would be in inverse proportion to the resistances. In Fig. 1000 the current from the battery $B$ divides at $x$, a part flowing through the known resistance $a\ b$ and the balance through the unknown

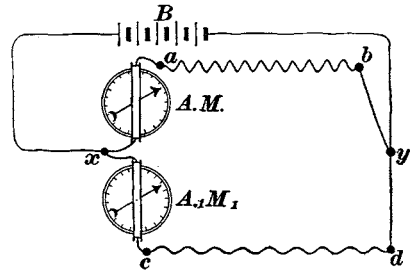

FIG. 1000.

resistance $c\,d$. Ammeter $A\,M$ measures the current in $a\,b$ and ammeter $A_1\,M_1$ measures the current in $c\,d$.

It is to be noted that the ammeters and their connecting wires should be of such low resistance as not to add materially to the resistance of either branch of the circuit.

EXAMPLE.—If ammeter $A\,M$ indicates 3.6 amperes and ammeter $A_1\,M_1$ indicates 4.2 amperes, what is the resistance of $c\,d$ if $a\,b$ is 10.5 ohms?

SOLUTION.—As the currents are inversely proportional to the resistances,

$$4.2 : 3.6 :: 10.5 : x;$$

or
$$x = \frac{3.6 \times 10.5}{4.2} = \frac{37.80}{4.2} = 9 \text{ ohms.} \quad \text{Ans.}$$

**2509.** In Fig. 1000 the drop along $c\,d$ must be the same as that along $a\,b$ (neglecting the ammeter resistances). If any point in $c\,d$ be selected, a point in $a\,b$ can be found that will have the same difference of potential between it and $x$ that the point in $c\,d$ has.

If a galvanometer is connected across from the point in $c\,d$ to the point in $a\,b$, no current will flow through it, as there is no difference of potential between the points. Fig. 1001 represents this condition.

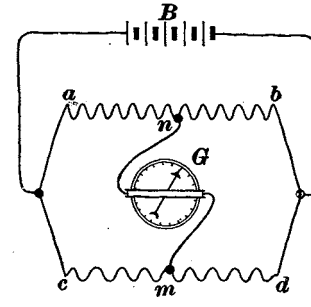

FIG. 1001.

It is obvious that the resistance from $a$ to $n$ must be the same proportion of the total resistance $a\,b$ that the resistance from $c$ to $m$ is of $c\,d$, in order that the drop in $a\,n$ shall be the same as in $c\,m$. If the point $n$ be moved to any point in $a\,b$, the point $m$ must be correspondingly moved on $c\,d$, in order that there may be no current flowing though $G$, and that the proportion $a\,n : a\,b :: c\,m : c\,d$ may still hold good.

It is also evident that the same proportion holds good for $n\,b$ and $m\,d$; i. e., $n\,b : a\,b :: m\,d : c\,d$.

From the above proportions,

$a\,n : c\,m :: a\,b : c\,d$, and $n\,b : m\,d :: a\,b : c\,d$.

Therefore, $a\,n : c\,m :: n\,b : m\,d$.

That is, the resistance of $a\,n$ is to the resistance of $c\,m$ as the resistance of $n\,b$ is to the resistance of $m\,d$.

From this proportion, it is evident that if $a\,n$, $c\,m$, and $m\,d$ be known, the resistance of $n\,b$ may be readily calculated.

This affords a ready means for measuring resistance, which, as will be shown, is very flexible and universally applicable.

**2510.** In Fig. 1002, $M$, $N$, and $P$ are three known resistances, which may be varied by known amounts. An unknown resistance $X$ is connected to $c$ and $b$, completing the

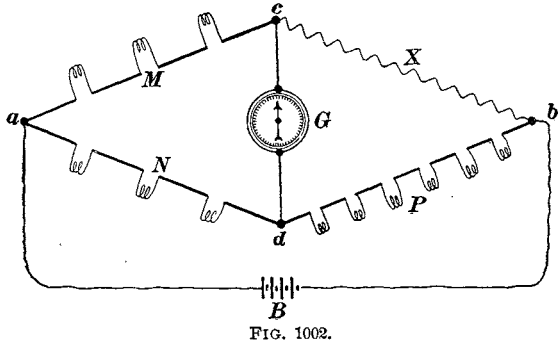


FIG. 1002.

branch $a\,c\,b$ of the circuit from $a$ to $b$. Through this circuit a current flows from the battery $B$. Any one of the three resistances $M$, $N$, and $P$ may be adjusted until the galvanometer $G$ indicates that the points $c$ and $d$ are at the same potential; then, from the proportion given in Art. **2509**, $M : N :: X : P$.

It is obvious that if $M$ be equal to $N$, $X$ will be equal to $P$, while if $X$ be a very high or very low resistance it may be measured equally well by changing the ratio of $M$ to $N$. In any case,

$$X = \frac{M}{N} \times P. \qquad \textbf{(459.)}$$

This method of measuring resistance is known as the Wheatstone bridge method, and the instrument used is called a **Wheatstone bridge**, or, more commonly, a **bridge.**

In practice, the arms *M*, *N*, and *P* of the bridge are made up of a number of carefully prepared resistance coils, accurately adjusted to different resistances, fixed in a box, on the top of which are arranged blocks of brass, which form the terminals of the coils. The brass blocks are so situated that by inserting a metallic plug between any two of them the corresponding resistance coil is cut out, or *short-circuited;* that is, the current passes from block to block through the plug instead of going through the coil, as this path offers practically no resistance to the current. In this way the resistance of the arms of the bridge is changed.

Fig. 1003 shows a section of a box of coils showing the brass blocks and the method of cutting out the coils. *a*, *b*, *c*, *d*, *e*, *f*, and *g* are the brass blocks, to which are connected the

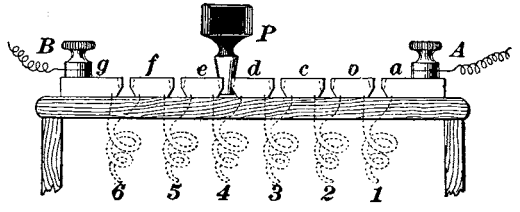


FIG. 1003.

coils *1*, *2*, *3*, *4*, *5*, and *6*. The brass plug *P* is made to fit tightly between the blocks.

The current from the battery is not allowed to flow continuously through the resistance coils, which might introduce errors owing to the heating effect of the current, but the battery circuit and galvanometer circuit are each provided with a key. On pressing the battery circuit key, the current passes through the bridge, and on then pressing the galvanometer key, it is seen, from the motion or lack of motion of the needle, if the proportion of resistance is correct. It is usual to make the arms *M* and *N* of comparatively few coils, with ratios of 10; for example, 1, 10, 100, and 1,000 ohms. By cutting out, for instance, all but the 1-ohm coil in one arm, and leaving all the coils in the other, the ratio of *M* to *N* is 1,111 to 1, or 1 to 1,111, as the case may be; so that an instrument thus arranged would measure resistances

varying from 1,111 times the largest value of $P$ to $\frac{1}{1111}$ of the smallest value of $P$.

For bridge measurements requiring a considerable degree of accuracy, it is best to use a sensitive reflecting galvanometer, which will respond to very slight differences in potential between $c$ and $d$ (in Fig. 1002).

**2511.** In Fig. 1004 is shown an arrangement of a bridge in which $H\,G$ corresponds to arm $M$ (in Fig. 1002), $E\,F$ to

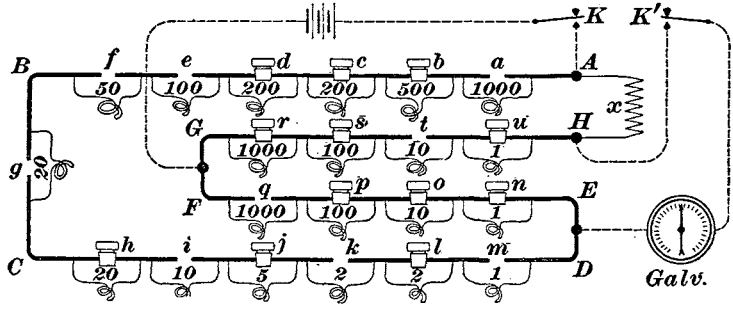


FIG. 1004.

arm $N$, $A\,B\,C\,D$ to arm $P$, and $x$ to the unknown resistance. $K$, $K'$ are the keys for closing the battery and galvanometer circuits, respectively. The number against each coil represents the resistance of that coil. It will be seen that with the resistances in $A\,B\,C\,D$, a great number of combinations can be made with suitable cutting in or cutting out of coils by means of the plugs, as at $a$, $b$, $c$, $d$, etc.

EXAMPLE.—1. If in the figure, as shown, the galvanometer shows no deflection on pressing the keys $K$, $K'$, what is the resistance of $x$?

SOLUTION.—In arm $M$ ($H\,G$) the 10-ohm coil is in circuit, the others are short-circuited by the plugs $r$, $s$, and $u$. In arm $N$ ($E\,F$) the 1,000-ohm coil is in circuit, the rest being short-circuited by the plugs $n$, $o$, and $p$. In arm $P$ ($A\,B\,C\,D$) the 1,000, 100, 50, one 20, 10, one 2, and one 1 ohm coils are in circuit, the rest being short-circuited by the plugs $b$, $c$, $d$, $h$, $j$, and $l$. The resistances are, therefore,

$M = 10$ ohms;

$N = 1{,}000$ ohms;

$P = 1{,}000 + 100 + 50 + 20 + 10 + 2 + 1 = 1{,}183$ ohms;

and by formula **459**, $X = \frac{M}{N} \times P$, or $\frac{10}{1{,}000} \times 1{,}183 = 11.83$ ohms. Ans.

EXAMPLE.—2. What plugs would have to be *inserted* in $P$ to measure a resistance of 21.7 ohms in $x$, if the 1-ohm coil only be used in $M$ and the 10-ohm coil only be used in $N$?

Ans. $a$, $b$, $c$, or $d$, $e$, $f$, $g$, $h$, $l$, or $k$, $m$.

**2512.** The resistance of the coils is usually stamped on the top of the box, that for each individual coil being marked beside the space between the brass blocks to which the coil is attached, so that, after having made the necessary adjustments, it is easy to read off the resistance in either arm of the bridge by adding the figures opposite the spaces unfilled by plugs.

The coils themselves are wound on spools of insulating material, and in reliable instruments are carefully standardized. In order that the current flowing through a resistance coil of a considerable number of turns should not create a magnetic field which might affect the galvanometer, the coils are wound *non-inductively;* that is, for each turn around the spool in one direction is wound a turn in the opposite direction, so that the magnetic effects are neutralized. In working with a sensitive galvanometer this precaution is very necessary. The usual method of winding the spool is to measure off the length of wire required and fold it in the middle; then, starting at this fold, the two parts of the wire are wound on as one wire. A current circulating in a spool so wound will pass through one half the wire in one direction and the other half in the reverse; so the magnetic effects, as well as the self-induction, are rendered practically zero.

In making resistance measurements with a Wheatstone bridge, it is not necessary to know either the current flowing or the E. M. F. of the source of current; so almost any source of a steady current of low E. M. F. is suitable for bridge work. It is customary to use two or three cells of battery, except for measuring high resistances, when more cells, up to 30 or 40, should be used.

**2513.** For measuring low resistances, a modification of the Wheatstone bridge, known as the **slide wire** or **meter** bridge, is used. A diagram of this bridge is shown

in Fig. 1005. A wire $a\,b$ of uniform cross-section is stretched between the heavy copper blocks $c$ and $d$. $R$ is a known and $X$ an unknown resistance, both of which are connected at one end to the heavy copper block $e$, and at the other to the blocks $c$ and $d$, respectively. The galvanometer is connected between the block $e$ and a contact piece $n$, sliding on the wire $a\,b$. It will be seen that this is a form of the Wheatstone

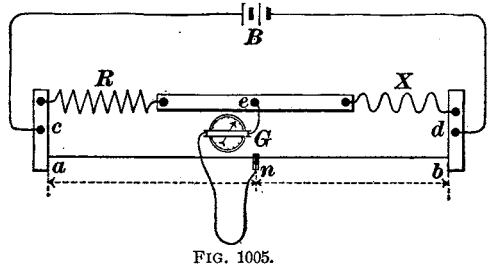


FIG. 1005.

bridge where the arms $M$ and $N$ are replaced by $R$ and $a\,n$, and the adjustable resistance by $n\,b$. From the consideration of the principles of the Wheatstone bridge,

$$R : X :: a\,n : n\,b;$$

or,

$$X = R \times \frac{n\,b}{a\,n}.$$

The copper blocks $c$, $e$, and $d$ are made heavy, so that they will introduce no appreciable resistance into either arm of the bridge. As the wire $a\ b$ is of uniform cross-section, its absolute resistance need not be known; as the resistance of the two parts $a\ n$ and $n\ b$ will be directly proportional to their lengths, the formula

$$X = R \times \frac{n\,b}{a\,n}$$

will hold good if $a\ n$ and $n\ b$ represent *length* instead of *resistance*. It is not even necessary to know the actual lengths of $a\ n$ and $n\ b$; their ratio is sufficient. It is customary, however, to make the length of the wire $a\ b$ one meter in this form of slide-wire bridge; whence the name *meter bridge*. The slider $n$ is usually arranged so that one end slides along a scale the length of the wire, divided into any convenient number of divisions; in the case of a meter bridge, into millimeters; so that the lengths $a\ n$ and $n\ b$

may be read directly from the scale. The known resistance $R$ is not usually made adjustable; instead *standard coils* are used, the usual sizes being 0.1, 1, and 10 ohms, the particular coil used being selected according to the resistance $X$. This makes the construction of the bridge much cheaper than the ordinary form, and as standard resistance coils of great accuracy may be purchased already prepared, the bridge may be cheaply and easily constructed.

**2514.** These standard resistance coils are usually of the form shown in Fig. 1006. The resistance coil itself is enclosed in a brass shell, and the whole filled with paraffin. The two projecting wires are of heavy copper, and serve as terminals. In order to insure good contact, when great accuracy of measurement is required, the terminals of the copper bars $c$, $e$, and $d$, where the resistances $R$ and $X$ are attached, are usually made in the form of mercury cups, instead of binding-posts, so that in connecting the standard resistance coil it is only necessary to hang the ends of the terminals in the mercury cups.

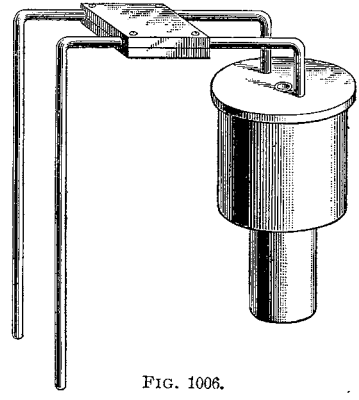

FIG. 1006.

It is not at all necessary that the wire of the slide-wire bridge be stretched out straight, as shown in Fig. 1005. This is a very convenient way to make such a bridge, but they are often built with the wire wrapped around an insulating cylinder, or stretched around the edge of a support, which may be circular or square, or of other shape; the main point being to support a length of wire so that the ratio of the distance between any point on the wire and one end to the whole length of the wire may be determined.

**2515.** The slide-wire bridge is more especially suited, as stated, to the measurement of low resistances, such as determining the *specific resistance* of metals, etc. The **specific resistance** of a conducting substance is the

resistance of unit length of unit cross-section of that substance; that is, the resistance of a piece of metal 1 centimeter long, whose area of cross-section is 1 square centimeter, is its specific resistance. Expressed in ohms, the specific resistance of flint glass is 16,700,000,000,000,000,000, and that of annealed silver is .000001500, their ratio being about 1 : 11,000,000,000,000,000,000,000,000. To prevent the constant repetition of zeros in writing these and similar values, prefixes have been adopted to express multiples or submultiples of a unit, as per the following list:

**MULTIPLES.**

| Prefix. | Amount of Multiplication. | | |
|---|---|---|---|
| | Expressed in Words. | Expressed in Figures. | |
| deka | ten times | 10 | $10$ |
| hecto | one hundred times | 100 | $10^2$ |
| kilo | one thousand times | 1,000 | $10^3$ |
| mega | one million times | 1,000,000 | $10^6$ |
| bega | one billion times | 1,000,000,000 | $10^9$ |
| trega | one trillion times | 1,000,000,000,000 | $10^{12}$ |
| quega | one quadrillion times | 1,000,000,000,000,000 | $10^{15}$ |

**SUBMULTIPLES.**

| Prefix. | Amount of Division. | | |
|---|---|---|---|
| | Expressed in Words. | Expressed in Figures. | |
| deci | one-tenth | $1 \div 10$ | $10^{-1}$ |
| centi | one-hundredth | $1 \div 100$ | $10^{-2}$ |
| milli | one-thousandth | $1 \div 1,000$ | $10^{-3}$ |
| micro | one-millionth | $1 \div 1,000,000$ | $10^{-6}$ |
| bicro | one-billionth | $1 \div 1,000,000,000$ | $10^{-9}$ |
| tricro | one-trillionth | $1 \div 1,000,000,000,000$ | $10^{-12}$ |

Using these prefixes, the specific resistance of flint glass would be said to be 16,700 quegohms ($16,700 \times 1,000,000,000,000,000,000 = 16,700,000,000,000,000,000,000$ ohms) and that of annealed silver 1.500 microhms, since

$$\frac{1.500}{1,000,000} = .000001500 \text{ ohm.}$$

In Art. **2301** the resistance of various metals for 1 inch of length and 1 square inch in area has been given. These values may be reduced to *specific resistance* by performing the necessary calculations. The specific resistances of some of the substances commonly termed insulators are given in Table 85.

**TABLE 85.**

| Substance. | Specific Resistance. |
|---|---|
| Mica | 84 tregohms |
| Gutta-percha | 449 tregohms |
| Hard rubber | 28 quegohms |
| Paraffin | 34 quegohms |
| Porcelain | 540 quegohms |
| Flint glass | 16,700 quegohms |
| Olive oil | 1 tregohm |
| Lard oil | 350 begohms |

Table 86 gives the specific resistance of some of the more common solutions used as electrolytes.

**TABLE 86.**

Specific resistance of various electrolytes in ohms at 50° F.

| Liquid. | Specific Gravity. | Specific Resistance. |
|---|---|---|
| Copper sulphate Saturated solution | 1.205 | 29.30 |
| Zinc sulphate Saturated solution | 1.440 | 33.60 |
| Zinc sulphate | Solution giving least resistance. | 28.22 |
| Common salt | | 4.70 |
| Sal ammoniac | | 2.50 |
| Sulphate of soda | | 11.30 |
| Sulphuric acid | | 1.38 |
| Nitric acid | | 1.29 |
| Hydrochloric acid | | 1.32 |

## TEMPERATURE COEFFICIENT.

**2516.** The resistance of any conducting body changes with changes in the temperature. In the case of electrolytes, non-metallic substances (insulators and carbon), an increase in temperature decreases the resistance, while in the metals and their alloys an increase of temperature increases the resistance. The percentage of change of resistance with unit change of temperature is known as the **temperature coefficient.**

Thus, a piece of copper wire which is known to have a resistance of 10 ohms at a temperature of 32° F. is found to have a resistance of 11.11 ohms at 82° F. These changes in resistance, due to variations of temperature, become quite important in practical work, and allowance must generally be made, in all calculations involving conductors subject to changes of temperature, for the increase or decrease of their resistance.

**2517.** The formulas representing the effects of the *increase* of temperature upon the conductivity of a substance may be written as follows:

Assume $r_1$ = original resistance;

$r_2$ = resistance after rise of temperature;

$a$ = temperature coefficient for each degree Centigrade;

$b$ = temperature coefficient for each degree Fahrenheit;

$C°$ = degrees Centigrade rise of temperature. (See Table 88.)

$F°$ = degrees Fahrenheit rise of temperature.

Then, $$r_2 = r_1 (1 + a C°), \qquad (460.)$$

and $$r_2 = r_1 (1 + b F°). \qquad (461.)$$

The values of $a$ and $b$ may be found in Table 87.

**2518.** The formulas for the decrease of resistance with *decrease* of temperature may likewise be stated.

Let $r_1$ = original resistance;

$r_2$ = resistance after lowering of temperature;

$a$ = temperature coefficient for each degree Centigrade;

$b$ = temperature coefficient for each degree Fahrenheit;

$C°$ = degrees Centigrade fall of temperature;

$F°$ = degrees Fahrenheit fall of temperature.

Then, $$r_2 = \frac{r_1}{1 + a\,C°}. \qquad \textbf{(462.)}$$

$$r_2 = \frac{r_1}{1 + b\,F°}. \qquad \textbf{(463.)}$$

## TABLE 87.

### TEMPERATURE COEFFICIENTS FOR VARIOUS METALS.

| Name of Metal. | For Centigrade. ($a$) | For Fahrenheit. ($b$) |
|---|---|---|
| Silver | .00377 | .002094 |
| Copper | .00388 | .002156 |
| Gold | .00365 | .002028 |
| Aluminum | .00390 | .002167 |
| Platinum | .00247 | .001372 |
| Iron | .00453 | .002517 |
| Tin | .00365 | .002028 |
| Lead | .00387 | .002150 |
| Antimony | .00389 | .002161 |
| Bismuth | .00354 | .001967 |
| Mercury | .00088 | .000489 |
| German silver | .00044 | .000244 |

EXAMPLE.—A copper conductor has a resistance of 15 ohms at a temperature of 20° C. What will be its resistance ($a$) at 50° C.? ($b$) at 8° C.?

SOLUTION.—($a$) The original resistance = 15 ohms = $r_1$. The change in temperature is $50° - 20° = 30°$ C. = C°. Then, since this is an increase, formula **460** will apply, for which, from Table 87, $a = .00388$ for copper, and we have $r_2 = 15\,[1 + (.00388 \times 30)] = 16.746$ ohms. Ans.

($b$) In this case the change of temperature is a decrease, and $C° = 20 - 8 = 12$. Then, by formula **462**, the changed resistance $r_2 = \frac{15}{1 + (.00388 \times 12)} = 14.33$ ohms. Ans.

For metals having a different temperature coefficient from that of copper, the foregoing formulas should be changed by inserting the proper constant, taken from Table 87, in place of .00388 or .002156.

**2519.** The following table of Centigrade and Fahrenheit degrees is given to facilitate the rapid conversion from one scale to another.

**TABLE 88.**

**TABLE OF CENTIGRADE AND FAHRENHEIT DEGREES.**

| Deg. C. | Deg. F. | Deg. C. | Deg. F. | Deg. C. | Deg. F. | Deg. C. | Deg. F. |
|---|---|---|---|---|---|---|---|
| 0 | 32.0 | 26 | 78.8 | 51 | 123.8 | 76 | 168.8 |
| 1 | 33.8 | 27 | 80.6 | 52 | 125.6 | 77 | 170.6 |
| 2 | 35.6 | 28 | 82.4 | 53 | 127.4 | 78 | 172.4 |
| 3 | 37.4 | 29 | 84.2 | 54 | 129.2 | 79 | 174.2 |
| 4 | 39.2 | 30 | 86.0 | 55 | 131.0 | 80 | 176.0 |
| 5 | 41.0 | 31 | 87.8 | 56 | 132.8 | 81 | 177.8 |
| 6 | 42.8 | 32 | 89.6 | 57 | 134.6 | 82 | 179.6 |
| 7 | 44.6 | 33 | 91.4 | 58 | 136.4 | 83 | 181.4 |
| 8 | 46.4 | 34 | 93.2 | 59 | 138.2 | 84 | 183.2 |
| 9 | 48.2 | 35 | 95.0 | 60 | 140.0 | 85 | 185.0 |
| 10 | 50.0 | 36 | 96.8 | 61 | 141.8 | 86 | 186.8 |
| 11 | 51.8 | 37 | 98.6 | 62 | 143.6 | 87 | 188.6 |
| 12 | 53.6 | 38 | 100.4 | 63 | 145.4 | 88 | 190.4 |
| 13 | 55.4 | 39 | 102.2 | 64 | 147.2 | 89 | 192.2 |
| 14 | 57.2 | 40 | 104.0 | 65 | 149.0 | 90 | 194.0 |
| 15 | 59.0 | 41 | 105.8 | 66 | 150.8 | 91 | 195.8 |
| 16 | 60.8 | 42 | 107.6 | 67 | 152.6 | 92 | 197.6 |
| 17 | 62.6 | 43 | 109.4 | 68 | 154.4 | 93 | 199.4 |
| 18 | 64.4 | 44 | 111.2 | 69 | 156.2 | 94 | 201.2 |
| 19 | 66.2 | 45 | 113.0 | 70 | 158.0 | 95 | 203.0 |
| 20 | 68.0 | 46 | 114.8 | 71 | 159.8 | 96 | 204.8 |
| 21 | 69.8 | 47 | 116.6 | 72 | 161.6 | 97 | 206.6 |
| 22 | 71.6 | 48 | 118.4 | 73 | 163.4 | 98 | 208.4 |
| 23 | 73.4 | 49 | 120.2 | 74 | 165.2 | 99 | 210.2 |
| 24 | 75.2 | 50 | 122.0 | 75 | 167.0 | 100 | 212.0 |
| 25 | 77.0 | | | | | | |

**Relations of Thermometric Scales:**

I.—*To convert Fahrenheit to Centigrade, subtract 32, multiply by 5, and divide by 9.*

For example, 50° Fahrenheit $= \frac{(50 - 32)\,5}{9} = 10°$ Centigrade.

II.—*To convert Centigrade to Fahrenheit, multiply by 9, divide by 5, and add 32.*

For example, 100° Centigrade $= \frac{9 \times 100}{5} + 32 = 212°$ Fahrenheit.

## INSULATION.

**2520.** In order to transmit electricity from one point to another, that is, to make the electric current follow a definite path in a conductor, it is necessary that the conductor should be separated from all points between which and the conductor there is a difference of potential by substances whose resistance is so high that that difference of potential can establish no appreciable current.

If two conductors supplying current to a lamp, for example, were laid directly on the ground, the current would flow directly from one conductor to the other through the earth, the earth being a good conductor. If the wires be surrounded by glass tubes, the resistance offered to the passage of the current from wire to wire through the glass and the earth would be so great that the current would be infinitesimal, and the full strength of the current could be utilized in the lamp. Or, if the wires were suspended in the air upon glass knobs attached to poles, again the resistance between conductors, or from the conductors to the earth, would be comparatively enormous. This resistance is known as the **insulation resistance** of the circuit, and, it is obvious, should be as great as possible.

**2521.** In almost all electrical appliances, insulating materials are as necessary as conducting materials, and the measurement of the *insulation resistance* of such apparatus is often very important.

In telegraph and telephone line construction, bare iron or copper wires are used, and are supported on glass knobs. From the high specific resistance of glass, it would be reasonable to suppose that this would insulate the wires very thoroughly from the earth, which would be the case were it not for the fact that the surface of the glass insulators is always covered with a film of dust and moisture, which is of much less resistance than the glass. Glass insulators are, therefore, made so as to give a considerable length of surface between the point of attaching the wire and the point of support of the glass. Fig. 1007 shows such an insulator, which is supported by a wooden pin with a thread cut on the end, which screws into the thread moulded in the glass *B*. The wire being fastened in the groove *C*, any leakage of current from the wire must pass over the surface of the glass from *C* to the supporting pin. The length of this surface is materially increased by the groove *A*. This form of insulator is known as a *petticoat insulator*.

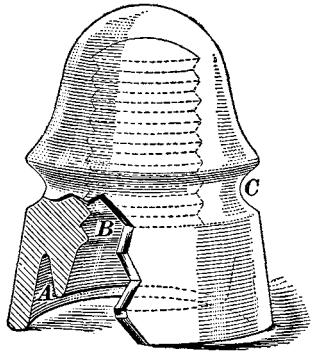

FIG. 1007.

The insulation resistance of one of these insulators would, of course, be very high, even if considerable moisture were present, but as in a long line strung on these insulators the insulation resistances are all in multiple, the total insulation resistance of the line may be low.

**2522.** Fig. 1008 shows an easy method of testing the approximate resistance of a line *L*, in which *G* is a galvanometer, *B* a battery, and *R* a known resistance, which should be high, say 10,000 ohms. *K* is a key or switch, which, when contact is made with terminal *b*, connects the resistance *R* through the galvanometer to the battery *B*; when contact is made to the terminal *a*, the battery is connected to the earth by the earth plate *E*, which may be a

metal plate buried in moist earth, or the wire may be attached to a water or gas pipe, which, being buried in the earth, makes an excellent earth connection.

By connecting the battery to the resistance $R$ by means of the switch $K$, the needle of the galvanometer will be de-

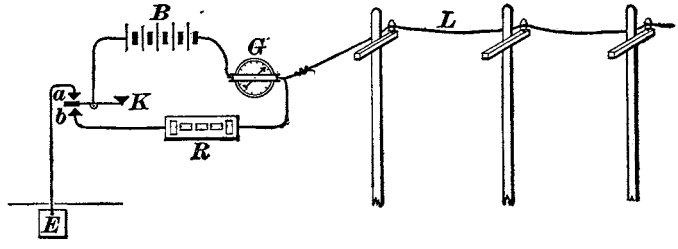


FIG. 1008.

flected a certain amount, which should be noted. Then, on connecting the battery to the earth plate $E$, the circuit will be completed through the insulation resistance between the line $L$ and the earth. The current flowing will again produce a deflection of the galvanometer needle. The currents which flow through the known resistance $R$ and the insulation resistance of the line $L$ will be inversely proportional to those resistances; so, knowing the galvanometer constant, the currents and, from their ratio, the insulation resistances of the line may be calculated.

If a tangent galvanometer be used, the resistances will be *inversely proportional to the tangents of the angles of deflection;* that is,

$$R : \tan d_1 = I : \tan d,$$

where $R$ = known resistance;
$I$ = insulation resistance;
$d$ = the angle of deflection when $R$ is in circuit;
$d_1$ = the angle of deflection when $I$ is in circuit.

From the above proportion,

$$I = \frac{R \tan d}{\tan d_1}. \qquad \textbf{(464.)}$$

That is, *the insulation resistance of a line is equal to a*

*given resistance multiplied by the quotient obtained by dividing the tangent of the angle of galvanometer deflection when that resistance is in circuit by the tangent of the angle of deflection when the circuit is through the line.*

EXAMPLE.—The known resistance = 10,000 ohms ; the deflection of the galvanometer when $R$ was in circuit was 60° ; the deflection of the galvanometer when $I$ was in circuit was 33° ; what was the insulation resistance of the line in ohms ?

SOLUTION.—tan $d^\circ = 1.732$.

tan $d^\circ_1 = .649$.

$R = 10{,}000$ ; therefore, by formula **464,**

$$I = \frac{10{,}000 \times 1.732}{.649} = 26{,}700 \text{ ohms, nearly.} \quad \text{Ans.}$$

**2523.** As the number of paths for the current through the insulation increases with the length of the line, the insulation resistance of the line decreases as the length of the line increases; so the total insulation resistance *multiplied* by the length of the line gives the insulation resistance per unit of length. The usual unit of length for overhead telegraph and telephone lines is one mile.

EXAMPLE.—What is the insulation resistance per mile in the above example if the line be 7.5 miles long ?

SOLUTION.— $26{,}700 \times 7.5 = 200{,}250$ ohms, or .2 megohm, practically. Ans.

This is about the insulation resistance required for ordinary telegraph and telephone work.

The above method of testing requires a sensitive galvanometer of fairly low resistance, and gives approximately precise results for resistances not exceeding about 30,000 ohms.

If the resistance much exceeds this limit, a shunt may be used with the galvanometer of any convenient multiplying power; for example, 100. The deflection through the known resistance being noted, the shunt should be removed for the line resistance measurement. Thus, a current through the insulation resistance of $\frac{1}{n+1}$ of the current through the known resistance (in the above case $\frac{1}{100}$) will give the same

deflection, and the line insulation resistance will be a corresponding multiple of the known resistance.

To obtain more accurate results, allowance must be made in each case for the resistance of the galvanometer and battery. Usually, these are not a sufficient per cent. of the total resistance of either circuit to affect the result much.

**2524.** Another good method of measuring insulation resistance is to make this resistance one arm of a Wheatstone bridge, as represented in Fig. 1009. By making the

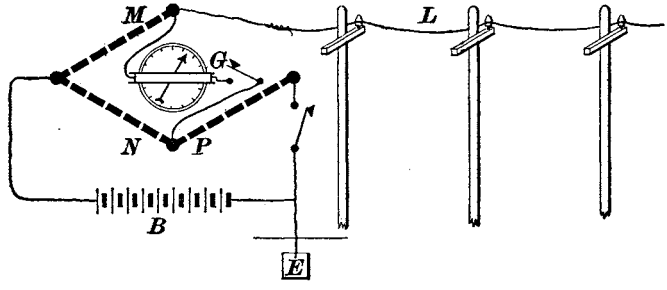


FIG. 1009.

resistance of $M$ great in proportion to $N$, resistances as high as 2,000,000 ohms may be measured with a bridge as ordinarily arranged. (See Fig. 1004.)

**2525.** By **grounding** the distant end of the line $L$, the resistance of the conductor which makes up the line may be measured by the same methods. *Grounding* a circuit consists in connecting it electrically with the earth, usually by means of a metal plate buried in *moist* earth, or to the pipes of a water or gas system. Grounding is conventionally represented as at $E$, Figs. 1008 and 1009. The resistance of the earth is so slight that for small currents it may be usually neglected, if the grounding is well done.

**2526.** The insulation resistance of apparatus for electric light and power work must be considerably greater than that for telegraph and telephone use, and the wire used is, except in special cases, covered with insulation instead of being bare.

This insulation must not only have a high specific resistance, but it must be able to meet various other requirements. In wire for overhead construction, for example, the insulation must stand the abrasion of tree branches, etc., be reasonably fireproof, water-proof, able to withstand the action of the weather, and flexible enough to allow the wire to be reeled or strung in place without injury to the insulation.

It is obvious that many substances of high specific resistance, such as glass or porcelain, would not fill some of the above conditions. In fact, there is scarcely any *one* substance that would answer. The best grades of insulated wire are usually made with a layer of rubber, or some compound composed largely of rubber, surrounding the wire, and protected by an additional covering of braided cotton or similar device, soaked in some reasonably fireproof and weather-proof compound.

In order to thoroughly test the insulation resistance, contact should be made with the whole outer surface of the insulation. This is best done by immersing the wire in a tank of water, slightly salted to make it conducting, as shown in Fig. 1010. The tank is of metal, and the insulation resistance is measured between the water surrounding the wire and the wire itself, as shown at *a b*. Connection with the water is made by a binding-post attached to the metal tank, or if the tank be glass or china, a metal plate is used, dipping in the water.

FIG. 1010.

**2527.** A long piece of wire prepared for test in this way would have a large area of insulating material between two conducting bodies, i. e., the wire and the water. On connecting the wire and water to the poles of a battery, a charge of electricity will spread itself over the inner and outer surfaces of the insulation, which will cause a momentary rush of current from the battery. Another phenomenon which also appears is that known to telegraph engineers as

**electrification.** The exact nature of this phenomenon is not known, but it has been held by eminent authority to be a *polarization* of the insulation, and its effect is to cause a continuation of the first rush of current due to the static charge, that gradually grows smaller and smaller, until after the lapse of some few minutes the current becomes steady. On disconnecting the battery and replacing it with a piece of wire, a back current will flow through the wire from surface to surface of the insulation until it is *depolarized.*

In testing the insulation resistance of long pieces of wire in water, these effects may interfere materially with readings, especially if the Wheatstone bridge method be used. With the following methods of testing, however, it is usually sufficient to wait, after closing the current, until the current has become steady before taking readings.

In testing long cables for submarine use, or long pieces of wire, it is sometimes customary to take the resistance readings after the electrification has continued for a certain definite time, usually 1 minute. This is always so stated in the results of the test, thus: "Insulation resistance per mile after 1 minute's electrification, 400 megohms."

Where the surface area of the insulation is small, the electrification is hardly perceptible, and ordinarily will have no effect on the readings, even if a bridge be used.

**2528.** The following method is like that described in Art. **2522,** Fig. 1008, except that as the insulation resistance of a short length of well-insulated wire would be quite high, it would probably be necessary to use a shunt with the galvanometer.

Fig. 1011 is a diagram of connections for such a measurement. The shunt $S$ is connected in parallel with the galvanometer $G$ by inserting a metal plug between the metal blocks at $a$. The switch $K$ connects either the metal tank $T$ or the known resistance $R$ with the battery $B$.

The best method of procedure is to first read the deflection through the insulation resistance of the wire $W$ with

the shunt disconnected. Then connect in the shunt and read the deflection through the known resistance $R$, changing the shunt $S$ until the deflection is approximately the

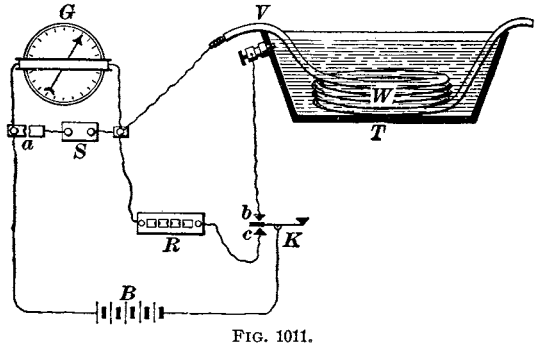


FIG. 1011.

same as before. Then, knowing the multiplying power of the shunt used, the insulation resistance of the wire may be calculated as in Art. **2522.**

EXAMPLE.—In a tangent galvanometer the resistance is 600 ohms; deflection through insulation = 38°; with a shunt of 8 ohms, deflection through resistance = 42°; resistance $R = 10{,}000$ ohms. What is the insulation resistance?

SOLUTION.—Multiplying power of shunt $= \frac{600}{8} + 1 = 76$.

The deflection through the resistance $= d° = 42$, and the deflection through the insulation $= d°_1 = 38$. Then, $\tan d° = .9004$; $\tan d°_1 = .7813$.

To get the true value of the current in resistance $R$, $\tan d°$ must be multiplied by the multiplying power of the shunt.

$.9004 \times 76 = 68.43$ = tangent of the angle to which needle would be deflected if shunt were not used. (68.43 is the tangent of about 89° 10′, at which point a tangent galvanometer could not possibly be read with a precision of under 50%.)

By formula **464,**

$$I = \frac{10{,}000 \times 68.43}{.7813} = \frac{684{,}300}{.7813} = 876{,}000 \text{ ohms, nearly.} \quad \text{Ans.}$$

**2529.** It is evident that the theory of the above method of testing insulation resistance is that, if the voltage of the battery be constant, the current sent through the two resistances will be inversely proportional to those resistances.

The current from the battery is very small in either case, although when passing through the resistance $R$ it is about

70 times as much as when the insulation resistance is in circuit. This difference would scarcely affect an ordinary battery, and as the actual insulation resistance of a specimen of wire is seldom wanted with an accuracy greater than 95–90% (that is, within 5 or 10%), this method gives good results.

**2530.** Another method of measuring insulation resistance that does not require the use of a shunt with the galvanometer is shown in Fig. 1012. To make the test, a battery

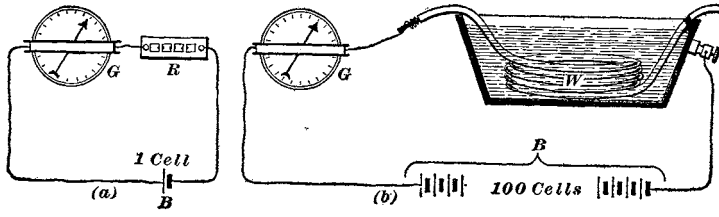


FIG. 1012.

of 100 cells is required. The cells should be uniform in kind, size, and condition.

The galvanometer should be connected in series with the insulation resistance and the cells, as shown in Fig. 1012 (*b*), and the deflection noted.

The galvanometer should then be connected in series with one cell of the battery and a known adjustable resistance, which should be high (say 10,000 ohms, as before), and the deflection under these conditions [Fig. 1012 (*a*)] noted. The resistance should be adjusted so as to give about the same deflection as the first reading.

It is evident that the 100-cell battery would give 100 times the current through the resistance and galvanometer that the single cell does, and assuming that the angle of deflection of the galvanometer is directly proportional to the current flowing, 100 times the deflection, if that were possible. So, calling $d$ the deflection through the resistance, with 1 cell, then $100\,d$ would be the deflection with 100 cells; but the deflection through the insulation resistance with 100 cells is known; call it $d_1$.

Then, as before, $I : R :: 100\,d : d_1$, or if $x =$ the number of cells and $R =$ the extra resistance,

$$I = \frac{R\,x\,d}{d_1}. \qquad \textbf{(465.)}$$

That is, *the insulation resistance of a cable is equal to a given resistance multiplied by the quotient obtained by dividing the deflection through the given resistance with one cell by the deflection through the cable with a number of cells, this product being multiplied by that number.*

EXAMPLE.—If the deflection with 100 cells through the insulation resistance was 37, and through 9,000 ohms with 1 cell was 42, what was the insulation resistance?

SOLUTION.—In this example the given resistance $= 9{,}000$ ohms $= R$; the deflection through this resistance with 1 cell $= 42° = d$; the number of cells used for the insulation test $= 100 = x$; and the deflection through the insulation with these cells $= 37° = d_1$. Then, by formula **465,**

$I = \frac{9{,}000 \times 100 \times 42}{37} = 1{,}020{,}000$ ohms, nearly, or about 1 megohm. Ans.

This method is based upon the supposition that the available E. M. F. of the battery will be directly proportional to the number of cells, which, with a little care in the selection of cells, will be the case, and that the current taken from the cells will not be great enough with either measurement to affect the E. M. F., which will again be the case, and the precision of this form of test will be amply good for most insulation measurements.

**2531.** As many insulations deteriorate after having been under water some time, readings should be taken of the insulation resistance at intervals during a considerable time to observe this deterioration, if there be any. For example, readings taken after the wire had been immersed 15 minutes, 1 hour, 3 hours, 10 hours, 24 hours, would show any effect that wetting would have that would be serious.

If a break occur in the insulation under the water, the water will come in contact with the metal wire, and the ensuing electrolysis will liberate bubbles of gas, which will alternately collect and pass off at the break. This will so vary the resist-

ance that the current will not be steady enough to allow its value to be read. The galvanometer needle will irregularly swing back and forth, and it will be useless to attempt to measure the insulation resistance, especially as the action would indicate defective insulation.

**2532.** It is not altogether necessary to immerse the wire in water, although this is very convenient, as the water makes contact with the entire outer surface of the insulation, as the wire does with the entire inner surface, besides testing the water-proof qualities of the insulation.

For some tests the wire may be closely wrapped around a smooth bright metal bar—a section of shafting for example—and the resistance between this bar and the wire measured. Or two pieces of the wire may be twisted together, and the resistance between the two wires measured.

It is often desirable to test the insulating qualities of sheets of paper, mica fiber, or similar substances. A convenient way to prepare them for such a test is to make two smooth brass plates smaller than the pieces of insulation to be tested, which should be placed between them. The insulation resistance may then be measured between the two brass plates, and from the area and length (thickness) of the piece of insulation between the plates its specific resistance may be calculated. Another way is to wrap the insulation around a smooth metal bar as before—a piece of shafting for example—and bind the outside closely with fine bare copper wire. The insulation resistance may then be measured between the wire and the bar. Many other methods of preparing insulation for tests will suggest themselves as occasion requires.

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## ELECTRICAL APPARATUS.

**2533.** The following is a description of the free electrical apparatus with which the student is furnished in connection with this subject. Directions are given for performing certain experiments calculated to help the student to a better understanding of the subject of Electrical Measurements. Unless the student has had previous instruction of a like nature, he is earnestly requested (though not required) to

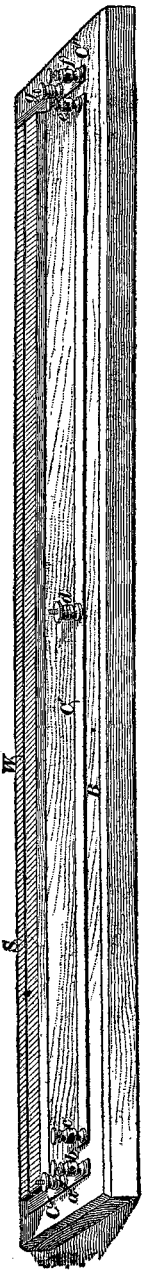


Fig. 1013.

make all the experiments mentioned, and to keep a record of his results by answering the questions under the heading Experiments with Electrical Apparatus, which follows the description of the instruments. He may forward his record to the School, if he so desires, for correction and approval when he sends his answers to the questions on Electrical Measurements, but he will be marked and his work computed in connection with his work on the questions above referred to.

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### DESCRIPTION OF APPARATUS.

**2534. The Slide-Wire Bridge.**—This is a Wheatstone bridge of the slide-wire form (Art. **2513**), and is illustrated in Fig. 1013. The slide wire *W*, made of German silver wire, is stretched across a scale *S*, of the same length as the wire, divided into 1,000 equal divisions, every 5th division being marked, and every 50th division numbered, in both directions, starting from each end. Three strips of copper *C*, *C'*, *C''* are fastened to the board, as shown, and to these are screwed the terminals *a* and *b*; *c*, *d*, and *e*; *f* and *g*, respectively.

From an inspection of the figure, it will be seen that the strip *C* corresponds to the piece *d* in Fig. 1005; *C'* corresponds to the middle section *e*, and *C''* to the piece *c* in the same figure.

The **resistance coils** furnished for use with this bridge are of the form illustrated in Fig. 1014. The resistance coil is made up of a coil of German silver wire *R*, insulated with silk, wound on a wooden bobbin, or spool, *S*. Through the head of the spool two pieces of heavy copper wire *t*, *t* are driven, the ends of the resistance coil being soldered to these wires; they form the terminals of the coil. The two wires (*t*, *t*) are the same distance

apart as the holes in the terminals *b*, *c* or *e*, *f*, Fig. 1013, so that a coil may readily be connected in its proper position by

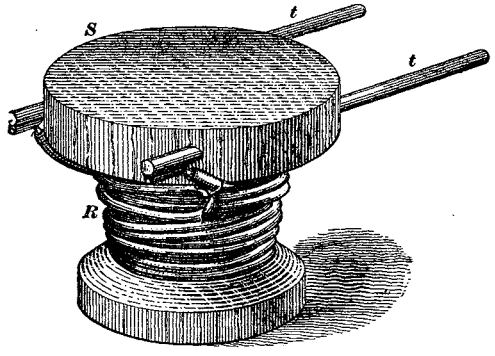


FIG. 1014.

slipping the two terminal wires through those holes, and clamping them in position by means of the milled-head screws.

With each bridge are furnished two resistance coils, one of 1 ohm, the other of about 10.5 ohms, resistance. These may be readily distinguished, as the 1-ohm coil is covered with a strip of leather, while the wire of the other is exposed. Also, the 10.5-ohm coil is made of much finer wire than that used for the 1-ohm coil.

**2535.** The **galvanometer** is a combination tangent and detector galvanometer, available for use in either capacity. The detector galvanometer consists of a coil of insulated wire wound on a wooden form, and divided in the center to allow for the support of a magnetic needle which swings in the center of the coil. A perspective section of the coil and its support is shown in Fig. 1015. Here *B* represents the wooden form on which the coil is wound in two parts, *C C* and *C' C'*. An

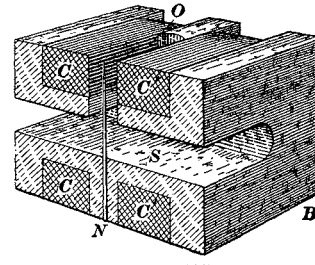


FIG. 1015.

opening is made in the form, passing completely through the coils, thus forming the space $S$ in which the magnetic needle is free to swing. Another opening $O$ is made in the top of the partition between the two parts of the coil, extending through to the space $S$. This provides a means for placing the magnetic needle in position. In the center of the wooden form is placed an ordinary steel needle $N$, extending nearly to the top of the coils in the center of the opening $O$; this needle forms the pivot on which the magnetic needle swings.

The magnetic needle and the pointer that is attached to it are illustrated in Fig. 1016. The construction is as follows: The magnetic needle $M$ is made from a piece of flat steel about $\frac{1}{2}$ inch long and $\frac{3}{16}$ inch wide, pointed at the ends. Before being hardened, a hole is punched in the cen-

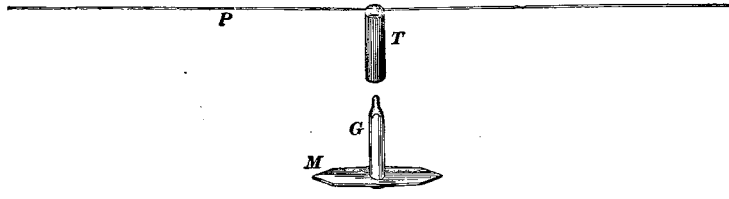


FIG. 1016.

ter of this piece, and when the piece has been hardened and magnetized, a short glass tube $G$, closed at the top, is fastened in the hole. This forms the bearing which rests on the pivot in the center of the coils; the smooth glass surface resting on the steel point makes a bearing that is remarkably free from friction, so that the galvanometer is very sensitive. The pointer which indicates the deflection of the needle is a fine glass rod $P$, blackened at the ends, and attached in the middle to a light tin tube $T$, which slides over the glass bearing $G$, and is held in place by its friction with the bearing.

The coils and pivot are mounted in the center of a circular wooden case that is turned from a solid block; a paper scale is mounted over the coils, and is divided on one side into degrees (numbered to 90 by tens each way from a zero

mark), and on the other side the scale is marked to represent tangents. The ends of the pointer on the needle move over the scale divisions and indicate the angle of deflection of the needle. The whole is protected by a circular glass cover, held in place by a ring of brass wire sprung into a groove under the top edge of the wooden case, as will be seen by examining the instrument. Connection to the coil is made by means of two binding-posts on the case, shown at *a*, *b* in Fig. 1017.

When the instrument is used as a tangent galvanometer, the case containing the magnetized needle and coil is placed within the circle *c* on a cross support having a dowel which fits into a hole in the center of the case. The galvanometer may, therefore, be turned through any angle, while still keeping the magnetized needle in the center of the large circle. On this circle are wound four coils of two turns each of No. 18 insulated wire, and the ends of these coils are brought out to terminals on the base. Thus, the terminals *d*, *d'* form the ends of one coil, *e*, *e'* are the terminals for the second coil, and so on. The galvanometer should be so placed within the coil that the scales are one on each side of the circle. When the whole instrument is then turned so that the glass pointer is at right angles to the coil and over the zero marks, the axis of the magnetized needle will be in the plane of the coil.

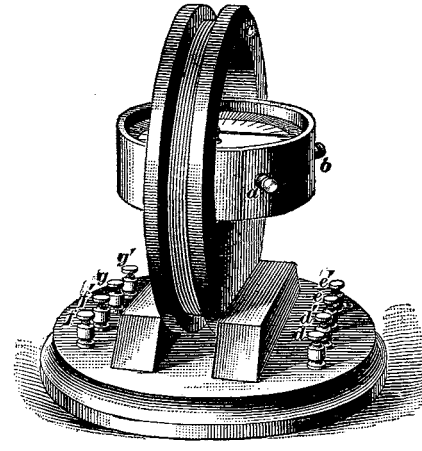

FIG. 1017.

When the instruments are received, they should be carefully unpacked and prepared for use.

In setting up the galvanometer, the glass cover should first be removed by springing out the brass wire ring and

introducing a thin knife-blade or a toothpick under the edge of the glass. The cotton which is placed on the glass pointer to protect it while in transit must then be carefully removed, after which the glass should be replaced and the ring sprung in. The apparatus is then ready for use.

**2536.** A diagrammatic representation of the connections of the bridge for ordinary resistance measurements is shown in Fig. 1018. From this it will be seen that the battery $B$ (which is the Leclanche cell already furnished the student) is connected to the copper contact strips to which

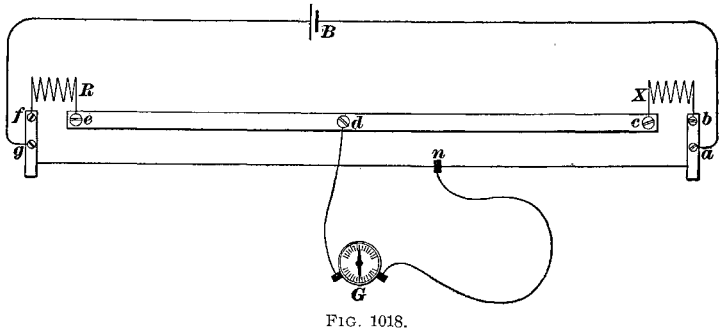


FIG. 1018.

the ends of the slide wire are also fastened. The known resistance $R$ and the unknown resistance $X$ are connected between the outer and middle strips.

One terminal of the galvanometer is connected to the middle strip at $d$ by a wire clamped under the screw, the other terminal being connected to the proper point on the slide wire by a piece of insulated wire having a contact piece at the end. This end is pressed on the slide wire and moved along until a point is reached where alternately removing it from and touching it to the slide wire produces no deflection of the galvanometer. With care in observing that the galvanometer needle is actually *not* deflected even a fraction of a scale division, this point may be very accurately located. By reading the number of the division on the scale at this point, the relation between the lengths of

the slide wires $g\,n$ and $n\,a$ may be readily found, and the value of the unknown resistance $X$ found by applying the formula given in Art. **2513,** but substituting the point $a$ for $b$ and $g$ for $a$, as these letters in Fig. 1018 correspond to the ends of the wire in Fig. 1004, $X = R\frac{n\,a}{n\,g}$.

For example, suppose the 1-ohm coil to be used as $R$, and that the position of the point $n$, where an application of the galvanometer lead to the slide wire produces no deflection of the galvanometer, to be opposite division 415 on the scale starting at $g$; this will be the third division from the line marked 400, in the space between 400 and 450. The corresponding number read on the scale which starts from $a$ will be 585. The position of this point $n$ will hereafter be called the *bridge reading;* in this case the bridge reading is 415 or 585. We may now find the value of the unknown resistance $X$ by the formula above,

$$X = 1 \times \frac{585}{415} = 1.41 \text{ ohms.}$$

The accuracy of this bridge does not require that the results be carried out to more than three significant figures.

If the relative position of $X$ and $R$, Fig. 1018, be reversed, the formula will obviously read $X = R\frac{n\,g}{n\,a}$. For uniformity in all problems given in this section, the known resistance will be considered to be in the position shown in Fig. 1018.

In using the detector galvanometer, see that it rests on a level surface, so that the needle and pointer will swing clear. This may be tested by causing the needle to deflect (e.g., by momentarily connecting the galvanometer to the battery terminals), first in one direction and then in the other; the needle should, after two or three oscillations, return to the same position from either side.

When using the tangent galvanometer, the instrument may be leveled by means of the three leveling screws in the base; in fact, the galvanometer may, for most purposes, be kept in position on this base.

See that no magnets or large pieces of iron are near the galvanometer, or, if this is unavoidable, see that the relative position of the galvanometer and the magnets or pieces of iron is not changed while making a test.

Set the galvanometer up in such a position that the ends of the pointer coincide with the zero divisions of the scale.

If either the pointer or pivot is not exactly central, it may be that each end will not coincide with the zero marks at the same time. If this is the case, get one end into the proper position and take all readings from that end of the pointer.

Do not rub the glass cover with a piece of cloth or paper before taking a reading, as the static charge thus induced on the glass will attract the glass pointer, thereby causing it to indicate incorrectly.

In making all experiments, note on a piece of paper or in a note-book the apparatus used, and how; if necessary, draw a diagram of connections, etc. Write down each result as soon as each part of the experiment is completed; *do not trust to memory for results.* Make all experiments twice, if possible, thus checking the first results. By taking the above precautions and exercising care in taking the readings, reliable and instructive results may be obtained with this simple apparatus by performing the experiments mentioned in the succeeding pages.

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### EXPERIMENTS WITH ELECTRICAL APPARATUS.

**Experiment 1.**—As stated above, one of the resistance coils has 1 ohm resistance, the other about 10.5 ohms. It is desirable that this second coil have 10 ohms resistance, to facilitate calculation, etc. The process of winding these coils is as follows: The given length of wire is cut off and folded in the middle; the ends are then soldered to the copper terminals and the doubled wire wound on the spool, the middle of the length of the wire thus coming on the outside of the spool, where it is held by a piece of thread. By cutting this thread the middle of the wire is released, and a length may be unwound, the insulation scraped off,

and the two bare wires firmly twisted together, which will have the effect of lessening the resistance of the coil. For this experiment, then,

(*a*) Find the resistance of the fine wire resistance coil, using the other coil as the standard, and calling its resistance 1 ohm.

(*b*) Figure out the bridge reading which would result if the fine wire resistance coil were of 10 ohms resistance.

(*c*) Lessen the resistance of the fine wire coil, a little at a time, in the manner described, until it is of 10 ohms resistance. State the various steps of the operation fully.

(*d*) From the results of experiment (*c*), what is the total length of wire in the fine wire coil as furnished?

**Experiment 2.**—Measure off about 40 feet of the insulated wire furnished with the first set of apparatus. Connect this in the place of the unknown resistance *X*, Fig. 1018. Use the 1-ohm coil for the known resistance and measure the resistance of the wire.

(*a*) What is the resistance per foot of the wire?

(*b*) Assuming it to be pure annealed copper, what is the diameter of the wire, calculated from the above measurement?

**Experiment 3.**—Connect up the bridge, battery, and galvanometer as shown in Fig. 1019, using the 10-ohm coil as the known resistance *R*. It will be seen that in this case

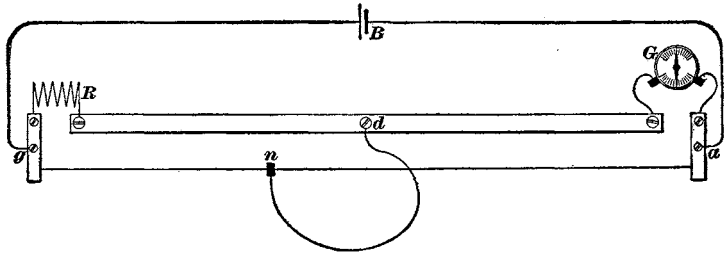


FIG. 1019.

the galvanometer takes the place of the unknown resistance, and a plain wire of the galvanometer circuit, in the ordinary method of connection. (Fig. 1018.)

When the connections are made, a current will flow through the galvanometer, giving a certain deflection. If the wire that takes the place of the galvanometer circuit in the ordinary method is pressed down on the slide wire at *any other point* than where no current passes through it, the amount of current in the circuit will be changed and the deflection of the galvanometer will correspondingly change. Consequently, if a point on the slide wire is found where connecting the wire produces *no change* in the galvanometer deflection, that point will give a bridge reading from which the galvanometer resistance may be calculated by the formula already given.

(*a*) Perform the foregoing experiment and calculate the resistance of the galvanometer.

(*b*) Explain the theory of this measurement.

**Experiment 4.**—Scrape the insulation off one end of each of two short pieces of wire for about 6 inches. Wrap the bared ends firmly, one around one of the terminals of the 10-ohm coil and the other around the other terminal, using about 3 inches of the bared ends. This will leave 3 inches or so projecting from each terminal (besides the insulated part), which should be connected to the terminals of the galvanometer, thus connecting the 10-ohm coil and the galvanometer in parallel, or, in other words, shunting the galvanometer with the 10-ohm coil.

(*a*) Calculate the combined resistance of the galvanometer and its shunt.

(*b*) Measure this combined resistance on the bridge by the method described in Experiment 3, using the 1-ohm coil for the known resistance. How do the two results compare?

(*c*) What is the multiplying power of this shunt?

**Experiment 5.**—Check up the results of the measurements given in Experiments 1 and 3 by reversing the positions of the known resistance and the unknown resistance, using the modified form of the formula as given in Art. **2536.** How do the results compare?

**Experiment 6.**—In measuring the resistance of apparatus located at some distance from the bridge, it is necessary to take into account the resistance of the wires leading to the resistance that is to be measured. This can best be done by measuring the resistance of these leads separately, their circuit being completed by twisting or pressing the distant ends of the leads together, either before or after the regular resistance measurement is made, and deducting this resistance from the total resistance of the circuit measured.

Perform this experiment, measuring the resistance of the 1-ohm coil located 20 or 30 feet away from the bridge. Use the 10-ohm coil as the standard, and some of the wire supplied with the first lot of apparatus for the leads. Give the total resistance of the circuit, the resistance of the leads, and the resistance of the coil.

**Experiment 7.**—Secure a piece of the carbon from an arc lamp, 3 or 4 inches long. If coated with copper, scrape the copper off or eat it off with acid.

(*a*) Twist the bared ends of two short pieces of wire around the carbon at points as near the ends as possible, and measure the resistance of the carbon between these two points.

(*b*) Measure carefully the diameter of the carbon and the length between the points where the lead wires are attached, and from these figures calculate the resistance of the carbon for an inch cube; i. e., what would be the resistance of a piece of the carbon experimented upon if of 1 square inch sectional area and 1 inch long?

## SUGGESTIONS FOR EXPERIMENTS.

**2537.** If the student has access to an electric-light station he can measure the resistance of the various circuits of the dynamos or other appliances, or of the lines, at times when the station is not running, or can measure such other resistances, of between .05 and 200 ohms, as the opportunity may allow.

Other standard resistances may be prepared on the same lines as those furnished with a bridge; if made of higher or

lower resistance than those furnished, they will increase the range of resistances that may be measured, although accurate measurement of high resistances (500 ohms or over) should not be expected.

The best method of calibrating the tangent galvanometer is to compare it with a standard direct reading instrument—a Weston ammeter, for example. If this can not readily be done, it may be calibrated by the copper sulphate electrolysis method described in Art. **2496** and following. The weight measurements should be carefully made on a delicate pair of scales. Any good apothecary has such a pair of scales, and would probably perform the weighings for a small sum.

In this method of calibration, copper wires may be substituted for the copper plates described in Art. **2498,** they being easier to clean and handle. Two wires should be used, coiled into open spirals, one about twice the diameter of the other; the smaller should be placed inside the larger, and connected to the positive pole of the battery, thereby becoming the electrode to be weighed.

Many other useful applications of this apparatus which might be mentioned will occur to the student as he advances in the Course.

## PRACTICAL MEASUREMENTS.

### INSTRUMENTS.

**2538.** Most of the apparatus and tests so far described are more for laboratory use than for the shop or station, and now such accurate and reliable portable measuring instruments are made that many measurements before referred to may be made with as great a degree of precision and much greater facility than

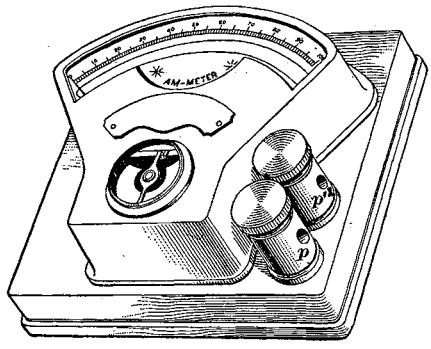


FIG. 1020.

with the various galvanometers and other apparatus already described. Some of the best forms of portable instruments

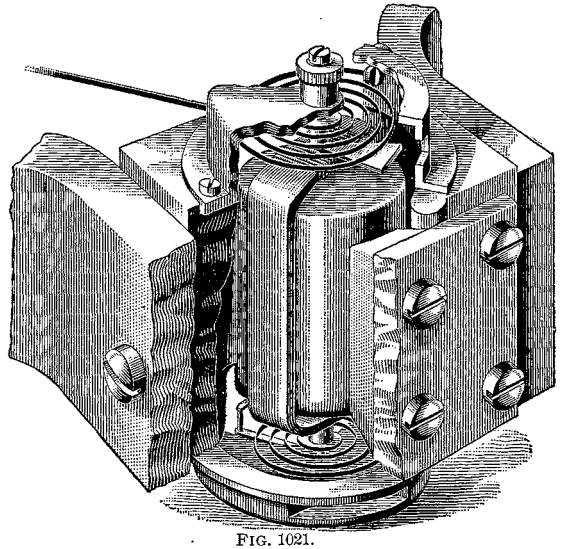

FIG. 1021.

made are those known as the Weston instruments. Their general form is shown in Fig. 1020. These instruments are made on the principle of the D'Arsonval galvanometer (Art. **2476**), as shown in the sectional view, Fig. 1021.

Fig. 1022 shows the magnetic circuit of this form of instrument. The permanent magnet *A A* has soft iron pole-pieces *P*, *P* fastened to it by the screws *S*, *S*, and bored

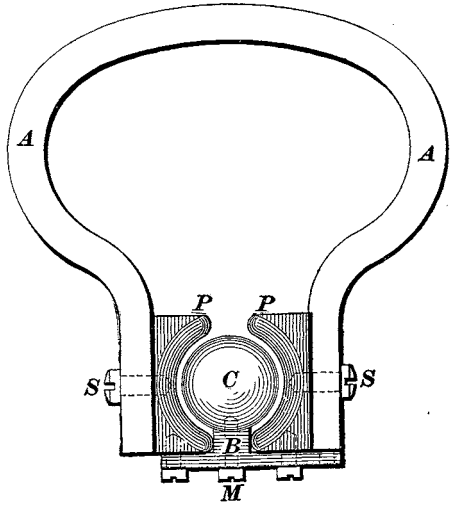


FIG. 1022.

out to make a cylindrical opening. In the center of this opening is a stationary soft iron cylinder *C*, supported in place by a screw *M* passing through a lug on the brass plate *B*. This cylinder being of less diameter than the opening through the pole-pieces, there is left a narrow gap between the pole-pieces and the iron core, as shown. The lines of force from the permanent magnet pass across this space, making a strong and uniform magnetic field.

The movable part of the instrument is shown in Fig. 1023. It consists of a rectangular coil *C* of fine wire wound on an

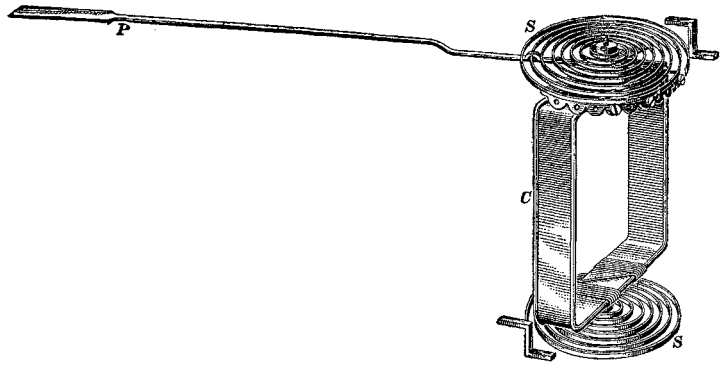


FIG. 1023.

aluminum or thin copper bobbin, which is suspended vertically between two delicate jeweled bearings. Two flat horizontal spiral springs *S*, *S* oppose the tendency of the coil to rotate, and at the same time conduct the current to the suspended coil.

A thin aluminum pointer *P*, attached at right angles to the coil, moves over a scale and indicates the deflection of the coil from its normal position, which is as shown in Fig. 1021. On a current being sent through the coil by means of the springs *S*, *S*, there is a tendency for the coil to move through the magnetic field (Art. **2438**), which it will do until the torsion of the spiral springs equals the force with which the coil tends to move, when the coil will come to rest, and the pointer will indicate the angle of deflection of the coil.

The magnetic field being practically uniform, the angle of

deflection is closely proportional to the current in the coil, so the scale divisions are very uniform, as is shown by Fig. 1024, which is a scale about three-fourths size.

The copper or aluminum bobbin on which the coil is wound, in moving through the magnetic field, has an electromotive

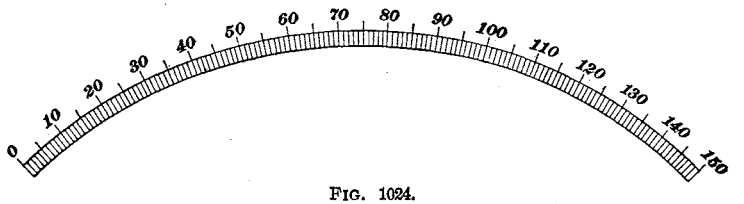


FIG. 1024.

force set up in it which causes a current to circulate around the bobbin as long as the bobbin moves. This current circulates in the opposite direction to the current in the coil; hence, it tends to oppose the motion of the coil. As this tendency exists only when the bobbin is moving, it has the effect of preventing the needle from swinging too far over the scale, thus bringing it quickly to rest at the proper point.

This *damping effect* is due almost entirely to the currents in the bobbin. The friction is so slight that it has practically no effect on the position the needle will take. This is shown by the fact that the needle having been deflected by a current will respond to very minute variations in that current; that is, the instruments are very *sensitive*.

An instrument whose moving system possesses this feature of coming to rest quickly at the proper point is known as a **dead-beat** instrument; this is a very important feature, for it assists the rapidity of taking measurements very materially. The moving system is practically the same for all direct-current Weston ammeters and voltmeters. If the instrument is designed for a voltmeter, a high resistance, located in the back of the case, is connected in series with the movable coil; if for an ammeter, the coil is connected in parallel with a short, thick piece of copper or some alloy, so that only a small part of the current passes through the movable coil, and the resistance of the instrument is extremely low. By

reason of this extremely low resistance of the ammeters and the high resistance of the voltmeters, they consume very little energy indeed, and may be left continuously in circuit without undue heating.

For example, a 15-ampere Weston ammeter has an internal resistance of .0022 ohm; when measuring a 10-ampere current, the drop (C R) is .022 volt, and the watts expended (C E) = .22, or about one thirty-four-hundredth $\left(\frac{1}{3,400}\right)$ of a horsepower.

The resistance of a 150-volt voltmeter is about 19,000 ohms. Measuring 110 volts, the instrument would take $\frac{110}{19,000} = .0058$ ampere, nearly, with a consumption of energy of .638 watt, nearly, or about $\frac{1}{1,200}$ of a horsepower.

The conducting parts of the instrument are made of an alloy having a very low temperature coefficient, so that moderate changes in the temperature of the instrument do not affect its readings appreciably. Beneath the needle just inside the scale is a mirror. On looking down on the needle, by getting the needle directly over its reflection in the mirror, errors due to not getting the needle in line with the scale (known as **parallax**) are eliminated. These several good features make these instruments very reliable and convenient for making all sorts of electrical measurements, and as they may be obtained in a great variety of ranges, their use is very general.

There are many other forms of portable instruments made, most of them being constructed on the same general principle as the Weston, and they may often be used in making various measurements to good advantage.

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### SIEMENS DYNAMOMETER.

**2539.** Another instrument which is largely used for measuring currents is the Siemens dynamometer. This instrument is constructed on the same fundamental principle that the Weston and many other electromagnetic instru-

ments are, namely, that a conductor carrying a current will tend to move, if in a magnetic field, with the direction of the lines of force at an angle to the direction of the current.

The working parts of this instrument, one form of which is shown in Fig. 1025, consists of two rectangular coils of wire, one, *F*, fixed, the other, *M*, movable. The normal position of the movable coil is with its plane at right angles to the plane of the fixed coil, and it is suspended in this position by a fiber. To the top of the coil is also attached a light helical spring *S*, the other end of which is attached to a milled nut *T*. On turning this nut the spring will be tightened, thus acting to move the coil.

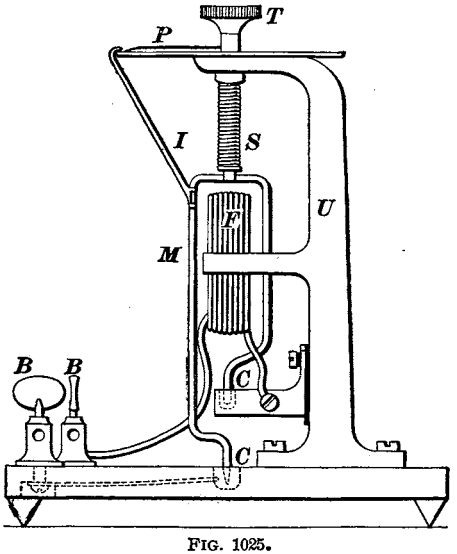

FIG. 1025.

The two coils are connected in series, connection being made to the movable coil by means of mercury cups *C*, *C*, into which the ends of the coil dip.

On sending a current through the two coils in series, the mutual action of the two coils tends to move them into parallel planes. The effect is to rotate the movable coil about its vertical axis; by turning the milled nut, a tension may be put on the spring which will return the coil to its original position. The force exerted by the spring on the coil is proportional to the angle through which the milled head attached to the spring is turned; so, by a pointer *P*, attached to the milled head, the force required to pull the coil back to its central position may be indicated.

A pointer *I*, attached to the movable coil, is opposite a

zero mark on the scale when the movable coil is at right angles to the fixed coil.

As the two coils are in series, doubling the current in one coil doubles it in the other, so the mutual force of both coils is doubled, and the force acting on the movable coil is quadrupled; that is, the force on the movable coil, hence the torsion in the spring necessary to bring the pointer on the coil back to zero, is *proportional to the square of the current.*

These instruments are seldom made direct reading, but are furnished with a table which gives the deflections corresponding to various current strengths. Intermediate values may be interpolated or calculated.

The fixed coil is usually wound in two parts of unequal number of turns and size of wire; either coil may be used, thus varying the range of the instrument. This form of instrument is especially useful, as it may be used equally well for alternating current as for direct, since there is no iron or other magnetic material used in its construction.

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### EDISON CHEMICAL METER.

**2540.** As stated, most of the measuring instruments in commercial use depend on the electromagnetic effect of a current for their action; perhaps the only electrochemical current meter that is in commercial use is the Edison chemical meter, which is extensively used by the Edison Illuminating Companies. In this instrument a fixed proportion of the current passing through the meter is shunted through an electrolytic bath consisting of two zinc plates dipping in a solution of sulphate of zinc. The plates, solution, and connectors are all mounted in little glass jars, and two jars are set up in each meter, one to act as a check on the other. At the end of a certain fixed time (usually thirty days) the jars and their contents are replaced by others, and the ampere-hours of current that have been used by the customer calculated from the gain in weight of the negative plate. By various ingenious devices in the several parts of the meter, the effects of various sources of error are almost

entirely removed. Great care, however, must be exercised in removing the jars and caring for their contents. Fig.

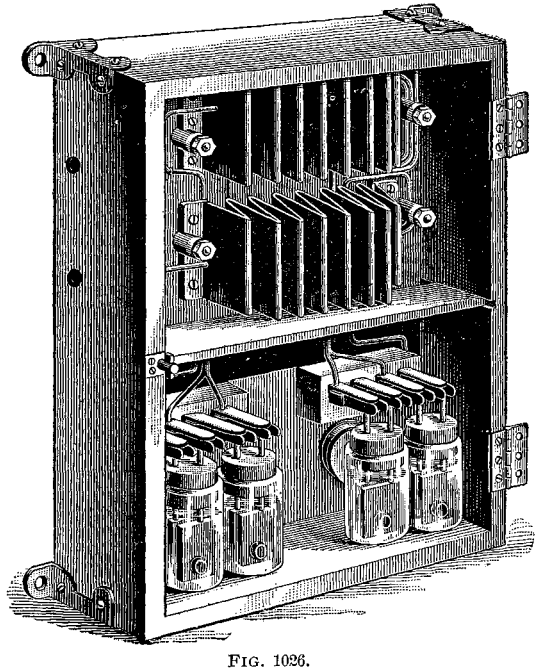

FIG. 1026.

1026 gives a view of the latest type of Edison chemical meter.

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### CARDEW VOLTMETER.

**2541.** The representative instrument of the class that measures the heating effect of the current is the **Cardew voltmeter,** illustrated in Fig. 1027.

In this instrument a long wire *w*, usually of some platinum alloy, is stretched from end to end of the long tube *a* ; each end is fastened to the dial end of the tube; the wire then passes over pulleys at the end of the tube and back to the dial end, where a spring attached to the middle of the wire keeps it stretched taut. On a current being sent through the wire, the heat caused by the passage of the current

expands the wire; the addition to its length is taken up by the spring, and the motion of the middle of the wire which is attached to the spring is transmitted to a needle *b* by suitable multiplying gear, so that the motion of the needle over the dial is a measure of the amount of expansion of the wire.

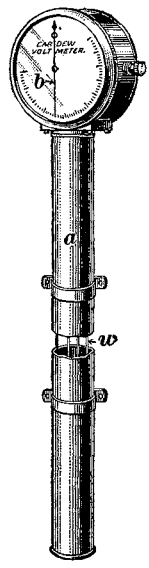

FIG. 1027.

The wire is usually of small diameter and considerable specific resistance, so that it in itself has resistance enough to allow the instrument to be used as a voltmeter for potentials less than about 100 volts without external resistance. This voltmeter may be used either for alternating or direct currents, is remarkably dead-beat, and simple in construction. Its internal resistance is low for a voltmeter, and, in consequence, it takes considerable current, enough in many instances to seriously affect some conditions of an experiment. This instrument has no particular law of deflections by which the scale is divided; the principal divisions are determined by comparing the instrument with a standard, and the intermediate divisions interpolated.

There are several other instruments made on this principle, commonly known as *hot-wire instruments;* the Cardew is the best known.

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### WATTMETERS.

**2542.** The energy expended in a circuit being the product of the current and the electromotive force, these factors may be measured separately, and multiplied together to obtain the number of watts expended. Instruments have been designed, however, which automatically perform this multiplication, thus measuring watts directly, one of the best known being the **Siemens** wattmeter.

This instrument is of the same general form as the current-meter, Fig. 1025, the difference between the instruments being that in the wattmeter the two coils are not

in series. This instrument measures at all times the product of the current in any circuit and the difference of potential between the ends of that circuit. The stationary coil is in series with the outside circuit; consequently the total current flows through it. The movable coil is in series with a resistance great enough to prevent the full difference of potential between the mains sending more than a small amount of current through the movable coil. This coil and the resistance are then connected in parallel with the rest of the circuit, as shown in Fig. 1028, where $F$ is the fixed coil of the instrument; $M$, the movable coil; $R$, the resistance that is connected in series with $M$; $D$, the source of electricity, and $C$, the external circuit, the energy expended in which it is desired to measure.

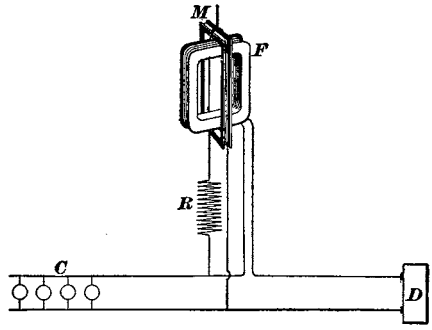

FIG. 1028.

It is evident that if the drop in volts through the circuit $C$ be constant, the current through $M$ will also be constant. The force acting on the movable coil will then vary directly as the current in the coil $F$; the potential being constant, the watts expended in the circuit will also vary directly as the current. If the current in the coil $F$ is constant, variations in the E. M. F. will vary the current in the coil $M$ in the same proportion, and the force on the coil $M$ will then vary directly as the E. M. F.; the current in the circuit $C$ being constant, the watts will also vary directly as the E. M. F. So, in either case, the force acting on the movable coil (consequently the force required to bring it to zero position) varies directly as the watts. When variations occur in both current and potential simultaneously, the same holds true, and the force required to bring the coil to the zero position is proportional to the watts.

The general appearance of the wattmeter is almost precisely the same as that of the current dynamometer. The resistance used with the movable coil is usually made a separate piece of apparatus; when made so that it has no *self-induction*, the wattmeter may be used for measuring the energy expended in alternating-current circuits.

### THE THOMSON RECORDING WATTMETER.

**2543.** The Siemens wattmeter gives the instantaneous value of the watts expended in the circuit. The Thomson wattmeter is, as its name indicates, a recording meter, and its readings give the product of the watts and time, i. e., the watt-hours. The construction is simple; the principle is, broadly, that of the Siemens dynamometer. The movable coil is not held to zero position, but revolves, and does not surround the fixed coil, but revolves between two fixed coils. The movable coil is really a small *drum-wound armature*, provided with a small commutator made of silver to prevent oxidation. The effect of using the commutator is to make the effective plane of the coil (armature) take a position at right angles to the plane of the fixed coils.

The connections of this instrument are made on the same principle as those of the Siemens wattmeter. The fixed coils are in series with the circuit, and the movable coil and a resistance in series with it are in parallel with the circuit.

The amount of energy expended in the circuit is measured by the rotation of the movable coil, a worm on the shaft on which the movable coil is mounted engaging with a set of gears which operate a dial similar to a gas-meter dial, so that the energy expended in a certain given time in the circuit may be read directly from the dial in watt-hours.

The friction of the apparatus being exceedingly small, the retarding force on the coil that opposes its tendency to rotate is imparted by a thin copper disk attached to the shaft on which the movable coil is mounted. This disk is rotated between the poles of strong permanent magnets; the lines of force from the magnets cutting the disk set up electromotive forces between adjacent points on the disk;

the disk being of copper, the resistance between those points is very low, so that a considerable current may flow. This current tends to retard the rotation of the copper disk, and this tendency increases directly as the speed. As in the Siemens wattmeter, the force acting to rotate the movable

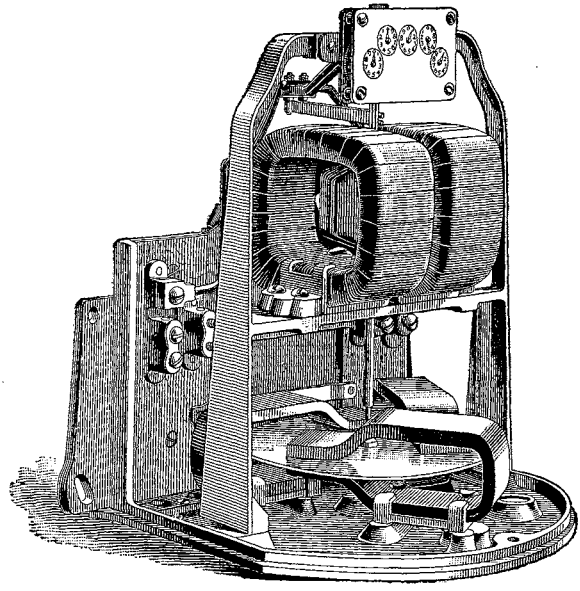

FIG. 1029.

coil increases directly as the watts; therefore, the number of revolutions of the moving system of the meter will be directly proportional to the watts expended in the circuit. This meter may be used for either alternating or direct currents, and gives very accurate results. Fig. 1029 represents the Thomson meter with the cover removed.

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### SHALLENBERGER METER.

**2544.** This meter is constructed on a similar principle to the Thomson meter, but is designed to be used only on alternating-current circuits, as is also the **Duncan** meter. Other recording meters are in use, but are usually complicated in construction and rather unreliable in operation.

In addition to the Siemens wattmeter, there have recently been introduced general forms of portable direct-reading wattmeters, which are giving good satisfaction, and are more convenient to use than the Siemens form.

## SWITCHBOARD INSTRUMENTS.

**2545.** In lighting and power stations and similar places, it is often desirable to know the approximate number of amperes, volts, or watts delivered by a machine or machines, and for this purpose instruments have come into use which, while not sufficiently accurate for making reliable measurements to a great degree of precision, are very useful in indicating approximately the output of a machine or the load on a circuit. The scales of such instruments are usually large and open, so they may be read from a distance. Many forms of such instruments are made by different manufacturers; their principle of operation is usually the electromagnetic effect of the current, but their details of construction will not be described here.

## MEASUREMENTS WITH COMMERCIAL INSTRUMENTS.

**2546.** Most of the measurements previously described as being made with some form of galvanometer can be made with good commercial instruments—the Weston, for example.

In the Weston instruments, the terminals of the ammeter are both on the same (right) side of the instrument (see Fig. 1020), and are made large and heavy, while in the voltmeters the terminals are on opposite sides, are made small, and are usually covered with rubber, in order that they may be handled without danger from shocks. Some of the voltmeters are made with the resistance coils in two sections, of such relative value that, when only one section is in circuit, the scale readings are some convenient submultiple of the readings when both sections are used. In this case the instrument is provided with an extra binding-post

on the left side, and the scale divisions have two values; for instance, the voltmeter with a range of 150 volts may have the resistance so divided that by using the third binding-post the range will be 15 volts and the scale divisions will have $\frac{1}{10}$ their former value.

Measurements of current strength or difference of potential are very simple. To measure the number of amperes flowing in a circuit, it is only necessary to connect an ammeter of proper capacity in series with the rest of the circuit, as shown in Fig. 1030, and read the amperes directly from the position of the pointer on the scale. The resistance of the ammeter, as pointed out, is so low that it will not affect the total resistance of the circuit appreciably. The difference of potential between two points in a circuit, or the E. M. F. of a battery, or other source of E. M. F., may be readily measured by connecting the terminals of a voltmeter to the proper points of the circuit and reading the voltage direct, as shown in Fig. 1031.

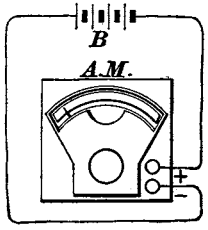

FIG. 1030.

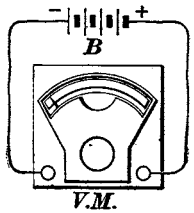

FIG. 1031.

By using instruments of the proper range, very low or very high resistances may be measured. Fig. 1032 shows a way of measuring a very low resistance—in this case a section of copper rod. Here a current from the battery $B$, measured by the ammeter $A$, flows through the section of copper rod $R$, and the drop between the points $C$ and $D$ is

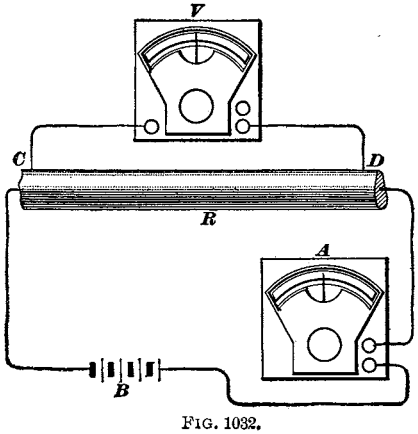

FIG. 1032.

measured by the voltmeter $V$. As the drop through a short section of copper rod would be very slight, except with an enormous current, a voltmeter capable of measuring very small differences of potential must be used. They may be had to measure from 0 to .05 volt, such an instrument being known as a *millivoltmeter*.

EXAMPLE.—If, in the above figure, the reading of the ammeter be 34.5 amperes, and that of the millivoltmeter be .00875 volt, what is the resistance of the copper rod between $C$ and $B$?

SOLUTION.— $R = \frac{E}{C} = \frac{.00875}{35.4} = .000247$ ohm. Ans.

High resistances may be measured in a similar manner by using a low-reading ammeter (mil-ammeter) and a high-reading voltmeter. The high-reading voltmeters may also be used to measure very high resistances, such as insulation resistances; the method of connecting up for such a test is shown in Fig. 1033. Here $R$ is the insulation to be measured, $B\,C$ a battery or other source of E. M. F., which should be as high as convenient, as long as it is within the range of the instrument, $V\,M$ the voltmeter, and $K$ a switch for shunting the resistance $R$. As the resistance of the switch $K$ is practically nothing, it is evident that when it is closed the voltmeter is connected directly to the terminals of the battery and will measure its E. M. F., and when the switch $K$ is open the resistance $R$ is in series with the voltmeter. The formula for finding the value of $R$ in ohms is

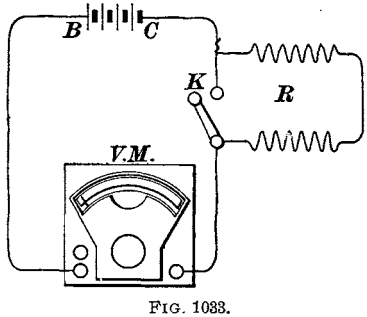

FIG. 1033.

$$R = r\left(\frac{d}{d_1} - 1\right), \qquad \textbf{(466.)}$$

where $d$ = deflection of voltmeter with the resistance $R$ *not* in circuit, $d_1$ = deflection of voltmeter with resistance $R$ in circuit, and $r$ = resistance of voltmeter.

This formula is obtained as follows: The E. M. F. of the

battery $B\,C$ being constant, the drop through the voltmeter only or the voltmeter and resistance in series will be the same, that is, $C\,r = C_1 R + C_1 r$.

As the deflection of the voltmeter needle is proportional to the current, this may be written

$$d\,r = d_1 R + d_1 r;$$

or, $$d\,r - d_1 r = d_1 R;$$

or, $$\frac{d\,r}{d_1} - \frac{d_1 r}{d_1} = R;$$

or, $$\frac{d\,r}{d_1} - r = R;$$

hence, $$r\left(\frac{d}{d_1} - 1\right) = R,$$

which is the formula given.

In the simple case where the resistance to be measured is just equal to the voltmeter resistance, it is evident that the deflection of the voltmeter with the resistance in series with it would be half that when the voltmeter alone is in circuit, which satisfies the equation as follows:

Given, $$r \times (\tfrac{2}{1} - 1) = R.$$

Then, $$r \times 1 = R,$$

and $$r = R.$$

EXAMPLE.—If the E. M. F. of the battery, as measured by the voltmeter, is 100 volts, and the deflection, when the resistance to be measured is in circuit, is 40 volts, what is the value of that resistance in ohms if the resistance of the voltmeter is 18,000 ohms?

SOLUTION.—In this case $d = 100$, $d_1 = 40$, $r = 18{,}000$. Then, by formula **466**,

$$R = 18{,}000\,(\tfrac{100}{40} - 1) = 18{,}000 \times 1.5 = 27{,}000 \text{ ohms.} \quad \text{Ans.}$$

**2547.** It will be seen that this method of testing insulation is on exactly the same principle as that shown in Fig. 1008 (Art. **2522**), the known resistance in this case being that of the instrument itself. Slight variations in the E. M. F. of the source of supply do not affect the result very materially, and when an approximately constant known E. M. F. is available, such as an electric-lighting circuit, insulation tests may be made with great facility by merely connecting the voltmeter in series with the E. M. F. and

the insulation resistance. On the assumption that the E. M. F. has a constant (known) value, a table may be prepared showing the insulation resistance corresponding to various deflections of the voltmeter.

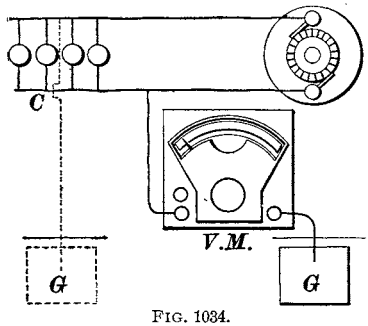

FIG. 1034.

This affords a ready means of testing the insulation resistance of lighting circuits where the E. M. F. of the dynamos is constant, if the voltmeter is of high resistance; by connecting the voltmeter between one side of the circuit and the ground, the deflection of the needle will give the insulation resistance of the *other side* of the line, or will show the presence of a "ground," as represented in Fig. 1034. Both sides may be tested in this manner, and it is usual to provide a small switch or other convenient apparatus for readily making the desired connections.

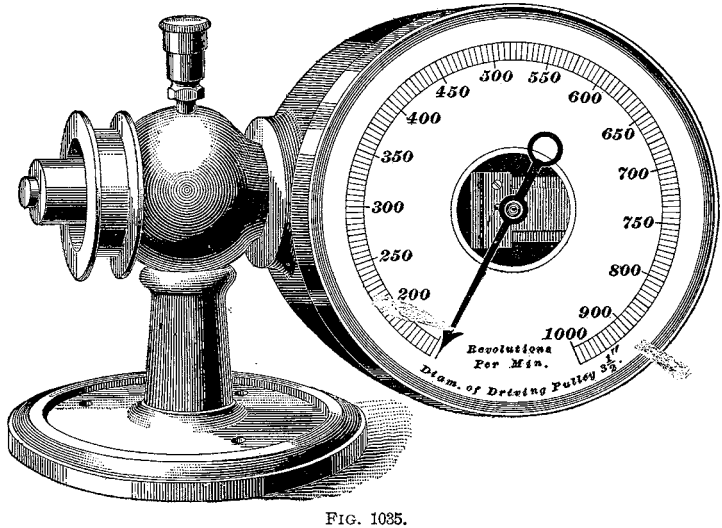

FIG. 1035.

**2548.** For many electrical measurements, it is necessary to know the *rate of revolution* of certain moving parts

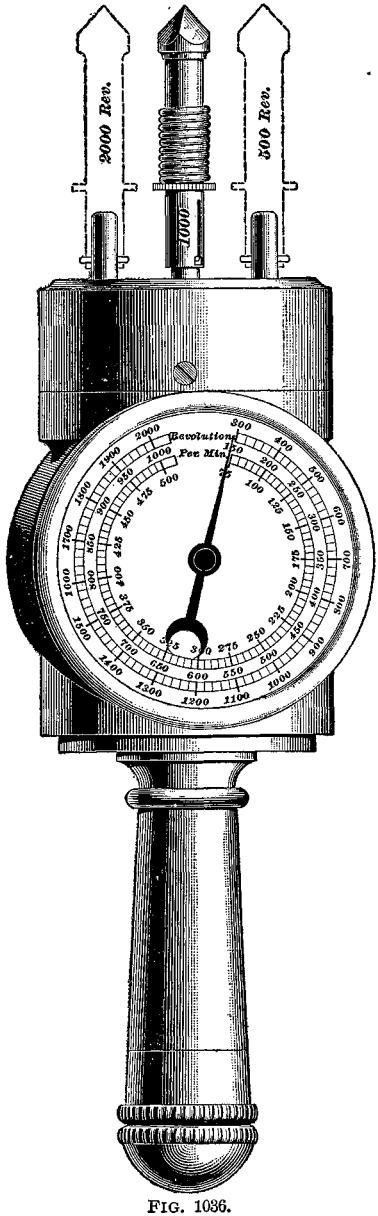


FIG. 1036.

of machinery. The number of revolutions made by the machinery in one minute or other length of time does not necessarily give its rate of revolution, so that for accurate work the ordinary *revolution counter* is scarcely suitable. Instruments called **tachometers** are made which indicate by the position of a needle on a dial the *rate of revolution* of the apparatus to which they are connected. The principle of these instruments is similar to that of a centrifugal engine governor; two weights are thrown out from their center of rotation by centrifugal force, and their tendency to move is overcome by a spring. By suitable gearing the motion of the weights is made to actuate a pointer which moves over a suitably divided dial, thus indicating the rate of rotation of the weights.

Fig. 1035 shows a form of tachometer which, being belted to a pulley of suitable diameter by a light belt, will give the rate of revolution of that pulley.

The form shown in Fig. 1036 is intended to hold in the hands. A three-sided

point on one of the spindles of the instrument is intended to be thrust into the center mark of a revolving shaft, when the rate of revolution of that shaft is indicated on the dial. It is usual to make three little ridges in the sloping sides of the center mark of the shaft with a three-sided punch (supplied with the instrument), to insure that the point on the tachometer shaft will not slip when the instrument is applied.

**2549.** Electrical measurements may be broadly stated to be *measurement of current.* The principal methods of measuring current and their general applications have been described, but for particular cases these methods often require much modification in detail, and to arrive at certain results many combinations of such methods may be made, according to the requirements of the case in hand. Some of these combinations and modifications for special cases will be described where necessary in succeeding sections.

# BATTERIES.

## DEFINITIONS.

**2550.** An **electric battery** is a combination of a number of separate electric sources. Thus, a voltaic or galvanic battery (see Arts. **2238** and **2239**) is a combination of a number of separate voltaic cells properly joined together.

The term battery is also applied to a combination of Leyden jars (see Art. **2232**) properly joined together so as to form a so-called **Leyden battery.** A battery of this kind, however, has very little practical value, in the present state of the art, compared to the value of the two great classes of batteries treated of in this discussion, namely:

I. **Primary batteries.**

II. **Secondary** or **storage batteries,** sometimes called **accumulators.**

**2551.** A **primary battery** is a combination of a number of **primary cells** so as to form a single source.

**2552.** A **secondary** or **storage battery** is a combination of a number of **secondary cells** so as to form a single electric source.

**2553.** Primary batteries, as well as secondary batteries, depend for their operation upon the chemical action which takes place between certain different substances when brought into contact with each other. The whole theory and operation of cells and batteries being thus dependent on chemical action, it is necessary to give here some principles of **chemistry,** which is that science which treats of the composition of matter, of the changes produced therein by the action of heat and other natural forces, and of the action and reaction of different kinds of matter upon each other.

## PRINCIPLES OF CHEMISTRY.

**2554.** **Chemical action** is that which produces a change in the chemical condition of matter, and may be action of **decomposition,** i. e., splitting a substance up into other distinct substances; or action of **recomposition,** i. e., uniting two or more different substances into a new one.

**2555.** Decomposition can not go on indefinitely; if a substance be split up by decomposition, and the resulting substances (if possible) be again split up, and so on, a point will be reached where substances are found which by no known process can be further decomposed. Such substances are called **elements.**

**2556.** A **chemical compound** is the union of two or more elements to form a new substance. Compounds may be formed by the union of two or more compounds; but this is merely a new union of the elements which originally formed the uniting compounds.

**2557.** There have so far been discovered about seventy-two substances which seem to be elements. About half of these are very rare; the balance, the more important, are given in Table 89. To prevent constant repetitions of their names, and to aid in expressing the composition of substances, there has been assigned to each element a *symbol*, consisting of the initial letter, or the initial letter and another letter of its Latin name, which is often different from its common name. These symbols are given in column 2, Table 89.

**2558.** The exact nature of chemical action is not known, any more than is the exact nature of electricity or heat; but it is similar to other physical phenomena in that chemical action is a manifestation of energy. This energy is apparently stored up in the atoms of the elements as *potential energy*, and causes such atoms to have an *affinity for*, or tendency to combine with, other atoms, this affinity being greater or less according to the relative amount of potential energy stored in the combining atoms. Under the proper conditions, these affinities cause the atoms to combine,

which allows their potential energy to appear as kinetic energy, usually in the form of heat. Thus, chemical combination develops kinetic energy, while to perform chemical decomposition, kinetic energy must be supplied.

**2559.** The heat given out by the formation of a compound is known as the **heat of formation** of that substance. The amount of this heat has been measured in the case of some substances, and tables giving these values are published in most works on chemistry.

NOTE.—The heat of formation is usually expressed in calories (per gram of the substance), the calorie used being the *lesser*, or *gram-degree*, calorie which is the heat required to raise 1 gram of water 1° C. It is obviously .001 of the calorie defined in Art. **1130.**

**2560.** An element is the ultimate *substance* to which any compound can be *chemically* subdivided. As has been explained in Art. **1089,** all matter (every substance) is (mechanically) composed of *molecules*, they being the smallest *particles* into which the substance can be *mechanically* subdivided without being resolved into its elements. The molecules are each made up of a number of *atoms* of the elements of which the substance is composed, and in any given substance each molecule is always composed of the *same total number of atoms* of its elements combined in the same proportions; if the proportionate number of atoms of any element is changed, a new substance is formed. When an element exists uncombined, its atoms do not exist alone, but group together into molecules, just as the atoms of the different elements group together to form the molecules of the compound.

**2561.** By very careful analysis and measurement, it has been determined that *elements always combine in certain fixed proportions or multiples of those proportions;* from this fact, it is possible to assign to each element a number, which number, or a multiple of it, will represent the proportion, by weight, of that element which enters into any compound. To this number is assigned the name **atomic weight,** and these numbers represent the *relative weights*

*of the atoms* of the elements. The *actual* weight of an atom has been calculated, but is unimportant here.

Hydrogen being the lightest of the elements, the weight of its atom is taken as the unit, and the atomic weights of all other elements calculated therefrom. The atomic weights of the more common elements will be found in column 3 of Table 89.

**TABLE 89.**

**THE PRINCIPAL ELEMENTS.**

| 1. Name of Element. | 2. Symbol. | 3. Atomic Weight. | 4. Valency. | 5. Chemical Equivalent. | 6. Electro-chemical Equivalent. Grams per Coulomb. |
|---|---|---|---|---|---|
| Aluminum..... | *Al* | 27.00 | III | 9.00 | .00009324 |
| Antimony ..... | *Sb* | 120.00 | V | 24.00 | .00024860 |
| Arsenic..... | *As* | 75.00 | V | 15.00 | .00015540 |
| Barium..... | *Ba* | 137.00 | II | 68.50 | .00070960 |
| Bismuth..... | *Bi* | 208.90 | V | 41.78 | .00043280 |
| *Boron* ..... | *B* | 11.00 | III | 3.66 | .00003792 |
| *Bromine*..... | *Br* | 79.95 | I | 79.95 | .00082100 |
| | | | VII | 11.42 | .00011840 |
| Cadmium..... | *Cd* | 112.00 | II | 56.00 | .00058020 |
| Calcium..... | *Ca* | 40.00 | II | 20.00 | .00020720 |
| *Carbon* ..... | *C* | 12.00 | IV | 3.00 | .00003098 |
| *Chlorine*..... | *Cl* | 35.45 | I | 35.45 | .00036730 |
| | | | VII | 5.07 | .00005252 |
| Chromium..... | *Cr* | 52.10 | II | 26.05 | .00026990 |
| | | | VI | 7.44 | .00007708 |
| Cobalt ..... | *Co* | 59.00 | II | 29.50 | .00030560 |
| | | | VIII | 7.38 | .00007646 |
| Copper..... | *Cu* | 63.40 | I | 63.40 | .00065680 |
| | | | II | 31.70 | .00032840 |
| *Fluorine*..... | *Fl* | 19.00 | I | 19.00 | .00019680 |
| | | | VII | 2.57 | .00002663 |
| Gold ..... | *Au* | 197.30 | I | 197.30 | .00204400 |
| | | | III | 65.77 | .00068140 |
| *Hydrogen*..... | *H* | 1.00 | I | 1.00 | .00001036 |

**TABLE 89**—*Continued.*

| 1. Name of Element. | 2. Symbol. | 3. Atomic Weight. | 4. Valency. | 5. Chemical Equivalent. | 6. Electro-chemical Equivalent. Grams per Coulomb. |
|---|---|---|---|---|---|
| *Iodine* | *I* | 125.85 | I | 125.85 | .00130300 |
| | | | VII | 17.98 | .00018630 |
| Iron | *Fe* | 56.00 | II | 28.00 | .00029010 |
| | | | IV | 14.00 | .00014500 |
| Lead | *Pb* | 206.95 | II | 103.48 | .00107200 |
| | | | IV | 51.74 | .00053600 |
| Magnesium | *Mg* | 24.30 | II | 12.15 | .00012590 |
| Manganese | *Mn* | 55.00 | II | 27.50 | .00028490 |
| | | | VII | 7.86 | .00008143 |
| Mercury | *Hg* | 200.00 | I | 200.00 | .00207200 |
| | | | II | 100.00 | .00103600 |
| Nickel | *Ni* | 58.00 | II | 29.00 | .00030040 |
| | | | VIII | 7.25 | .00007510 |
| *Nitrogen* | *N* | 14.03 | V | 2.81 | .00002911 |
| *Oxygen* | *O* | 16.00 | II | 8.00 | .00008288 |
| | | | VI | 2.67 | .00002766 |
| *Phosphorus* | *P* | 31.00 | V | 6.20 | .00006423 |
| Platinum | *Pt* | 195.00 | II | 97.50 | .00101000 |
| | | | IV | 48.75 | .00050500 |
| Potassium | *K* | 39.11 | I | 39.11 | .00040520 |
| *Selenium* | *Se* | 79.00 | II | 39.50 | .00040920 |
| | | | VI | 13.17 | .00013640 |
| *Silicon* | *Si* | 28.40 | IV | 7.10 | .00007355 |
| Silver | *Ag* | 107.90 | I | 107.90 | .00111800 |
| Sodium | *Na* | 23.05 | I | 23.05 | .00023880 |
| Strontium | *Sr* | 87.60 | II | 43.80 | .00045370 |
| *Sulphur* | *S* | 32.06 | II | 16.03 | .00016610 |
| | | | VI | 5.34 | .00005532 |
| *Tellurium* | *Te* | 125.00 | II | 62.50 | .00064750 |
| Tin | *Sn* | 119.00 | II | 59.50 | .00061640 |
| | | | IV | 29.75 | .00030820 |
| Zinc | *Zn* | 65.30 | II | 32.65 | .00033820 |

The names of the non-metallic elements are printed in *italics*.

**2562.** In indicating the elements which make up any substance, the symbols of those elements are commonly used; also, to indicate the number of atoms (if more than one) in the molecule, a small number is suffixed to the symbol. The expression of the chemical constitution of a substance by means of the symbols, with the relative number of atoms of each element suffixed, is called the **chemical formula** of that substance.

Thus, a substance (water) whose formula is $H_2O$ is composed of hydrogen and oxygen, and each molecule of water is composed of two atoms of hydrogen and one of oxygen. The atomic weights of $H$ and $O$ (from Table 89) are 1 and 16, respectively. Therefore, any weight of water is composed of $2 \times 1 = 2$ parts by weight of hydrogen and $16 \times 1 = 16$ parts by weight of oxygen. The total number of atoms in 1 molecule of water being $2 + 16 = 18$, if 1 gram of water were decomposed there would result $\frac{2}{18} = .1111+$ gram of hydrogen and $\frac{16}{18} = .8889-$ gram of oxygen. (Compare this with Art. **2493.**)

**2563.** An apparent exception to the above statements is the metal mercury, which seems to unite with most of the other metals in all proportions, forming **amalgams** of the metals. These amalgams, however, are generally considered to be merely mechanical mixtures, and not true chemical compounds. Some metals, such as zinc, gold, silver, lead, and others, form amalgams at ordinary temperatures, it being merely necessary to clean the surface of the metal thoroughly before placing it in contact with the mercury.

An amalgamated metal in a chemical formula is indicated by placing the symbol $Hg$ after and above the symbol of the metal amalgamated; thus, $Zn^{Hg}$.

**2564.** As the same elements occur in many different substances, it is evident that they must be capable of replacing each other; that is, in a molecule of a given substance the atoms of one element present can be replaced by a certain number of atoms of another, thus forming a new compound. This number is not necessarily the same as the number of

atoms of the element replaced. For example, *one* atom of carbon ($C$) can replace the *four* atoms of hydrogen ($H$) contained in *two* molecules of water ($2H_2O$), forming $CO_2$. From this it follows that *the weight of one element which will replace unit weight of another element in a compound is not always the same as the ratio of the atomic weights of the two elements.* The weight of the replacing element may be said to be the (chemical) equivalent of unit weight of the replaced element. Taking for the standard replaced element the lightest, hydrogen, and calling its unit weight 1, the least weight of any other element which will replace 1 part by weight of hydrogen in a compound, or will unite with 1 part by weight of hydrogen, is its actual **chemical equivalent,** or *combining weight.* (See column 5, Table 89.) The chemical equivalent of hydrogen is evidently the same as its atomic weight, 1. Now, in *binary* compounds (compounds consisting of only two elements) containing hydrogen, the proportion of the hydrogen in the compound is never *less* than 1 atom of $H$ to 1 atom of the other element, though often more; consequently, from the definition, the chemical equivalent is never greater than the atomic weight, and may be less.

**2565.** The ratio of the atomic weight to the chemical equivalent of an element is thus equal to or greater than 1. In fact, as it is considered that there are comparatively few atoms of each element in any molecule, this ratio is always small, and always a whole number. This ratio is also *the number of atoms of hydrogen which would be required to replace one atom of the given element*, and is called the **valency,** or **atomicity,** of the element. The valency of the more common elements is given in column 4, Table 89. It can also be shown from the above statements that the number of atoms of one element required to replace a given number of atoms of another element which are in combination with a given number of atoms of a third element is *inversely proportional to the respective valencies of the replaced and replacing elements.*

For example, each molecule of water ($H_2O$) contains two atoms of $H$ and one of $O$. If the $O$, whose valency is II, is replaced by $Cl$, whose valency is I, *each* of the two atoms of $H$ will combine with one atom of $Cl$, forming, not $H_2Cl_2$, but two molecules of $HCl$ (written $2HCl$). Thus, two atoms of $Cl$ of valency I are required to replace one atom of oxygen of valency II.

**2566.** Elements sometimes combine in other proportions than the above statements would allow; but such substances are seldom *stable*, readily uniting with additional atoms of the proper elements until the proportions are as indicated by the valencies. However, some elements seem to have two different valencies, as will be noticed in column 4, Table 89; the lower valencies give the more stable compounds. It should be remembered that the above principles of atomic weight, valency, etc., are not the expression of any chemical theory, but the result of long and careful observation and measurement; this, however, is not infallible, and apparent violations of the foregoing statements will be encountered, though they may be generally used with consistent results.

**2567.** At ordinary temperatures and pressures, five of the elements, hydrogen, oxygen, nitrogen, fluorine, and chlorine, are gases; mercury and bromine are liquids; while all the rest, including all metals excepting mercury, are solids. All the solids except carbon have been liquefied at various temperatures.

Few elements, except the more common metals and oxygen and nitrogen, are extensively used or found in an uncombined state; they usually occur in various combinations, which are divided into three classes: *acids*, *bases*, and *salts*.

**2568.** An **acid** may be defined as a compound containing hydrogen, which hydrogen may be replaced by a metal when presented to it in the form of an oxide or hydrate. The combination of oxygen with any other single element is called an **oxide.** A **hydrate** is the substance

formed by the union of an element, or, more often, a metallic oxide, with the elements of water. This should not be confounded with a **solution,** which is merely a mechanical mixture of some solid with water, or similar liquid.

Acids are usually sour to the taste, and will readily cause chemical action. Most acids contain oxygen, being formed from the union of an oxide of a non-metal and water; but in some few acids oxygen is absent. Table 90 gives a list of the more common acids, with their chemical formulas and other data.

**TABLE 90.**

**COMMON ACIDS.**

| 1. Name of Acid. | 2. Chemical Formula. | Specific Gravity. | |
|---|---|---|---|
| | | 3. Pure Acid. | 4. Commercial Acid. (Average.) |
| Hydrochloric..... | $HCl$ | 1.227 | 1.14 to 1.16 |
| Hydrobromic..... | $HBr$ | 1.515 | ..... |
| Nitric..... | $HNO_3$ | 1.530 | 1.33 to 1.41 |
| Sulphuric..... | $H_2SO_4$ | 1.846 | 1.70 to 1.83 |
| Chromic ..... | $H_2CrO_4$ | ..... | ..... |

NOTE.—*HCl* and *HBr* are in reality gases, which dissolve readily in water, forming the liquid known by the above names. The specific gravity given is that of the solution (maximum).

**2569.** A **base** is a compound, usually an oxide or hydrate, of a metal, which metal is capable of replacing the hydrogen of an acid when the two are in contact. Some particularly active bases are known as *alkalies*, which are soluble in water. The principal alkalies are sodium hydrate, $NaOH$, potassium hydrate, $KOH$, and ammonium hydrate (aqua ammonia), $NH_4OH$.

**2570.** A **salt** is the substance resulting from the replacement of the hydrogen of an acid by the metal of a base. The action of the stronger acids and bases on each other is

very violent. By some chemists the acids are considered to be *salts of hydrogen.*

Some combinations of non-metallic elements act in many ways similar to the metals, and can form oxides and hydrates and bases, and replace the hydrogen in acids, and tnese groups of elements should be included in the above definitions. Such a group is $NH_4$, which is sometimes called **ammonium.** There are several other similar groups. They act and may be handled as elements; their valency is the difference between the valency of the separate elements. Thus, in the above case, $NH_4$, the valency of $N$ is V, while that of $H_4$ is $4 \times \text{I} = \text{IV}$; hence, the valency of $NH_4 = \text{V} - \text{IV} = \text{I}$.

**2571.** In chemistry, substances are given names in accordance with their composition, although many of the more common substances have popular names. For example, the crystals of copper sulphate are popularly known as blue vitriol. Ordinary compounds of a metal and non-metal are named from both components. The Latin name of the metal is given first, and for its last syllable, *um*, is substituted *ic*; to this is added the name of the non-metal, with its last syllable changed to *ide.* Thus, a compound of iron and sulphur is named *ferric sulphide.*

In the case where an element has two valencies, distinction is made between the two compounds which may be formed from the same elements by substituting the termination *ous* for *ic* in the name of the metal, when referring to the compound having the *lower proportion* of the non-metallic element, which is usually oxygen. For example, copper forms two oxides: *cupric oxide*, $CuO$, and *cuprous oxide*, $Cu_2O$. The prefixes *per* and *proto* are sometimes used instead of the terminations *ic* and *ous*, respectively. The names of acids are derived from their principal constituent (aside from the hydrogen) by changing the last syllables of its name to *ic.* Thus, the principal acid formed from sulphur is called *sulphuric acid* ($H_2SO_4$). The acids which do not contain oxygen are distinguished by the prefix *hydro*, as *hydrobromic acid* (*HBr.*). (See Table 90.)

**2572.** The names of the salts resulting from the action between bases and acids are derived from the name of the acid by taking the first syllable of the principal constituent of the acid and adding *ate*. Thus, salts formed from bases and sulphuric acid are named *sulphates*, and from nitric acid, *nitrates*.

In the case where oxides are formed with non-metals of more than one valency, the acids formed from such oxides by their union with water take the *ic* and *ous* terminations, just as the metallic compounds do. For example, there are two oxides of sulphur, $SO_2$ and $SO_3$. The acid formed from the first is known as *sulphurous acid*, and from the second *sulphuric acid*. The salts of an acid ending in *ic* have the termination *ate*, as stated above, while the salts of the *ous* acids end in *ite*. It is evident, from the use of the terminations, that the *ate* salts and the *ic* oxides contain greater proportions of oxygen; *ite* salts and *ous* oxides are usually unstable, readily combining with oxygen to form the higher salts or oxides.

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## ELECTROCHEMISTRY.

**2573.** A current of electricity passing through a conducting liquid will decompose the liquid, the amount of the various elements set free being proportional to the quantity of electricity passing through the liquid. (Art. **2493.**)

The amount (weight) of any element which will be liberated by a given quantity of electricity is *proportional to the chemical equivalent of that element*; hence, from the amount of hydrogen (or other element whose valency is always I) set free by unit quantity of electricity, the amount of any other element that will be set free by the same quantity of electricity may be calculated. The chemical equivalent of hydrogen being 1, the amount of hydrogen liberated by one coulomb of electricity becomes a multiplier, and by multiplying the chemical equivalent of each element by this multiplier the **electrochemical equivalents,** or the weight of each element liberated per coulomb, results. (See column 6, Table 89.)

**2574.** There is reason to believe that *all chemical action generates* E. M. F.; but in order that this E. M. F. may be utilized, the chemical action must take place in and between conducting bodies.

In order that the E. M. F. may be continuously maintained—that is, that the chemical action be continuous—at least one of the bodies acted upon must be a liquid. This liquid is called the **electrolyte** (see Art. **2238**). An electrolyte does not necessarily contain water; it may even be made by melting one of the elements of the cell.

**2575.** The simplest form of a cell consists of at least two bodies, of which one at least must be a liquid, in and between which two bodies the chemical action goes on which generates the E. M. F. In order that this E. M. F. may be utilized to cause a current to flow, provision must be made for connecting an external circuit with the two bodies between which the action takes place.

Such a cell is usually composed of an electrolyte (often called the *exciting liquid*), into which are placed two conducting bodies; at least one of the bodies is metallic, and it is between this body, called the **anode,** and the electrolyte that the chemical action takes place.

Strictly speaking, the surface of contact between the liquid and the metal is the place of action, and would more properly be called the anode.

The other body, called the **cathode,** serves mainly as a means of connecting the external circuit to the electrolyte, the other end of the circuit being connected to the anode. Connection is actually made to the parts of the anode and cathode which project from the cell, these being then called the **electrodes** of the cell. This is the usual construction, although in some cells the chemical action takes place between two different liquids, in which case whatever solid conducting bodies are used act merely as connectors or terminals.

Examples of such cells will be pointed out in the description of the various types.

**2576.** The chemical action which takes place is as follows : When the two elements of the cell are placed in the electrolyte, the fact of there being a *chemical affinity* between the various substances in the cell sets up a difference of potential, which appears as between the terminals of the cell; this affinity may or may not set up a chemical action, but so long as the external circuit is open, whatever action may occur is only local, and its energy appears as heat. The reason that no chemical action occurs is that the atoms, having combined, have given up most of their potential energy, and so remain in the combinations they have assumed; as soon, however, as the external circuit is closed, the difference of potential which exists equalizes itself, and causes a momentary current to flow through the external circuit *from* the cathode *to* the anode, the cathode being at the higher potential.

This current decomposes the electrolyte, breaking up the compounds therein and restoring to the various atoms their potential energy. Some of these atoms then unite with the material of the anode, and the E. M. F. is maintained, causing the flow of current to be continuous.

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### ELECTROCHEMICAL CALCULATIONS.

**2577.** In the following we shall show the exact relation existing between the current and the chemical work; that is to say, we shall show how to calculate the amount of chemical work which a given current can perform, and, conversely, the quantity of current evolved when a definite amount of chemical work is done.

**2578.** Whenever an electrolyte is decomposed by a current, the resolved elements have a tendency to reunite. This tendency is termed **chemical affinity.** Thus, when an electric current has been sent through a solution of zinc sulphate ($ZnSO_4$), and the solution has thereby been split up into zinc, oxygen, and sulphur, then, as soon as the current ceases to flow, the zinc exhibits a tendency to recombine chemically with the disintegrated solution. This

tendency represents the strong chemical affinity of zinc for oxygen and sulphur. Also, when acidulated water has been decomposed electrically, the separated oxygen and hydrogen tend to reunite.

**2579.** This tendency to reunite is strikingly shown by an electromotive force which is set up in the solution after the decomposing current ceases. This E. M. F. can be shown to exist by connecting a galvanometer in circuit with the decomposed solution. The deflection of this instrument will show that this E. M. F. due to chemical affinity acts in the *opposite* direction to the E. M. F. of the decomposing current. In other words, it is an *opposing electromotive force.*

**2580.** Careful measurement has shown that when hydrogen and oxygen combine with each other, an electromotive force of 1.47 volts is set up. From this it follows that no water can be decomposed unless an electromotive force of at least 1.47 volts is utilized; for it requires this much alone to offset the opposing E. M. F. of recombination.

**2581.** With every electrolyte there is a similar minimum E. M. F. necessary to produce continuous decomposition. This E. M. F. can be calculated for any electrolyte if the heat of formation and the electro-chemical equivalent of its constituents are known. The heat of formation is the **thermochemical equivalent** of the substance. By the thermochemical equivalent is meant the amount of heat liberated by the chemical combination of the molecular weight of one substance with another. This energy is usually expressed in gram-calories; that is, the amount of heat necessary to raise the temperature of one gram of water 1° Centigrade. This thermochemical equivalent is a value found by careful experiment. Thus, one gram of zinc, for instance, converted into zinc sulphate ($ZnSO_4$), is known by experiment to give off about 4,000 heat-units as it combines. In Table 91 the heat of formation of various substances with oxygen is given.

**TABLE 91.**
**HEAT OF COMBINATION WITH OXYGEN.**

| 1 Gram of | Compound Formed. | Calories or Gram Degrees of Heat Produced. |
|---|---|---|
| Hydrogen | $H_2O$ | 34,000 |
| Carbon | $CO_2$ | 8,000 |
| Sulphur | $SO_2$ | 2,300 |
| Phosphorus | $P_2O_5$ | 5,747 |
| Zinc | $ZnO$ | 1,301 |
| Iron | $Fe_3O_4$ | 1,576 |
| Tin | $SnO_2$ | 1,233 |
| Copper | $CuO$ | 602 |

**2582. Electrochemical Equivalent.**—Experiment has shown that when 1 C. G. S. unit of current (Art. **2268**) passes through water, it liberates .0001036 gram of hydrogen. Now, since 1 C. G. S. unit of current equals 10 practical units or coulombs (Art. **2278**), it is evident that 1 coulomb will liberate only $\frac{1}{10}$ of this weight of hydrogen, or 1 coulomb liberates .00001036 gram of hydrogen. This quantity of hydrogen is always liberated by 1 coulomb of current, and similarly 1 coulomb of current will liberate a certain definite weight of any other electrolytic substance. The weight thus liberated by 1 coulomb, or by 1 ampere flowing for 1 second, is termed the **electrochemical equivalent** of the substance, and may be found tabulated for the most important elements in column 6 of Table 89.

**2583. Total Weight Liberated by Chemical Action.**—Experiment has furthermore shown that the total weight of any substance liberated by chemical action is directly proportional to the quantity of current flowing, so that if

$z$ = electrochemical equivalent of any substance;
$Q$ = number of coulombs;
$W$ = weight in grams of liberated substance;

then, $$W = Q \times z. \qquad \textbf{(467.)}$$

EXAMPLE.—A current of .5 ampere was passed through an acidulated solution of water for 10 minutes. What weight of hydrogen was evolved?

SOLUTION.— $t = 10$ minutes $= 600$ seconds. $C = .5$ ampere. Then, by formula **405**, $Q = Ct = .5 \times 600 = 300$ coulombs. Referring to column 6, Table 89, we find for hydrogen $z = .00001036$; hence, by formula **467**, $W = 300 \times .00001036 = .003108$ gram of hydrogen. Ans.

**2584. Heat Formation by Chemical Action.**— In Art. **2581** the formation of heat during chemical action was explained. Experiment has shown that the total heat generated during chemical action is proportional to the weight of the substance liberated; so that if

$h$ = calories evolved per gram of substance;
$W$ = weight in grams of substance liberated;
$H$ = total calories evolved;

then, $$H = W \times h;$$

but, inserting the value of $W$ as given by formula **467**, we have as the total heat evolved in calories

$$H = Q \times z \times h. \qquad \textbf{(468.)}$$

**2585. Relation of Heat and Work.**—It can be shown by a simple calculation, knowing the mechanical equivalent of heat, that 1 calorie is equivalent to 4.2 joules of work. This being the case, formula **468** may be written to express the total joules $J$ of energy required to liberate a given weight of any substance; for, if $J$ = total joules of energy, then, by utilizing the notation of Art. **2584**,

$$J = 4.2\ Q \times z \times h. \qquad \textbf{(469.)}$$

**2586.** It is possible to express this work in another manner. By referring to Art. **2332**, it will be seen that the work done in joules in any electrical circuit can be expressed by the product of volts and coulombs of that circuit; or, if

$E$ = volts;
$Q$ = coulombs;
$J$ = joules;

then, $$J = E \times Q. \qquad \textbf{(470.)}$$

**2587. Calculation of E. M. F. Produced by Chemical Action.**—Comparing formulas **469** and **470**, we see that they are different expressions for the same quantity $J$, namely, the electrical work in joules done in the circuit; or,

$$J = 4.2\ Q \times z \times h, \text{ and}$$
$$J = E \times Q.$$

But, when two quantities are each equal to a third, they are equal to each other; hence,

$$E \times Q = 4.2\ Q \times z \times h.$$

Dividing both sides of this equation by $Q$ gives us an expression for the electromotive force in volts, namely,

$$E = 4.2\ h \times z. \qquad \textbf{(471.)}$$

This important result may be expressed in words as follows: *The electromotive force in volts of any chemical reaction is equal to the product of the electrochemical equivalent of the separated substance, the heat of combination of the substance per gram degree, and the constant 4.2.*

EXAMPLE.—Calculate the opposing E. M. F. set up by the hydrogen tending to unite with the oxygen during the decomposition of water.

SOLUTION.—Refer to Table 89, column 6, where for hydrogen $z = .00001036$, and to Table 91, column 3, where for hydrogen $h = 34{,}000$; then, by formula **471**, $E = 4.2 \times 34{,}000 \times .00001036 = 1.479$ volts. Ans.

NOTE.—In the same way we may calculate the opposing E. M. F. set up and effecting any particular electrolysis.

**2588.** In the above, the E. M. F. is calculated on the assumption that all the chemical energy developed is converted into electricity, and that none of the energy appears as heat. Practically, however, some heat is generated in almost every case during the electric activity. This is only a secondary consequence of the electric resistance of the cell. If the cell offers a negligible resistance, then the amount of heat electrically developed by the current would also be negligible, and all the chemical energy developed by chemical changes in the cell would be liberated outside the cell, that is, in the external circuit.

**2589.** It should be remarked, however, that owing to the incompleteness of our knowledge of thermochemical equivalents, and of the exact nature of the electrochemical actions in the cell, the E. M. F. of a cell can only in a few instances be practically predetermined.

### ELECTROCHEMICAL THEORIES.

**2590.** If more than one set of actions can take place in a cell, the effect of the various actions on the E. M. F. of the cell may be determined by properly applying formula **471** to each action; the E. M. F. of each action may be then added or subtracted to get the resulting E. M. F., according to the nature of the action.

If the substance forming the anode has an affinity for one or more elements of the electrolyte, and the substance forming the cathode has an affinity for the other element or elements of the electrolyte, it is evident that the tendencies of these elements to combine with the anode and cathode, respectively, will assist each other, and the E. M. F. of each action will add together in giving the resulting E. M. F. of the cell.

If the substances forming the anode and cathode, respectively, have each an affinity for *the same* element or elements of the electrolyte, it is again evident that the tendency of these elements to combine with the anode will be partly balanced by their tendency to combine with the cathode; hence, the E. M. F. which would result from either action alone must be *subtracted* from the other to obtain the resulting E. M. F.

This explains the case spoken of in Art. **2243,** where it is stated that a cell with zinc and iron as elements will give a less E. M. F. than a cell using zinc and graphite (carbon). In the zinc-iron cell a part of the electrolyte has an affinity for both the zinc and the iron, while in the zinc-graphite cell the electrolyte has no affinity for the graphite, and the full E. M. F. of the action on the zinc appears. The meaning of the Electromotive Series (Art. **2241**) should now be clear.

**2591.** The action which takes place in a cell if the electrolyte be an acid is the decomposition of the acid, the liberation of the hydrogen, and the formation of a salt of the metal of the anode by its union with the balance of the acid. If the electrolyte be a solution of some salt, the action is more complicated, and is about as follows: The water of the solution is decomposed, its oxygen uniting with the anode, forming an oxide, and the hydrogen is liberated, as before. The oxide which is formed then unites with the salt in solution, forming salts of the metal oxidized; these formations increase the E. M. F. which the cell would have were water alone the exciting liquid and the oxidation of the anode the only action.

**2592.** Thus it is seen that in almost all the chemical actions which occur in batteries, the attacking of the anode results from the decomposition of the electrolyte, hydrogen being liberated. This decomposition of the electrolyte takes place throughout the space between the anode and cathode; the hydrogen, however, does not appear throughout the electrolyte, but only at the surface of the cathode; for as soon as the electrolyte is decomposed into its elements, the union of the metal of the anode with the elements of the electrolyte with which it can combine can only take place with the atoms of the particular molecules which were at the surface of the anode; the free hydrogen atoms of these molecules then unite with the free elements of what was the next layer of molecules, reforming the original electrolyte; the displaced hydrogen atoms of these newly formed molecules unite with the free elements of the next layer of molecules, and so on all across the liquid, until at the point where the current leaves the liquid (the cathode) there are left the free hydrogen atoms of the last layer of molecules. These then appear at the surface of the cathode, providing the cathode is not a substance with which these free atoms may unite.

**2593.** The accompanying diagrams represent this action in the case of the zinc ($Zn$), sulphuric acid ($H_2SO_4$),

and copper (*Cu*) cell, given in Art. **2240.** One single line of the molecules of the electrolyte between the zinc and the copper plate is represented at *a*, Fig. 1037. Each molecule of the acid is made up of one atom of *S* and four of *O*, united with a molecule consisting of two atoms of *H*.

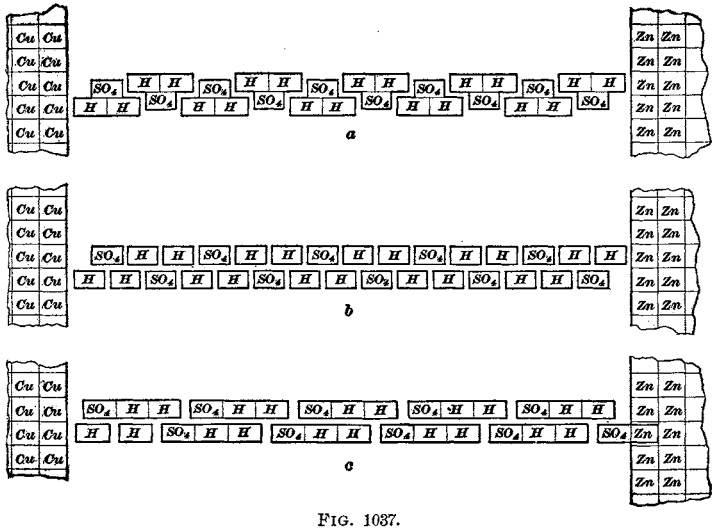


FIG. 1037.

No current is supposed to be flowing through the liquid. For convenience, it is assumed that the molecule of $SO_4$ is not decomposed by the current; actually, it probably is, but since in its action with the zinc it unites with it as a whole, the assumption is allowable.

In *b*, Fig. 1037, the molecules are represented as decomposed by a current, and each individual molecule of $SO_4$ and atom of *H* is separate. Now, the molecule of $SO_4$ at the right has a greater affinity for, or tendency to combine with, the zinc than it has to combine with the free atoms of *H*, and does so, as represented at *c*, Fig. 1037, and the remaining molecules of $SO_4$, not being in contact with the zinc, unite with the free atoms of *H* all the way across the liquid, until at the copper plate there are no free molecules of $SO_4$ left to combine with the last atoms of *H* in the line; consequently, the free atoms of *H* appear in the form of

gas at the copper plate. Of course the newly formed molecules of $H_2SO_4$ are immediately decomposed and reunited, which process continues with inconceivable rapidity, the result being a practically continuous formation of $ZnSO_4$ at the anode and the liberation of $H$ at the cathode as long as any current flows through the electrolyte. Now, it is evident that all the energy required to decompose *all but one molecule* in any line of molecules across the electrolyte is immediately given up by the reunion of the free atoms.
91 For this reason *the distance between the anode and the cathode, or their size, does not affect the amount of electrolyte decomposed by a given force, nor the energy required to perform the decomposition.*

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## POLARIZATION AND DEPOLARIZATION.

**2594.** If at or near the cathode there is some substance, such that the free hydrogen left by the decomposition of the electrolyte may unite with it, the energy liberated by such formation will add to the E. M. F. of the cell. If this free hydrogen can not unite with some substance at the cathode, it collects on the surface in bubbles as a gas. In addition to the reduction of the E. M. F. of the cell due to decomposition of the electrolyte, the formation of hydrogen also acts disadvantageously, as it forms in a layer on the surface of the cathode, which enormously increases the internal resistance of the cell, thus diminishing the current which the E. M. F. of the cell can send through any given external resistance. The formation of hydrogen on the surface of the cathode is known as **polarization,** and its removal, by any means, mechanical or chemical, is called **depolarization,** the agent used being called the **depolarizer.**

**2595.** If merely mechanical means of depolarization be used, the result is to prevent the increase of internal resistance of the cell; by causing the liberated hydrogen to *recombine* at the cathode, by chemical means, not only is the internal resistance not increased, but the actual E. M. F. of the cell is increased.

**2596.** Various mechanical devices for depolarizing cells have been used; the cathode has been arranged to be agitated in the liquid, or to be entirely removed from the liquid at intervals; or the cathode, and in some instances both electrodes, have been made in the form of disks, dipped for about half their diameter into the electrolyte. On rotating the disks, the hydrogen is prevented from forming on the cathode by its motion.

The power for performing these various movements has usually been derived from clockwork, and in some instances from the current given out by the battery. It is evident that such devices are commercially of little value, especially as chemical depolarizers may be easily used.

**2597.** The depolarization by chemical means may be accomplished by surrounding the negative element (cathode) with a solid or liquid substance, with which the free hydrogen may combine. This combination usually merely disposes of this element, and prevents the bad effects of a deposit on the cathode. Under these circumstances the compound formed at the cathode is usually water, the depolarizer being a substance rich in oxygen, with which the hydrogen combines. This water has the effect of diluting the electrolyte, already weakened by the combination with the anode; but, by properly selecting the depolarizer with reference to the electrolyte, the chemical combination at the cathode may be such that it will, either directly or by further combination, replace the part of the electrolyte which has combined with the anode, thus keeping the electrolyte of the same composition and strength throughout the life of the anode or of the depolarizer. Instances of both these classes of chemical depolarization will be noted in the description of the various cells.

**2598.** The *rate* at which any depolarizer will depolarize depends on many conditions; and no depolarizer will keep the E. M. F. of a cell constant for all currents, for, after a certain limiting current has been reached, the limit depending on the sizes of the various parts of the cell, the formation

of the free element of the electrolyte is more rapid than its absorption by, or recombination with, the depolarizer, and the surplus will collect on the cathode.

In the case of depolarizers which, by the formation of water, dilute the electrolyte, the E. M. F. will become less with continued use of the cell, even if the current output be small. These facts should be remembered in dealing with the various depolarizers.

**2599.** From the preceding remarks, it appears that in order to give a high E. M. F., the metal chosen for the anode must be one whose salts have a comparatively high value for their heat of formation. Such metals are potassium, sodium, strontium, calcium, and magnesium; potassium salts having the highest heat of formation, the others, in the order given, having lower.

**2600.** Having a high heat of formation means, however, that the metal has a great affinity for the elements necessary to form its salts or oxides; this being the case, they are liable to combine with such elements whenever the opportunity presents itself, taking them from the air, from water, or from salts of other metals which have a lesser affinity for the salt-forming elements. Consequently, the metals in the list given could not be used in the presence of acids or solution of salts, or even of water, without decomposing the liquid and rapidly forming salts or oxides, the whole of the energy of the action appearing as heat. In order, then, to have a practicable cell, the metal should not be attacked by the exciting liquid except as the exciting liquid is decomposed by the passage of the current. This is the reason for the extensive adoption of zinc, that being a metal whose heat of formation is comparatively high, at the same time not high enough to cause its salts and oxides to be formed with any degree of rapidity unless the necessary elements are presented to it in a free state, as they are in a voltaic cell by the decomposition of the electrolyte.

Besides, zinc is actually the cheapest of the metals, excepting iron, and, in proportion to the amount of kinetic

chemical energy possessed, is cheaper than any other metal which could be used.

**2601.** Batteries, as sources of electrical energy, are used mainly in cases where a current is required very intermittently, such as in ringing bells, lighting gas, etc., or where a small but steady current is required for long periods of time, as in telegraphy and telephony, or for laboratory and testing purposes. Their general use on a large scale, as sources of electrical energy for lighting or power purposes, is prohibited, at least at present, by the comparatively great cost of the material consumed, and the expense of installation and maintenance.

For example, the bichromate battery is about the cheapest in point of cost of materials consumed, and in this the materials alone would cost about 28 cents per horsepower per hour on a large scale, while the cost of electrical energy, using dynamos, is about 5 or 6 cents per horsepower per hour, ordinarily, and in many cases is much less. The cost of material in the silver chloride battery is about $135 per horsepower per hour.

This high cost of the power does not, however, prevent batteries from being largely used for the purposes outlined above, and their practical application is an important part of electrical engineering.

## CELLS.

### CLASSIFICATION.

**2602.** The various classes of voltaic cells may be divided as follows:

**Cells in Which There Is No Depolarizer.**—This is the simplest form of cell, and, on account of polarization, cells of this class, commonly called *open-circuit cells*, are not used for other than intermittent work.

**2603. Cells With a Depolarizing Electrolyte.**—In this class of cells the electrolyte is of such a nature that either no hydrogen is formed or the liquid contains a sub-

stance with which the hydrogen unites. As this action takes place mainly at the cathode, there is little distinction, as far as action goes, between this latter type and cells with a liquid depolarizer.

**2604. Cells With a Liquid Depolarizer.**—In this class of cells, however, the cathode is surrounded by a depolarizing liquid, which is prevented, by mechanical means, from mixing with the electrolyte.

The means usually employed are either to separate the two liquids by a porous partition, which allows of their electrical contact without mechanical mixture of the two, if their respective specific gravities be nearly the same; or, if these differ considerably, gravity will keep the two liquids apart, one over the other in the containing vessel.

**2605. Cells With a Solid Depolarizer.**—This class is identical in action with the class preceding, the depolarizer, however, being a solid instead of a liquid.

If the solid depolarizer is granular, or in the form of powder, it is often necessary to employ a porous partition between the cathode surrounded by the depolarizer and the electrolyte. This is merely to keep the depolarizer in place, and is dispensed with if the depolarizer is formed into a paste or solid body upon the cathode. In fact, the depolarizer may itself form the cathode, if it be a solid conducting material, the office of the cathode being primarily to establish a connection between the electrolyte and the external circuit.

**2606. Cells in Which an Elementary Substance Is Applied to the Cathode, Acting as a Depolarizer.**—This substance may be applied mechanically or chemically. In the former case, the body, in the form of a gas or liquid, is made to appear at the cathode by pumping or forcing it to that place from some external source of supply. In the chemical method, the cathode is surrounded by solid or liquid substances, which by their action on each other evolve some elementary body which combines with the free element of the decomposed electrolyte.

This is distinct from the action of cells with a liquid or a solid depolarizer, as the production of the elementary depolarizing body substance is independent of the electrical action of the cell, *going on all the time, whether the cell is in use or not*, variations in the current output of the cell having no influence on its production.

Voltaic cells are ordinarily classed as "single-fluid" and "two-fluid" cells; but as such a classification has little reference to this principle of operation, it will not be used in this discussion. The number of different kinds of cells that have been made is very large indeed, but they can all be subdivided into one of these general classes. Only a few typical cells of each class will be described.

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## CELLS WITH A NON-DEPOLARIZING ELECTROLYTE.

**2607.** This class of cells includes the cells of the **Volta** type, which consists generally of an electrolyte of acid or saline solution, into which are placed two or more plates of metal, one of which (usually of zinc) is acted on by the electrolyte.

**2608.** A simple form of this cell is illustrated in Art. **2238.** Its materials are zinc, dilute sulphuric acid, and copper, which give an E. M. F. of about .9 volt.

Many modifications of the form of this type of cell have been suggested and used, such as making the elements in strips and rolling them around each other in a helical form, with insulating material between, etc.; but all are open to the objection of rapid polarization.

**2609.** In place of copper as a cathode many other elements have been used, notably the **Smee** cell, using platinum or platinized silver, and cells of various makes in which the cathode is of iron.

In cells of this and other types, impurities in the zinc set up local actions, which diminish the E. M. F. of the cell and cause a wasting of the zinc. These local actions are almost

wholly prevented by amalgamating the zinc, which is usually done.

If a good quality of drawn or rolled zinc is used, this precaution is hardly necessary.

**2610.** Not long after the first use of the zinc, sulphuric acid, and copper battery, it was found that the copper or other metallic cathode could be advantageously replaced with porous carbon, and many cells were so constructed. The E. M. F. of such a cell is about 1.35 volts ordinarily. To prevent the electrolyte from becoming exhausted too quickly, there is sometimes placed in the cell a porous earthenware pot or cup, filled with strong sulphuric acid. As the dilute acid outside the porous cup becomes weaker, the stronger acid oozes through the sides of the porous cup and keeps up its strength. In some instances the carbon cathode has itself formed the porous cup. An objection to the use of porous cups in this type of cell is that its pores are liable to become clogged by deposits of zinc sulphate from the solution.

**2611.** Other acid electrolytes have been used in this type of cell. With either nitric or hydrochloric acids (diluted) the E. M. F. is not sensibly different from that with sulphuric acid as the electrolyte.

**2612.** Of the saline electrolytes, the best exciting liquid is considered to be a solution of ammonium chloride (sal ammoniac). The E. M. F. of a zinc, ammonium chloride, and carbon cell is about 1.15 volts.

**2613.** There are a great number of cells of this type in use for ringing bells, gas lighting, and doing other intermittent work. They are all alike in principle, but their mechanical construction differs somewhat. In the **Law** open-circuit cell, the carbon electrode is in the form of a hollow cylinder, enclosing a smaller hollow cylinder, each with a wide slit in one side. These cylinders hang vertically in the electrolyte, and the zinc hangs in the space formed by the slits in the side, being suspended from the cover of the

cell. This is an excellent form of cell, being well worked out in its mechanical details.

**2614.** In the **Little Giant** cell, the hollow carbon cylinder is continuous, except for a hole in the side for the circulation of the electrolyte, and the zinc, in the form of a rod, is suspended in the center of the carbon cylinder. The top of the cylinder is extended to form the cover of the cell, and the zinc is insulated from it by a porcelain bushing.

**2615.** The **Hercules** cell employs a corrugated solid carbon cylinder, the zinc element being made of sheet zinc bent into a cylinder surrounding the carbon.

**2616.** Many other forms of carbon or zinc elements may be and are used. The particular shape of the carbon has comparatively little to do with the satisfactory working of the cell, care and good design in the construction being more important. The element should be of such shape as not to be easily broken in transit, and, being usually molded into shape under pressure, should be of such proportions that it is cheap to make.

**2617.** In all the cells of this type the carbon is made as porous as possible, and of such shape that the surface exposed to the liquid is very large compared with the surface of the zinc. Thus, the average area of the internal circuit of the cell is made large, and at the same time advantage is taken of the slight depolarization, occurring with a porous carbon of large surface, due to the oxygen which porous carbon absorbs from the air, with which some of the evolved hydrogen combines. The E. M. F. of this type of cell is, therefore, slightly higher than those which employ a non-oxidizable metallic cathode, such as platinum. This depolarizing action takes place slowly, and, therefore, hydrogen will form on the cathode if a considerable current be taken from the cell, thus increasing the internal resistance. In intermittent work this is not objectionable, as the hydrogen is soon absorbed when the external circuit is opened.

**2618.** Another salt which has been much used in solution as an electrolyte is sodium chloride (common salt). The heat of formation of sodium chloride being greater than that of ammonium chloride, the energy required to decompose the electrolyte is greater; therefore, the E. M. F. of cells using this electrolyte is slightly lower, that of a zinc, sodium chloride, and carbon cell being about 1.08 volts.

However, this electrolyte being very cheap and of common occurrence, many makers of batteries have employed it. It has also been proposed to use sea-water as an electrolyte, by placing in the ocean immense plates of zinc and copper or carbon. This has never been commercially accomplished, for the consumption of zinc makes the cost of the electrical energy too great for this method to compete with others now in use.

**2619.** Electrical buoys have been constructed, in which plates of carbon or copper and zinc enter or leave the water as the buoy is rocked by the waves, thus causing a light to flash or a bell to ring intermittently.

**2620.** Various other salts in solution have been used as electrolytes, such as ammonium nitrate, alum, potassium sulphate, zinc sulphate, zinc chloride, potassium hydrate (caustic potash), etc.

The E. M. F. of cells using solutions of these various salts as electrolytes may be found from the values given in Table 92.

**2621.** The effect of substituting various metals for the zinc in this type of cell may be found from Table 93, which gives the E. M. F. of the action of dilute sulphuric acid on various metals. The values given in this table may be taken for the E. M. F. of cells using a platinum or carbon cathode; if other metals which appear in the table be used as the cathode, the E. M. F. of the action of the acid upon them must be subtracted to get the E. M. F. of the cell. (See Art. **2590.**) With other electrolytes, the substitution of other metals for zinc reduces the E. M. F. in about the same proportion as in the table.

**TABLE 92.**

**E. M. F. OF THE FORMATION OF VARIOUS SULPHATES.**

| Metal. | Formula of Sulphate. | E. M. F. Volts. |
|---|---|---|
| Potassium | $K_2SO_4$ | 2.35 |
| Zinc | $ZnSO_4$ | 1.35 |
| Cadmium | $CdSO_4$ | 1.05 |
| Lead | $PbSO_4$ | .90 |
| Tin | $SnSO_4$ | .88 |
| Iron | $FeSO_4$ | .83 |
| Aluminum | $Al_2(SO_4)_3$ | .70 |
| Copper | $CuSO_4$ | .47 |
| Silver | $Ag_2SO_4$ | .30 |
| Platinum | None | .00 |

**TABLE 93.**

**E. M. F. OF ZINC (PURE) WITH VARIOUS ELECTROLYTES.**

| Electrolyte. Acids. | E. M. F. Volts. | Electrolyte. Saline Solutions. | E. M. F. Volts. |
|---|---|---|---|
| $H_2SO_4$ | 1.35 | $NaCl$ | 1.08 |
| $HCl$ | 1.40 | $ZnSO_4$ | 1.32 |
| $HNO_3$ | 1.43 | $NH_4Cl$ | 1.15 |
| | | $NaOH$ | 1.35 |
| | | $KOH$ | 1.38 |
| | | Ordinary $H_2O$ | 0.90 |

## CELLS WITH A DEPOLARIZING ELECTROLYTE.

**2622.** The best known cells of this type are the so-called **bichromate** cells. These consist, broadly, of a zinc-carbon couple, with an electrolyte composed of a solution of some acid or other exciting liquid, mixed with a proportion of the *bichromate salts* of some metal. The bichromate salts are a peculiar series of salts formed by the oxide of

chromium having the formula $Cr_2O_7$, which is an unstable oxide, appearing only in combination with some other metal, such as potassium or sodium, forming the *bichromate salts* of those metals. The mixture usually employed as an electrolyte is sulphuric acid and potassium bichromate, $K_2Cr_2O_7$, although sodium bichromate, $Na_2Cr_2O_7$, is somewhat superior for the purpose, which is to act as a depolarizer. This office the bichromate salts perform perfectly, as they have a large proportion of oxygen, as is seen from their formulas; consequently, the hydrogen liberated by decomposition of the electrolyte is consumed as fast as generated, forming water and a salt known as *chrome alum*, which forms in crystals of a purplish color. This results in a high E. M. F. (usually about 2 volts).

**2623.** The chemical actions in this class of cells are complicated; one result is the formation of chromic acid by the action of the acid in the electrolyte on the $K_2Cr_2O_7$, which will slowly attack the zinc whenever in contact with it, whether there be any current flowing or not. This leads to the device—which is almost universally adopted—of lifting the anode, or both elements, from the liquid when the cell is not in use. Cells which are in continuous use are liable to have their internal resistance increased by a deposit of the crystals of chrome alum on the cathode, these crystals being poor conductors. In certain forms of cells the construction is such that this is not liable to occur.

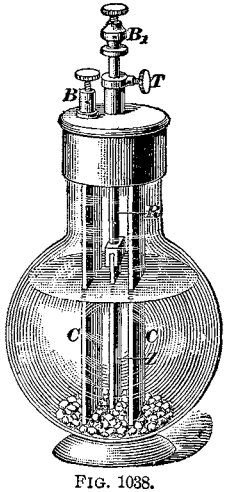

FIG. 1038.

**2624.** A familiar type of bichromate cell is the **Grenet** cell, shown in Fig. 1038, which consists of a bottle-shaped glass jar with a hard rubber or porcelain cover. From this cover two flat carbon plates $C$, $C$ are suspended, parallel to and a short distance from each other, as shown; between them hangs a zinc plate $Z$ supported by a sliding rod $R$, which

may be drawn up until the zinc is entirely out of the liquid; it is held in any position by the thumb-screw $T$. On the top of the brass rod is a binding-post $B_1$, the other terminal of the cell being the binding-post $B$, which is connected to the two carbon plates.

The electrolyte is composed of 3 parts of potassium bichromate, dissolved in 18 parts of water, to which is added 4 parts of sulphuric acid.

The E. M. F. of such a cell is 1.92 to 2 volts.

At ordinary temperatures, variations in the proportion of bichromate in the solution, within moderate limits, do not vary the E. M. F. or the internal resistance very much. Variations in temperature vary the internal resistance, but not the E. M. F., the internal resistance decreasing as the temperature increases. With the above proportion of sulphuric acid and bichromate in the solution, the sulphuric acid is first exhausted. Theoretically, for an equal life of both substances in the electrolyte, the correct proportions should be

$$\left.\begin{matrix} H_2SO_4 = 3.0 \\ K_2Cr_2O_7 = 7.0 \end{matrix}\right\} \text{ parts by weight,}$$

which proportion is often used. In fact, however, it is more necessary to keep up the strength of the depolarizer, that is, the bichromate, so the first given proportion will really give better results.

**2625.** A great variety of batteries of this type has been made, especially abroad, where they are called **Poggendorf's** cell; they do not differ in principle or material from the Grenet cell, but in mechanical details are more suited to general work. They are usually built with several cells, the various elements being connected in series to give an E. M. F. of 6 to 10 or more volts. All the elements are simultaneously raised out of or lowered into the liquid by a lever or windlass arrangement, as shown in Fig. 1039, which represents a battery of five cells all alike. The elements are of zinc and carbon, there being three plates of zinc, $Z$, and four of carbon, $C$, in each cell. The plates are

all suspended from a wooden cross-bar, so that they may be simultaneously raised or lowered by winding or unwinding

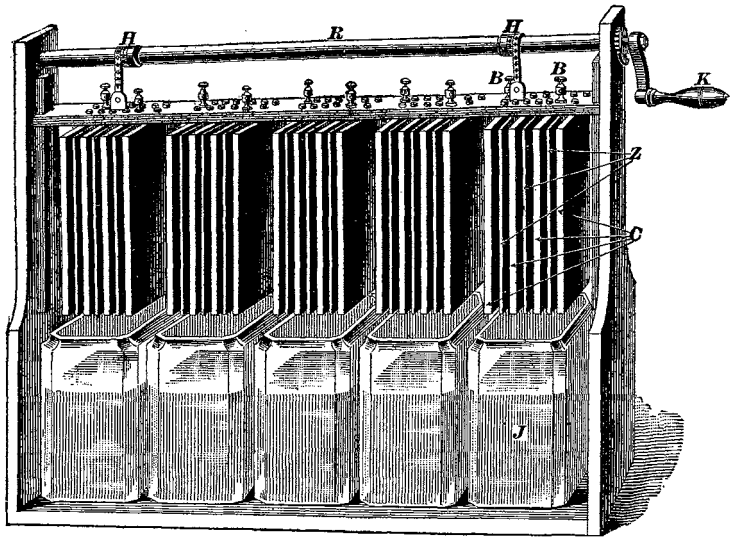


FIG. 1039.

the chains *H*, *H* upon the rod *R*, which is turned by means of the crank *K*.

The elements may thus be raised from the liquid contained in the jars *J* when the cells are not in use. The elements of each cell are provided with two binding-posts *B*, *B*, one of which is connected to the carbon and the other to the zinc plates. The various cells may then be used separately, or connected together in parallel or in series, as desired.

**2626.** An ingenious arrangement of bichromate cells for cautery work is that due to Chardin. In his battery the elements are normally held out of the liquid by a spring; by pressing a foot lever they may be gradually lowered into the liquid.

When just the ends of the elements are in the liquid, the internal resistance of the battery is considerable; but as the elements are lowered, this resistance decreases largely.

By varying the distance which the pressure on the foot lever causes the elements to dip into the liquid, a sensitive and easily managed method of control of the output of the battery is secured.

**2627.** Another type of bichromate cell consists of a closed vessel divided into two parts by a horizontal perforated partition. In one part the zinc and carbon elements are located. Enough liquid to fill one of the parts of the vessel is introduced; when the vessel is standing on one end, all the liquid is below the partition and the elements above, and in order to render the cell active, it is only necessary to turn the vessel completely over, when the liquid flows through the perforated partition and comes in contact with the zinc and carbon.

**2628.** Among the cells which may be said to belong to this class is a type of cell in which no free hydrogen or other gas is evolved in the decomposition of the electrolyte. Such electrolytes, which might more properly be called *non-polarizing*, are the solutions of some of the salts of metals having more than one valency. The salt containing the greater amount of the non-metallic element (the *ic* salt) is used as the electrolyte; on being decomposed, a salt of the metal of the anode is formed with a part of its non-metallic element, and the remainder is recombined to form the salt having the lesser proportion of the non-metallic element (the *ous* salt).

**2629.** An example of this type of cell is the **Pabst** cell, in which wrought iron and carbon are used as elements, and a solution of ferric chloride as the electrolyte. The ferric chloride is decomposed into ferrous chloride and free chlorine; the latter unites with the iron anode, resulting in an E. M. F. of .78 volt.

**2630.** Similar cells are also made, using a solution of ferrous sulphate as an electrolyte, the action being similar. There are other salts, with solutions of which zinc will combine without hydrogen being released, such as sulphite

of potassium or of sodium, and non-polarizing cells are constructed, employing solutions of these salts as electrolytes.

**2631.** Most single fluid cells in which the electrolyte is depolarizing are open to the objection that the zinc is attacked by the electrolyte at all times, whether the external circuit be closed or not; besides this, with the exception of the bichromate cells, the materials of the electrolyte are usually expensive, and not readily obtainable, and the commercial use of such cells is limited.

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## CELLS WITH A LIQUID DEPOLARIZER.

**2632. Nitric acid,** being rich in oxygen, is largely used as a depolarizing liquid in this class of cells.

Its use is objectionable from the fact that when deprived of a part of its oxygen, it gives off a gas, nitric oxide, which, on combining with the oxygen of air, becomes nitrogen peroxide, $NO_2$, a disagreeable and even dangerous corrosive gas; consequently, the best of ventilation is essential where cells with this depolarizer are used.

**2633.** The principal cells using this depolarizer are the **Grove** and **Bunsen** cells, and some of their derivatives. In the Grove cell the positive element is zinc; the negative, platinum. The platinum element is placed inside a porous cup and surrounded with nitric acid; outside the porous cup is the exciting liquid, sulphuric acid diluted with water. The E. M. F. of the Grove cell is 1.9 volts at ordinary temperatures.

**2634.** The Grove cell is a very old type, and has been made in many forms, but the expense of using the platinum element has led to the adoption of the Bunsen cell, which substitutes a carbon element for the platinum. With commercial nitric acid, specific gravity about 1.33, the E. M. F. of the Bunsen cell is 1.89 volts ordinarily; if pure (fuming) nitric acid, specific gravity 1.53, be used, the E. M. F. is

increased to about 1.96 volts. About .35 volt is due to the action of the depolarizer.

**2635.** Variations in the density of the nitric acid thus affect the E. M. F. of the cell only slightly, until the specific gravity of the solution falls to about 1.23; but at a density below this the acid has little or no effect as a depolarizer, although the liquid still contains about 30% of nitric acid.

As the commercial acid is most frequently used in the cell, only a small proportion of water is required to dilute it to a point where it can not be used. In fact, where commercial acid is used, only about 13% of the actual amount of the pure acid in the solution can be utilized, if nitric acid alone be the depolarizer.

The water formed at the cathode by the process of depolarization, therefore, is disadvantageous on account of its dilution of the depolarizer.

Several investigators have mixed sulphuric acid with the nitric, in various proportions, with good results. Sulphuric acid has a strong affinity for water, and will combine with it in considerable quantity; consequently, the water formed at the cathode is absorbed by the sulphuric acid, leaving the nitric acid at its full strength.

**2636.** Variations in the density of the exciting liquid also affect the E. M. F. of the cells to some extent, but not so much so as variation in the density of the depolarizer. The density ordinarily used is about 1.09 sp. gr. (13% by weight of acid). At this point the E. M. F. of the action of the exciting liquid on the zinc is about 1.53 volts.

As the action of pure water alone on zinc will give an E. M. F. of about .9 volt, variations of the density of the exciting liquid from 13% (by weight) of acid down to pure water will reduce the E. M. F. about .6 volt. Increasing the density of the liquid to about 1.23 gives a maximum E. M. F. (of the action of the acid on the zinc only) of about 1.6 volts; any further increase in the density does not increase the E. M. F. appreciably. To obtain the E. M. F. of the cell, to the above figures should be added the E. M. F.

due to the action of the depolarizer, about .35 volt, as stated above.

It is somewhat difficult to maintain sulphuric acid which has free access to the air at a density much above about 1.10, on account of the absorption of water from the air by the acid, and acid of about this density is ordinarily used.

**2637.** The proportions of the two acids in the cells are about 3 of exciting liquid to 1 of depolarizer, the depolarizer being of a specific gravity of about 1.33; with these proportions the cell will maintain its E. M. F. (within about 10%) for several days on a closed circuit.

The average internal resistance (as ordinarily constructed) is about 2 ohms.

**2638.** Many modifications of the Grove and Bunsen cells have been made, some consisting merely in changes in the mechanical arrangement of the parts, others substituting various depolarizers, exciting liquids, or elements.

For example, a carbon cup fitted with a tight cover has been used as cathode. On this being filled with nitric acid, the gas given off by the acid produces a pressure inside the cup, which forces the acid out through the pores of the carbon to the surface, where its depolarizing action takes place. This suppresses a part of the disagreeable fumes of the acid. To accomplish this same result, it has been proposed to cover the cell with an inverted vessel containing scrap tin, which will absorb the fumes. A layer of turpentine floating on the acid will prevent a large part of the fumes from being given off, as they combine with the turpentine.

**2639.** When iron or steel is placed in strong nitric acid it is not attacked, although this acid is a powerful oxidizing agent; but when the acid is diluted to about 1.20 sp. gr., or lower, the iron is strongly attacked.

Consequently, with a strong solution of nitric acid as a depolarizer, iron (usually cast iron) may replace the carbon element of the Bunsen cell, with good results, the E. M. F. being about 1.7 volts. Care must be taken, however, that the density of the depolarizer does not fall too low, or the

negative element will be consumed. In fact, a cell of this class may be constructed with only iron and nitric acid as elements, in the following order: Iron (anode), dilute nitric acid, porous cup, strong nitric acid, and iron (cathode).

**2640.** A cell similar to the foregoing, except that the negative element is carbon instead of iron, known as the **Maêche** cell, gives an E. M. F. of 1.5 volts, and has the advantage of giving off a much less quantity of nitrous vapor than the Bunsen. By substituting ordinary water for the dilute acid in the Maêche cell, the E. M. F. is reduced to about 1.2 volts; but owing to the difference in specific gravity of the two liquids (nitric acid and water), they soon mix somewhat through the walls of the porous cup.

**2641.** The E. M. F. of this type of cell is really generated in two parts: one at the surface of the anode, due to the action of the electrolyte on the anode, and the other at or near the cathode, due to the action of the depolarizing liquid on the hydrogen evolved. (See Art. **2590.**) Varying the material of the anode or the electrolyte will then affect that part of the E. M. F. just as in a cell of the class given in Art. **2602,** and the amount by which the E. M. F. is reduced or increased may be found from the values given in Tables 92 and 93, making due allowance for the E. M. F. due to the depolarizing action. The effect on the E. M. F. of varying the depolarizer may likewise be calculated from the values given in Table 94.

**TABLE 94.**

**DEPOLARIZING EFFECT OF VARIOUS SUBSTANCES.**

| Substance. Solids. | E. M. F. Volts. | Substance. Liquid. | E. M. F. Volts. |
|---|---|---|---|
| $MnO_2$(ordinary)..... | .33 | $HNO_3$ (concentrated)..... | .35 |
| $Pb_2O_3$..... | .81 | $H_2CrO_4$ ..... | .47 |
| | | $Cl$ gas dissolved in water..... | .64 |

**2642.** The foregoing values for the E. M. F. in Tables 92, 93, and 94 are about the average of the somewhat varying results of different experimenters.

The values also vary somewhat with different temperatures and degrees of concentration of the liquids; they will be seen to be approximately correct if compared with existing cells.

It will be seen from this table that either chromic acid or chlorine water (chlorine gas dissolved in water) used as a depolarizer would give a higher E. M. F. than nitric acid; but as these liquids decompose in the presence of air, they can not be commercially used, just as in the case of sodium or potassium as anodes. (See Art. **2599.**)

**2643.** Another important type of cell of this class is the **bichromate** cell, which differs from that described in Art. **2603,** in that the bichromate solution is not mixed with the electrolyte, but is separated from it by a porous partition, with the effect that the zinc is not seriously attacked on open circuit. As to the E. M. F., chemical action, etc., this type is not sensibly different from the bichromate cells described in Art. **2603.**

The bichromate solution is usually, with the cathode, placed in the outer vessel, the zinc and exciting liquid being inside the porous cup; the exciting liquid being usually sulphuric acid diluted with water to about 1.10 sp. gr., although solutions of sodium chloride or ammonium chloride are used.

**2644.** The depolarizing liquid is usually of the composition given in Art. **2624,** under the name **electropoion fluid.** A bichromate mixture is prepared by dealers in battery material, as follows (all parts by weight): Sulphuric acid, 2 parts, is mixed with water, 4 parts; in another vessel, 1 part of potassium bichromate is dissolved in 3 parts of boiling water, and while hot is mixed with the liquid first prepared. This liquid, when cold and more or less diluted, is suitable for use in most bichromate cells.

**2645.** The **Fuller** bichromate cell, one form of which is represented in Fig. 1040, is a very excellent cell of this type, being economical in operation. It consists of a glass jar containing the depolarizer (electropoion fluid diluted about one-half), into which is hung the carbon cathode *C*. In the center of the jar is placed the porous cup *P*, into which is poured a little mercury, and the zinc, which is in the form of a rod or wire *W*, with a conical lump *Z* cast on the end, placed in position. The mercury serves to keep the zinc well amalgamated.

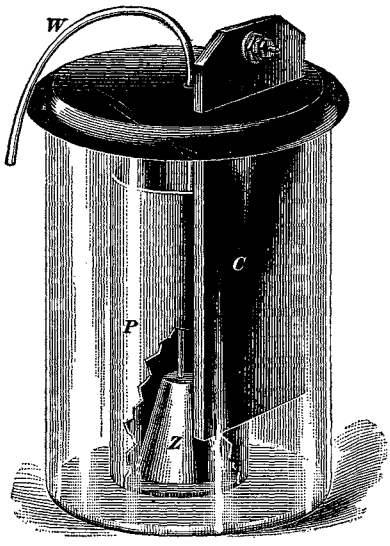

FIG. 1040.

The exciting liquid is either very dilute sulphuric acid, or, more commonly, pure water. The E. M. F. is 2.14 volts, and the internal resistance (of the type shown in Fig. 1039) usually about 1 ohm, depending, however, on the thickness and character of the porous cup. This type of cell is largely used for telegraphic purposes in England.

**2646.** Bichromate cells are often constructed in which the liquids employed have such a difference in their specific gravities that they may be placed one over the other in the cell, no porous partition being required to keep them from mixing.

**2647.** The **Partz** cell, one form of which is illustrated in Fig. 1041, is an example. This cell is a bichromate cell (see Art. **2643**), which uses a solution of sodium chloride, or of magnesium sulphate, as an electrolyte, surrounding the zinc *Z*, and a bichromate solution as a depolarizer, surrounding the carbon cathode *C*. The depolarizer, having a higher specific gravity than the electrolyte, remains at the

bottom of the jar, and the two liquids are kept separate. As the depolarizer is weakened by use, it is from time to time strengthened by the introduction of crystals in the glass tube *T*, which is suspended in the cell, having a small opening below the normal level of the bichromate solution. The crystals used are what the manufacturers call sulphochromic salt, which is formed by the action of sulphuric acid on some bichromate solution, and when dissolved in water gives the same results as the electropoion fluid (Art. **2644**).

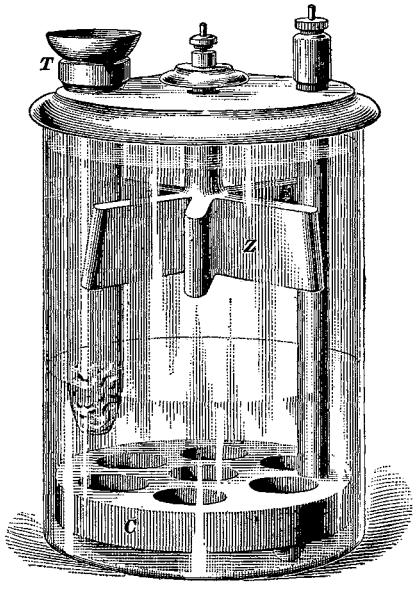

FIG. 1041.

With the cell shown, which employs a 6-in. × 8-in. jar, the internal resistance is about 1 ohm with a solution of magnesium sulphate, and about .5 ohm with a solution of sodium chloride, the E. M. F. being the same, 1.9 to 2 volts, in either case. This cell is good for either open or closed circuit work, as the polarization is very complete; at the same time, the local action on open circuit is almost imperceptible.

The chrome alum solution which forms, being heavier than the bichromate solution, descends to the lower part of the cell, so that the crystals form beneath the carbon plate, which is slightly raised from the bottom of the jar; consequently, the formation of these crystals does not appreciably increase the internal resistance of the cell.

**2648.** Another form of gravity bichromate, known as the **Kousmine** cell, has its liquids arranged in the reverse order to the above. The electrolyte is sulphuric acid

diluted to about 1.15 sp. gr. or less, and surrounds the zinc anode at the bottom of the jar. The depolarizer is a very weak solution of *potassium bichromate*, which floats on the sulphuric acid, being much lighter, and surrounds the carbon cathodes at the top of the jar. The heavy solution of chrome alum falls to the bottom, as in the Partz cell. The E. M. F. and actions of this cell are the same as in other bichromate cells, but its life is not long, the bichromate solution being soon exhausted by use.

**2649.** It can be readily seen that in cells of this class, consisting of the anode, exciting liquid, porous partition, depolarizing liquid, and cathode, a great number of different styles of cells may be constructed, by varying any of the four principal constituents, and a great many such variations have been made or suggested.

As pointed out in Arts. **2599** and **2600**, zinc is really the best and cheapest material for the anode; consequently, substituting other metals has not usually benefited the cell, except in special cases. The effect on the E. M. F. of such substitution may be readily found from Table 92, as before.

Great varieties of solutions have been used as electrolytes or depolarizing liquids; some with good results, and others without apparent reason, except to make a new cell.

**2650. M. D'Arsonval,** a French physicist, has made a series of cells, in which, by the action of the two liquids upon each other at their junction in the porous cup, an insoluble but conducting body is deposited in the pores of the porous cup, which prevents the gradual mixing of the liquids that usually takes place. For example, one of these cells is made up as follows: Zinc, solution of sodium hydrate (caustic soda), porous cup, ferric chloride, and carbon. The E. M. F. of this cell is about 2.7 volts; the action of the hydrogen on the ferric chloride reduces it to ferrous chloride and hydrochloric acid; at the same time ferric hydrate (which is insoluble, but a conductor) is formed in the pores of the porous cup.

**2651.** Various chloride salts have been used as depolarizers in cells of this class, the action being usually the reduction of the chloride to one containing a greater proportion of the metallic element. or else the entire reduction of the chloride, depositing the metallic element on the cathode; in either case the action of the hydrogen on the free chlorine forms hydrochloric acid.

**2652.** Many of the nitrate and sulphate salts have also been used as depolarizing liquids, and with a variety of electrolytes, generally acid; but the principal type of this class of cell, other than the Bunsen and the bichromate, is the type which employs as an electrolyte a salt of the metal of the anode, and as a depolarizer a salt of the metal of the cathode. The depolarizer is usually a salt formed by the same acid that formed the electrolyte salt; that is, if the electrolyte be a sulphate, the depolarizer is also a sulphate, etc. In this case the action is as follows: The passage of the current decomposes both liquids, and the hydrogen from the decomposed water unites with the non-metallic elements of the decomposed liquids, forming the acid from which the salt was formed, the metallic element of the depolarizer being deposited on the cathode; this acid attacks the anode, reforming the salt of which the electrolyte is composed. The electrolyte, therefore, is continually added to, while the depolarizer is continually reduced.

**2653.** Neglecting the intermediate reactions, which generally do not affect the E. M. F., it is evident that the E. M. F. of this type of cell is due to the energy given up by the formation of the salt of which the electrolyte is composed, less the energy required to decompose the salt of which the depolarizer is composed. Now, whatever may be the actual energy of the formation of the various salts, the *difference between the energies of formation of the same salts of any two metals is the same*, whatever the particular salt may be; for example, the *difference between* the heat of formation of zinc sulphate and that of copper sulphate is the

same as the difference between the heats of formation of zinc nitrate and copper nitrate.

**2654.** It naturally follows, that with given metals for the anode and cathode, the E. M. F. should be the same, whatever salt of the two metals be used as electrolyte and depolarizer, respectively. This is borne out in practice, as experiments have shown the E. M. F. under these circumstances to be practically the same.

In order, then, to obtain a high E. M. F., it is necessary to use as an anode a metal whose salts have a high heat of formation, and as a cathode a metal whose salts have a low heat of formation, just as in the other classes of cells.

For commercial use, the same considerations apply as to the other classes; that is, the materials used in the cell must be easily and cheaply obtained, even if they do not result in the highest possible E. M. F. The cells which best realize this condition are the **Daniell** cell and its derivatives.

**2655.** The Daniell cell uses for the anode, zinc; for the electrolyte, a solution of (usually) zinc sulphate, $ZnSO_4$; for the cathode, copper; and for the depolarizer, a solution of copper sulphate, $CuSO_4$. Sometimes, in setting up the cell, dilute sulphuric acid is used instead of the zinc sulphate, but this soon forms a solution of zinc sulphate; hence, the result is the same as if the zinc sulphate were used originally. The E. M. F. of the Daniell cell is given several values by different investigators, ranging from 1.059 to 1.079 volts. The London Post Office uses this cell as a standard, and calls its E. M. F. 1.07 volts.

The original form of the Daniell cell consisted of a glass jar, into which the zinc, in the form of a cylinder, was placed. Inside the zinc was a porous cup containing the cathode, a strip of sheet copper. The porous cup was filled with the $CuSO_4$ solution and the outer jar with the $ZnSO_4$ solution.

**2656.** To prevent the gradual weakening of the depolarizer, it is usual to put a considerable amount of copper sulphate crystals (commonly known as *blue vitriol*) into the

porous cup. As the liquid weakens, the crystals are gradually dissolved. Several modifications of the form of the original Daniell cell are in use, many of them designed to keep up the supply of copper sulphate as it is weakened.

**2657.** One such design, known as the **globe** or **balloon** cell, is shown in Fig. 1042, where $Z$ is the zinc anode, $P$ the porous cup, in which is the copper cathode $C$. To keep up the strength of the depolarizer, a glass globe $G$ is filled with crystals of copper sulphate $S$ and a little water, in which the copper sulphate gradually dissolves ; the solution, being heavier than the water, falls to the bottom of the neck of the globe and replenishes the solution in the porous cup. The neck of the globe extends down into the porous cup below the level of the liquid, so that the water may be retained in the globe. The globe rests on a ring of some soft material $R$, making a comparatively tight joint between the globe and jar, which prevents evaporation to a considerable extent. As ordinarily constructed, the globe holds about two pounds of copper sulphate crystals, which will usually last about six months. A cell similar to the above is used extensively for telegraph purposes in Russia.

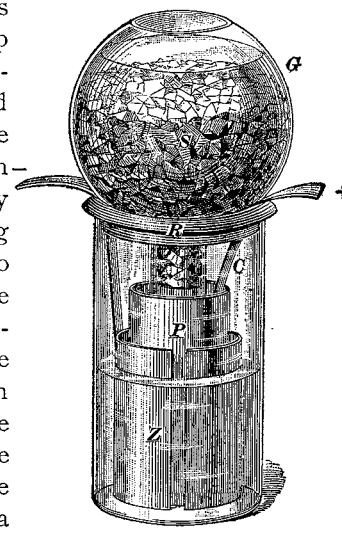

FIG. 1042.

**2658.** The specific gravity, at ordinary temperature, of a saturated solution of $ZnSO_4$ is about 1.44, while that of a saturated solution of $CuSO_4$ is about 1.20; hence, if saturated solutions of these salts are used, the zinc sulphate solution will be considerably heavier than the other; it has been found, however, that the best results are obtained from a saturated solution of copper sulphate, used with a solution

of zinc sulphate diluted to a specific gravity of about 1.10. The considerable difference in weight between the two solutions has led to their arrangement, one over the other, in the cell, the heavier copper sulphate being at the bottom.

**2659.** In the **Hussey** and the **Gethin** cells a porous partition is used to separate the two liquids, in the form of a porous cup, located in the upper part of the jar. This cup holds the zinc and the electrolyte; beneath it is the copper, made in the form of a cross of sheet copper, which is surrounded by crystals of copper sulphate.

**2660.** Since the proportion of the two liquids in the jar varies from time to time, the porous partition does not always mark the point of separation of the two liquids, and it increases the internal resistance of the cell; consequently, the batteries of this type that are more generally used are those which do not use any porous partition at all, depending on the difference in the specific gravities of the two liquids to keep them apart.

Such cells are called **gravity cells,** or *gravity Daniell cells*, and are very extensively used for telegraph and fire-alarm work in this country.

**2661.** As long as a current is flowing through the cell, the chemical action keeps the boundary-line of the two liquids sharply defined; but when the current ceases to flow the solutions gradually intermix, and the *copper sulphate*, coming in contact with the zinc anode, sets up local actions, which cause a deposit of copper on the zinc, and a consumption of the zinc itself. To prevent this action, these cells should be used only on a circuit which is closed practically all the time, which is the case with telegraph and fire-alarm lines.

**2662.** Practically the first cell of this type to be used was the **Callaud** cell, illustrated in Fig. 1043. In this cell the zinc $Z$ is in the form of a cylinder, suspended by hooks from the edge of the jar. The copper $C$ is a flat strip bent into a circle, which rests on the bottom of the jar. Con-

nection is made between it and the external circuit by means of a wire $W$, which is insulated with some rubber compound where it passes through the liquids. The position of the two liquids is shown in the illustration, the zinc sulphate ($ZnSO_4$) being at the top, as stated. This form of cell has been modified quite largely, it being now the practice to use large cast zincs instead of the cylinder of sheet zinc used in the Callaud form, which allows of a longer life for each cell.

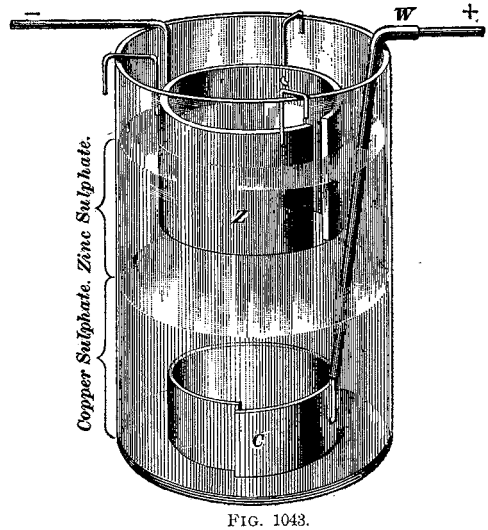


FIG. 1043.

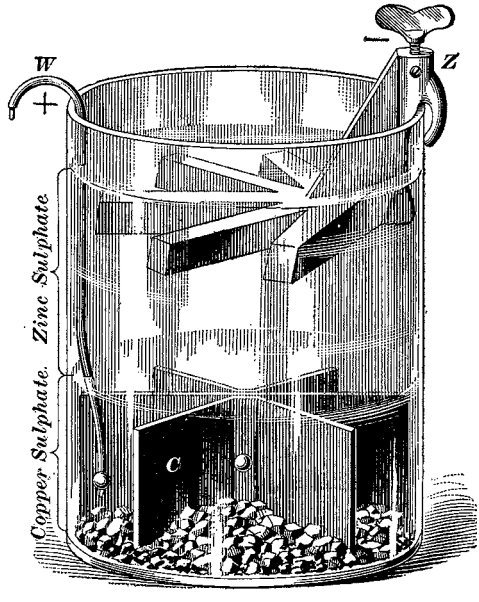


FIG. 1044.

**2663.** The form of gravity Daniell cell most used in this country is the familiar **crowfoot** cell, illustrated in Fig. 1044, where $Z$ is the zinc, from the shape of which the cell gets its name; $C$ is the copper, which is connected to the external

circuit by the wire *W*, which is insulated where it passes through the liquid. When the cell is set up the copper cathode is surrounded with copper sulphate crystals. The standard form of this cell is of the following dimensions:

Jar, 6 inches diameter, 8 inches high. Copper, made from three pieces of thin sheet copper 2 inches wide and 6 inches long riveted together in the middle; the outside pieces are then spread out, making the copper of a six-pointed star shape. To the middle strip is riveted a piece of No. 16 insulated copper wire. (See Fig. 1044.)

The zinc is of the shape shown in the illustration, and weighs 3 lb. About 2 pounds of sulphate of copper crystals are required to charge the cell.

**2664.** The usual practice in charging is to set up the elements in the cell, put in the copper sulphate, and fill up with clean water until the zinc is covered; the cell is then allowed to stand for about 24 hours. By the action of the zinc on the copper sulphate solution, zinc sulphate is soon formed around the zinc, and the cell is ready for use.

If desired for immediate use, a solution of zinc sulphate may be prepared and poured into the jar with the copper sulphate solution; in this case the zinc should not be placed in position until the two liquids have separated, which will be indicated by the upper part of the liquid becoming nearly colorless, while the lower part is of a deep blue color.

**2665.** The average internal resistance of a crowfoot cell of this size is about .5 ohm, and its E. M. F. is the same as the other forms of Daniell cell, 1.07 volts.

**2666.** The maintenance of this type of cell is simple, it only being necessary to renew the supply of copper sulphate crystals when the solution becomes weak, which is indicated by the fall of the blue-colored liquid below the top of the copper cathode; besides this, the density of the zinc sulphate solution should be occasionally measured with a hydrometer, and if too dense (above about 1.15 sp. gr.) a part should be removed and replaced by water.

**2667.** With the crowfoot form of zinc there is considerable waste, due to the size of the "stub" which is left when the zinc has been consumed so that it can not be used. Several forms of zincs have been designed to prevent this waste as far as possible.

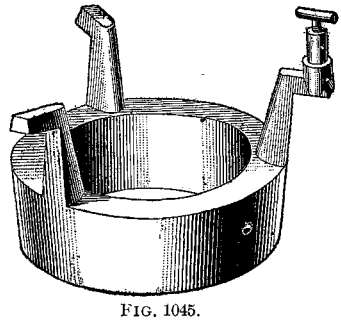

FIG. 1045.

**2668.** One form, used by the Baltimore (Md.) Fire Department, is cast into a ring with upwardly projecting lugs, which have shoulders upon them, by which the zinc is supported by the edge of the battery jar. This form of zinc is illustrated in Fig. 1045. The ring itself being entirely below the level of the liquid in the cell, it can be almost entirely consumed.

**2669.** Fig. 1046 illustrates another similar form, known as the *pinnacle* zinc, from the fact that it is supported on a vertical rod of insulating material, which is fastened at the lower end to the copper. This rod projects up through the liquids and enters the cavity in the center of

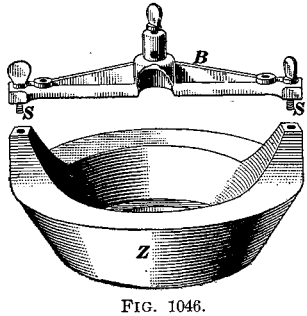


FIG. 1046.

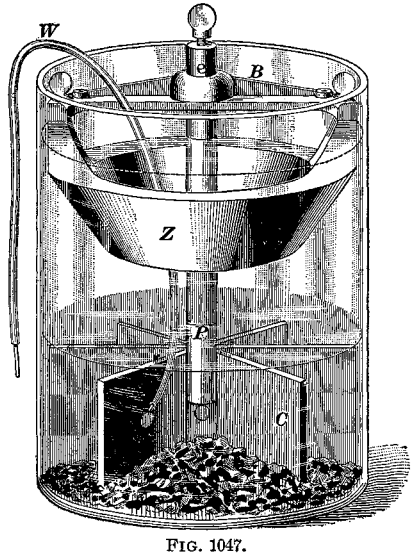


FIG. 1047.

the brass supporting piece $B$, which is fastened to the zinc $Z$ by the screws $S$, $S$. The complete cell is shown in Fig. 1047,

$Z$ being the zinc, $C$ the copper, and $P$ the rod of insulating material which supports the zinc by means of the supporting piece $B$.

**2670.** Another form of zinc in which there is no waste whatever is the D'Infreville *wasteless* zinc, illustrated in

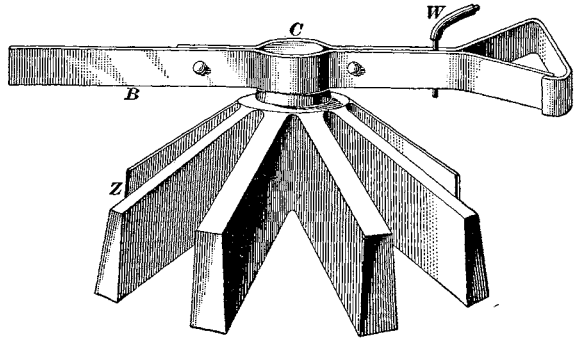


FIG. 1048.

Fig. 1048. This zinc is cast with a conical lug $C$ on the top, and a corresponding cavity in the under side of the zinc (see Fig. 1049). When the zinc is nearly consumed, it is removed from the support $B$, and the lug $C$ inserted in the cavity of a new zinc, which is then put in place in the support $B$. The old zinc is then underneath, and is entirely consumed. Fig. 1049 shows a cross-section of this form of zinc, showing a new zinc $A$, a partly consumed zinc $B$, and the stub of a third $C$.

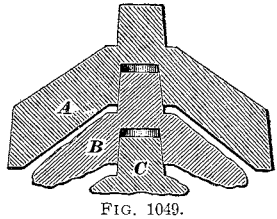


FIG. 1049.

The support $B$ (Fig. 1048) also serves as a connector, the end of the connecting wire being sprung in between the two brass strips of which the connector is made, as shown at $W$.

**2671.** The Daniell cell, in various forms, has been used as a standard cell in laboratory work and for testing purposes. It is well adapted to such work, if too great a degree of accuracy is not required, as the E. M. F. is practically unaffected by moderate changes in temperature or in the den-

sity of either solution used, or by the length of time the cell is in operation. For ordinary work the E. M. F. of such a standard cell may be taken at the value given; that is, 1.07 volts. (See Art. **2655.**)

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## CELLS WITH A SOLID DEPOLARIZER.

**2672.** The depolarizers which are used in this class of cell are generally substances containing a large proportion of oxygen, with which the free hydrogen unites, forming water; the balance of the depolarizer is sometimes dissolved in this water, but more often remains at the cathode in a solid form, the water merely serving to dilute the electrolyte. In the first case the solution formed usually acts to keep up the strength of the electrolyte. (See Art. **2597.**)

**2673.** Some few of the non-metallic elements which exist in the solid state will unite directly with hydrogen, and might be used as depolarizing cathodes; such a substance is the metalloid *tellurium*. Such elements are rare and are not used in commercial forms of cells.

**2674.** Among the most widely used depolarizers are the oxides of manganese, copper, and lead, and the chlorides of some of the metals.

The several sulphates of mercury also have a large proportion of oxygen, and are used for this purpose.

**2675.** The **Leclanche** cell is a well-known and widely used cell of this type. Its positive element (negative electrode) is zinc, usually in the form of a rod; the electrolyte is a saturated solution of ammonium chloride, $NH_4Cl$ (sal ammoniac), and the negative element is carbon, surrounded by manganic oxide, $MnO_2$ (black oxide, or peroxide, of manganese), which is the depolarizer. This being in the form of a coarse powder, it is usually contained in a porous cup, which allows free access of the electrolyte to the depolarizer and negative element.

Fragments of crushed coke (or carbon in other forms) are

often mixed with the manganic oxide to decrease the resistance of the contents of the porous cup.

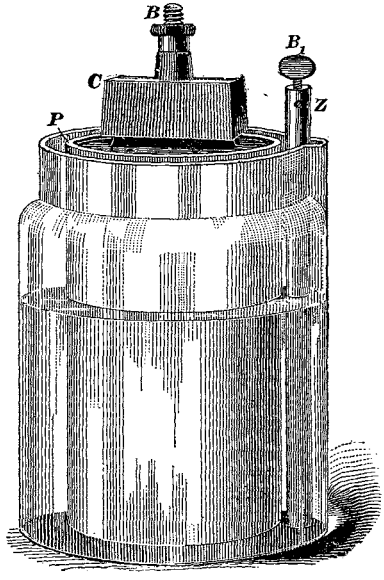


FIG. 1050.

Fig. 1050 shows the usual form of this type of cell. The porous cup $P$ contains the manganic oxide and the carbon electrode, which projects from the top of the cup, and to which a binding-post $B$ is attached.

The glass jar is circular, with a contracted top, in which a slight recess is formed to contain the zinc $Z$. The top of the zinc is provided with a binding-screw $B_1$, which serves as the negative terminal of the cell, $B$ being the positive.

The top of the jar is coated with paraffin to prevent the crystals of sal ammoniac "creeping" over the top of the jar as the liquid evaporates.

**2676.** The cell illustrated in Fig. 1050 is of the following dimensions:

| | |
|---|---|
| Jar, | $4\frac{1}{2}$ in. diameter, 6 in. high. |
| Zinc, | $\frac{3}{8}$ in. diameter, $6\frac{1}{2}$ in. high. |
| Porous cup, | 3 in. diameter, $5\frac{1}{2}$ in. high. |
| Carbon, | 6 in. $\times$ $1\frac{3}{4}$ in. $\times$ $\frac{5}{16}$ in., about. |

The weight of the zinc rod is about 3 ounces, about two-thirds of which is below the level of the liquid. There are about 16 ounces of peroxide in the porous cup, and it requires nearly 6 ounces of ammonium chloride to make sufficient solution for this size of cell.

For each ounce of zinc consumed in the cell, 2 ounces of manganic oxide and 2 ounces of ammonium chloride must also be consumed; so, from the amount of these materials

contained in the cell, it follows that there is enough peroxide in the porous cup to last while four zincs are being consumed, while the ammonium chloride will not last longer than $1\frac{1}{2}$ zincs. As the zincs are usually replaced when eaten away to about $\frac{1}{8}$ in. or $\frac{1}{16}$ in. diameter, the solution need not be replaced until two zincs have been consumed, and the contents of the porous cup will last as long as five or six zincs. The consumption of zinc in the Leclanche cell is about 23 ampere-hours per ounce of zinc, and as about $1\frac{3}{4}$ ounces of each zinc rod may be consumed, the life of each zinc is then about 40 ampere-hours. The E. M. F. of this type of cell is about 1.48 volts, and its internal resistance about 4 ohms.

**2677.** It is usual to seal the carbon and depolarizer into the porous cup by some compound, such as sealing-wax, leaving small tubes or holes, by which whatever gas not absorbed by the depolarizer may escape. This sealing necessitates the entire renewal of the porous cup, with contents, when the depolarizer is exhausted; to obviate this expense, some makers use a carbon porous cup and place the zinc inside, at the center, the space between the zinc and carbon being filled with peroxide.

**2678.** A form of Leclanche cell, made by the Law Battery Co., also replaces the clay porous cup by one made of carbon, but in this case the zinc is outside the carbon, as in the regular form. The carbon cup is made with a screw cover, also of carbon, which renders the replacing of the depolarizer a simple matter. This construction reduces the cost of maintenance of the cell, but increases the first cost.

**2679.** Another widely used form of Leclanche cell is the **Gonda** Leclanche, which uses no porous cup whatever; the manganic oxide is mixed with granulated carbon and some gummy substance, and compressed into cakes under great pressure. These cakes are attached to the sides of the carbon plate, and act in the same manner as the depolarizer in the regular form.

Fig. 1051 shows the construction of the elements of such a cell. The two cakes of depolarizer (called *gondas*) *G*, *G* are clamped one on each side of the carbon plate *C* by the soft rubber bands *R*, *R*, which also serve to hold the zinc rod *Z* in place. The zinc lies in a groove in a block of wood or clay *W*, which serves to keep the zinc away from the gondas. This block is sometimes done away with by supporting both zinc and carbon from a plate of insulating material, which also acts as a cover to the jar. In still other forms, the depolarizer is molded into a cylinder, in the center of which the zinc is supported.

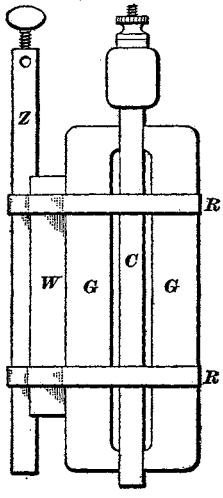

FIG. 1051.

A second zinc electrode is sometimes used in this latter form, consisting of a cylinder of sheet zinc encircling the cylindrical gonda, a common terminal being connected to both zincs.

The liquids and action of the gonda form are the same as in the regular Leclanche cell.

**2680.** Commercial sal ammoniac often contains a considerable amount of impurities, in the shape of other salts, which materially reduce the life of the electrolyte; not sufficiently, however, to warrant the cost of using the chemically pure salt, as prepared by chemists.

**2681.** Ammonium chloride has been found to be the only salt which works well with manganic oxide as a depolarizer, so the many other forms of cell that have been constructed, using this depolarizer, differ materially from the Leclanche type only in the mechanical arrangement of the parts.

**2682.** The principal chemical actions in this type of cell are the formation of zinc chloride and ammonia, and the reduction of the amount of oxygen combined with the man-

ganese. Besides these, there are other more complicated reactions which occur, but which do not affect the E. M. F. of the cell materially.

**2683.** Another solid depolarizer which is used in important commercial cells is cupric oxide, *CuO*. The **Lalande and Chaperon** cell uses an iron or copper negative element surrounded with a layer of cupric oxide. The positive element is zinc, the electrolyte a solution of *potassium hydrate* (caustic potash). On closing the external circuit, the potassium hydrate solution attacks the zinc, forming a compound oxide of potassium and zinc, known as *potassium zincate*, and liberating hydrogen, which combines with the oxygen of the cupric oxide, forming water, and depositing metallic copper on the cathode.

If the surface of a solution of caustic potash is exposed to the air, it will gradually form *potassium carbonate;* to prevent this action, cells of this type are either entirely enclosed or the surface of the liquid is covered with a thin layer of heavy oil.

Fig. 1052 shows one form of **Lalande and Chaperon** cell, in which the iron vessel *V* forms the negative elements, the positive terminal being a lug *A* cast on the side of the vessel. The *cupric* oxide *B* is in a layer at the bottom of the vessel. The zinc *D* is suspended from a rod *K*, which passes through a rubber stopper *G*, terminating in a binding-post *F*. The rubber stopper is provided with a valve *H*, which allows such gases as are evolved to escape.

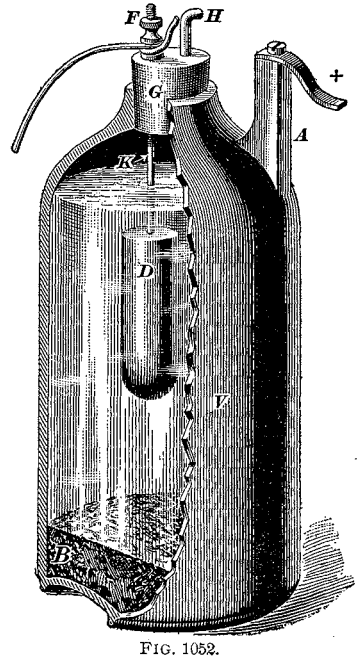


FIG. 1052.

**2710.** There are a great number of devices which require the application of a current intermittently; some, such as electric bells and other signals, electric gas-lighting apparatus and the like, are used infrequently and irregularly, and the amount of electricity required is small, so that almost any voltaic cell will do, depolarizing or not, provided there is no local action to cause waste when not in use; therefore, cells with liquid depolarizers (see Art. **2604**) are not well adapted to this work, as in the long periods in which these cells are not called upon to furnish current the two liquids will mix and usually cause local action.

**2711.** The cells most used for this work are the various zinc-carbon batteries, both of the class described in Art. **2602,** with non-depolarizing electrolytes, and of the class described in Art. **2605,** with solid depolarizers; of the latter, some form of Leclanche cell usually gives the best results. In hotels and large buildings where the bell or signal service is practically continuous, depolarizing cells are required, such as large Leclanche cells, bichromates (with separate fluids), if of good modern construction, Edison-Lalande, and the like.

**2712.** Electric currents are much used in physicians' and surgeons' offices; currents of a few milliamperes in strength, but of from 75 to 100 volts E. M. F., are applied for curative purposes, while currents of 10 to 20 amperes in strength are used for heating cautery loops in surgical operations, requiring an E. M. F. of from 4 to 8 volts. Miniature incandescent lamps, usually operated from the battery which furnishes current for the cautery, are also used to examine the interior of the body.

**2713.** The first appliance obviously requires a large number of cells of a small size; for occasional use, and where first cost is not such an object as compactness, a battery of small silver chloride cells is very convenient, while for more frequent use, requiring larger cells, some cheaper form of depolarizing cell is used.

Obviously, if the cells selected have a high E. M. F. (say 2 volts), a less number will be required than if the cells are of

a low E. M. F.; however, as in some instances the regulation of the current is obtained by switching in or out some of the cells, this regulation will be more uniform and gradual if the E. M. F. of each cell is low.

**2714.** For furnishing the larger currents for cautery work, large cells should be selected, those which are so arranged as to have a minimum internal resistance being best. As the use of porous cups in a cell increases the internal resistance largely, cells which employ them are not well suited for this work.

Bichromate cells are very convenient for this purpose, as their internal resistance is low and the E. M. F. high and steady. It is usually convenient to use the form of bichromate cell in which the elements are raised from the liquid when the cell is not in use, as the purpose for which the current is used involves personal and immediate attention to all parts of the apparatus.

**2715.** The most extensive application of cells of the Bunsen type is to electroplating and similar work, and cells of large size are made especially for this purpose.

Such work being usually carried on in establishments especially fitted up for the purpose, the various unpleasant features of the Bunsen cell, which make them objectionable for many purposes, may be readily provided for, and their high and constant E. M. F. utilized.

**2716.** The minor applications of primary batteries are almost innumerable. A study of the requirements of such cases will usually determine the best type of cell to use, but attention should also be paid to the mechanical construction of the cells selected, as on this point often depends their life and suitability for the work they are called upon to do.

The binding-posts should be firmly and substantially fixed to the elements, and should be thoroughly protected from possible contact with the electrolyte, as the resulting action will so corrode the joint between the two as to destroy the contact, besides possibly eating away the connecting wires and breaking the circuit.

Of the material of the positive element, as much as possible should be below the level of the liquid, as when that is consumed the balance must be thrown away, and this may represent a considerable loss.

Altogether, the cell should be substantial and compact, not liable to local action, and arranged so that its parts may be readily renewed with the least possible waste.

**2717.** In general, it must be remembered that the consumption of material in a primary cell (assuming no local action) is proportional to the output in ampere-hours; the *energy* output depends not only on the amount of materials consumed, but on the E. M. F. of the cell and its internal resistance, so that, other things being equal, the higher the E. M. F. of a cell and the lower its internal resistance, the greater its output for a given cost of materials.

**2718.** As stated, the most economical metal to use for the negative element is zinc, and the amount of zinc consumed in a cell may be readily determined from the output in ampere-hours and the chemical equivalent of zinc (again assuming no local action); but to find the total cost of the energy, to this must be added the cost of the depolarizer consumed, if any, and the cost of labor in renewing the materials and caring for the cells.

**2719.** The substances resulting from the chemical actions which take place often have a market value; usually, however, the expense of collecting or preparing such substances for sale will be greater than the price they will bring, so that in ordinary cases this should not be taken into account.

**2720.** It is evident that all the E. M. F. of a cell is not available to send a current through the external circuit, but that a part is expended in overcoming the internal resistance.

If the resistance of the external circuit is very great, this drop is of little importance; while if the external resistance

is very small, the internal resistance practically determines the amount of current flowing.

**2721.** The various methods of connecting up the cells of a battery, in parallel, series, or parallel series, are given in Art. **2250.**

If several cells, all of the same size and kind, are connected in series, their total internal resistance will equal *the resistance of one cell multiplied by the number of cells*, and their total E. M. F. will equal *the E. M. F. of one cell multiplied by the number of cells;* if they are all connected in parallel, their total resistance will be equal to the *resistance of one cell divided by the number of cells*, while their total E. M. F. will be equal to that of a single cell. From this it follows that if the external resistance is very small, increasing the number of cells in series will not increase the current in the external circuit appreciably, as the resistance increases nearly as fast as the E. M. F.; while if the external resistance is great, increasing the number of cells in parallel will not appreciably increase the current flowing, as the total resistance is not much altered, while the E. M. F. remains the same.

**2722.** For a given external resistance and a battery of a given number of cells, the maximum current will flow when the cells are so grouped that their internal resistance just equals the external; so that, in installing a battery, the resistance of the circuit and of the cells should be ascertained, and the cells grouped accordingly. This may be proved, numerically, as follows: $C = \frac{E}{R}$. Let $m$ cells be in series in $l$ rows, or a total of $m \times l$ cells. Let $E$ be the electromotive force and $R$ the internal resistance of each cell, and $r$ the resistance of the outside circuit. Substituting in above formula, $C = \frac{m E}{(m R \div l) + r}$ (*a*). Then, $C$ is greatest when $\frac{m R}{l} + r$ is smallest; that is, when $m$ and $l$ are chosen such that $\frac{m}{l} R$, the total internal resistance,

equals or approximates to $r$. Let us assume $m \times l = 12$, $E = 2$, $r = 3$, $R = 2$. Substituting in formula ($a$), and taking the following values of $l$,

$$l = 1. \quad C = \frac{12 \times 2}{(\frac{12}{1} \times 2) + 3} = \frac{24}{24 + 3} = .9 \text{ ampere.}$$

$$\text{Total internal resistance} = \frac{12 \times 2}{1} = 24 \text{ ohms.}$$

$$l = 2. \quad C = \frac{6 \times 2}{(\frac{6}{2} \times 2) + 3} = \frac{12}{6 + 3} = 1.3 \text{ amperes.}$$

Total internal resistance $= 6 \times 2 \div 2 = 6$ ohms.

$$l = 3. \quad C = \frac{4 \times 2}{(\frac{4}{3} \times 2) + 3} = \frac{8}{2\frac{2}{3} + 3} = 1.4 \text{ amperes.}$$

Total internal resistance $= 4 \times 2 \div 3 = 2\frac{2}{3}$ ohms.

$$l = 4. \quad C = \frac{3 \times 2}{(\frac{3}{4} \times 2) + 3} = \frac{6}{1\frac{1}{2} + 3} = 1.3 \text{ amperes.}$$

Total internal resistance $= 3 \times 2 \div 4 = 1\frac{1}{2}$ ohms.

It is thus seen that the largest current is obtained when the internal resistance approaches nearest to the value of the external.

Ordinarily, in telephone, telegraph, and fire-alarm work the external resistance is high, while for ringing bells, gas-lighting, and similar work the resistance is low; batteries for these purposes should be grouped accordingly.

**2723.** The internal resistance of a cell can not be measured in the same way as the resistance of a piece of wire, that is, by sending a measured current through it from some external source, measuring the drop in volts and calculating the result from Ohm's law; for the E. M. F. of the cell itself would either add to or subtract from (depending on the polarity of the current) the drop due to the current, and, hence, the calculated results would be at fault.

**2724.** A simple way to measure this internal resistance is to cause the cell itself to furnish a current through some known resistance. Then, by measuring the E. M. F. at the

terminals of the cell with a voltmeter, when the current is flowing and on open-circuiting the cell, the difference between the two readings will show the drop in volts due to the flowing of this current against the internal resistance of the cell.

For example, if a cell gives an E. M. F. of 1.5 volts on open circuit, and on being connected to an external resistance of 2 ohms the E. M. F. at the terminals drop to 1.25 volts, the drop in the cell is obviously .25 volt. The current is $C = \frac{E}{R} = \frac{1.25}{2} = .625$ ampere; therefore, the internal resistance of the cell is $R = \frac{E}{C} = \frac{.25}{.625} = .4$ ohm.

## ACCUMULATORS.

**2725.** A storage-battery, or, preferably, an accumulator, is an apparatus consisting of certain materials so arranged that when they have undergone chemical action, due to the influence of a current of electricity, the combination has acquired the properties of a voltaic cell, and is enabled to discharge into a closed circuit a current of electricity approximately the same as the original charging current.

Many forms of primary batteries may, when exhausted, be more or less regenerated by passing through them a current, from some external source, in the opposite direction to the current they themselves produce. It is customary, however, to consider as accumulators only those cells whose original construction is similar to an exhausted battery; that is, they can not be used as sources of electricity until they have been *charged* by passing a current through them.

**2726.** A great deal of confusion exists as to the use of the terms *positive* and *negative* in speaking of the plates of a secondary cell; for in charging the cell the current is in the reverse direction to that which flows when the cell is acting as a voltaic cell and discharging. It is customary, however, to speak of the plate at which the current enters the cell (while charging) as the *positive* plate. In fact,

whether charging or discharging, his plate is at a higher potential than the other, which justifies the above use of the term, although with respect to the chemical actions in the cell the positive and the negative plates are reversed in the two operations.

**2727.** Accumulators may be divided into two general classes: (1) **lead accumulators,** and (2) **bimetallic accumulators.** The larger proportion of cells now in use are of the first class.

**2728. Lead Accumulators.**—The original lead accumulators, as made by Planté, consist of two plates of lead, usually rolled together in a spiral, and separated by strips of rubber or other suitable insulating material; these are placed in dilute (about 10%) sulphuric acid. On sending a current from some external source through this cell, the water becomes decomposed, and the oxygen combines with the positive plate, forming lead oxide or peroxide, while the hydrogen collects at the negative plate.

On disconnecting the source of the applied current, and completing the external circuit of the cell, the water again is decomposed, the oxygen uniting with the hydrogen collected at the negative plate, and also with the lead plate itself, and the hydrogen uniting with the oxygen of the oxide of lead at the positive plate, thus producing a current in the opposite direction to the applied current.

**2729.** Owing to the fact that the formation of the layer of oxide prevents further oxidation, the amount of chemical change due to the applied current is small, so the secondary current from the cell is of short duration; after this current has ceased, however, the surface of the positive plate is much increased, owing to the removal of the oxygen from the lead oxide, leaving the metallic lead in a spongy form. On again sending a current through the cell a further oxidation of this (positive) plate takes place, and by continuing this process, reversing the current each time it is sent through, both positive and negative plates become porous to a considerable depth, thus very much increasing

the surface on which the oxidation can take place. This process might be carried on until the whole plate is reduced to spongy lead; in that case the plate would not hold together, so a sufficient amount of the original plate must be left for mechanical strength. After the plates are so *formed*, they are ready to be used as an accumulator.

**2730.** This forming process, however, is too long and expensive for commercial success, though it is considerably hastened by roughening the surface of the lead plates with nitric acid before commencing the process; it was soon superseded by the process invented by Faure, of coating the surface of the plates with some substance which by the first charging current is converted into lead peroxide on the negative plate and into spongy lead on the positive. This substance may be lead oxide (litharge), lead sulphate, minium ($Pb_2O_3$), lead peroxide, or mixtures of these substances.

**2731.** These substances are applied in various ways; one method is to make a paste of the substance (in this case usually minium), that for the negative plate being made with sulphuric acid, which changes the $Pb_2O_3$ into $PbSO_4$ (lead sulphate) and water, while that for the positive plate is made with water only. These pastes were originally applied directly to the surface of the plain lead plate; but as they proved to be only slightly adhesive, the plates were prepared by scratching or otherwise roughening the surface, which process has been gradually extended until the lead plates are now cast into *grids*, or latticework plates, in the spaces of which the paste is applied, or forced by hydraulic pressure. Some manufacturers do not use a paste of the active material, but employ the minium, litharge, or lead sulphate in the form of dry powder, forcing it into the grid under such enormous pressures that the powder is solidified.

**2732.** The grids are usually designed to hold the active material securely in position; to this end they are made with perforations which are not of the same area throughout the thickness of the plate, but wider or narrower in the

center, so as to hold the filling of active material by the dovetailing action of their shape, as will be shown later.

**2733.** After the grids have been filled with active material, they are set up in pairs in suitable vessels, and surrounded by an electrolyte consisting of sulphuric acid diluted to about 1.17 sp. gr., which density corresponds to about 20% of acid in the liquid. A *charging current* is then sent through the cell from some external source; the action of this current decomposes the water, the oxygen of which further oxidizes the lead oxide (litharge or minium) to peroxide, at the positive plate, the hydrogen going to the negative plate, where it reduces the lead sulphate to spongy lead by uniting with the $SO_4$, forming sulphuric acid. Thus, the active material becomes lead peroxide in the positive plate and spongy lead in the negative. By many investigators this lead peroxide is thought to be *hydrated lead peroxide;* that is, it contains a certain amount of hydrogen and oxygen in excess of the normal peroxide, and is represented by the formula $H_2Pb_2O_5$. This, as well as many of the actions which occur in accumulators, is not clearly established as yet.

**2734.** Continuing the charging current, when all the active material is thus converted, produces no further effect, except to continue to decompose the water; the resulting gases pass off through the water, giving it a milky appearance.

This phenomenon is known as *gasing* or *boiling*, and is an indication that the cells are fully charged. Continuing the charging current beyond this point, that is, overcharging the cells, does no harm to the plates, but the energy represented by the current is wasted.

**2735.** On discontinuing the charging current at the gasing point, and completing the external circuit of the cell, a current will flow in the opposite direction to that of the charging current, the resulting chemical action being to reduce the lead peroxide to lead oxide at the positive plate, and the spongy lead to lead sulphate at the negative; a

secondary action is the formation of a part of the lead oxide at the positive plate into lead sulphate. The sulphates thus formed are not all of the same proportions; one exists as red, another as yellow, and a third as white crystals, of which the white sulphate is best known, as it is formed when the cell is considerably discharged, and is extremely troublesome. This discharge may be continued until all chemical action ceases, and the E. M. F. consequently falls to zero; but this is not advisable, since, if the discharge is carried beyond a certain point, the red or yellow sulphates, probably by combination with the litharge (*PbO*), form the white insoluble sulphate, which has a higher proportion of lead than the others; this, being a non-conductor, materially increases the internal resistance of the cell, and when it is removed it usually carries some of the active material with it, as it is very adhesive.

**2736.** When the cells have been properly charged, the positive plate is of a brown or deep red color, while the negative is a slaty gray.

The presence of the insoluble sulphate is made apparent by the formation of a white coating or glaze over the plates, which are then said to be *sulphated.* If the cells are discharged and left to stand with the electrolyte in place, *sulphating* takes place rapidly.

**2737.** It will be noticed that sulphuric acid is formed during the charge, and decomposed during discharge; thus the proportions of it in the electrolyte, consequently the density of the electrolyte, vary with the state of charge of the cell; starting with a specific gravity of 1.17, when the cell is fully charged the specific gravity will be found to be about 1.22, indicating the presence of about 25% of sulphuric acid in the electrolyte.

**2738.** The chemical actions of charging or discharging do not take place simultaneously, as is shown by the variations in E. M. F. under different conditions of charge or discharge, nor are they probably the only actions which occur.

**2739.** The E. M. F. of this type of cell is approximately 2 volts, being 2.04 when slightly discharged, which gradually falls to 1.90 volts when nearly discharged. Beyond this point, further discharging causes the E. M. F. to fall more rapidly, the decrease after 1.8 volts being very rapid. (See Fig. 1037.)

**2740.** The rating of accumulators is usually based on their capacity when discharged to an E. M. F. of 1.8 volts; but in spite of this rating, the result of a long series of tests shows that in practice they should not be continuously discharged to below 1.9 volts, as below this point *sulphating* is very liable to occur, and, the nature of the chemical action being changed, it also leads to the distortion of the positive plate, which is known as **buckling.**

As the plates are located very close together in the cells to reduce the internal resistance, buckling is liable to cause the plates to touch, thus short-circuiting the cell.

**2741.** The cause of buckling seems to be the formation of sulphate in the plugs of active material which fill the spaces of the grids, thus causing the plugs to expand; lead having very little elasticity, the grid is forced out of shape. As usually constructed, the edges of the grid are heavier than the intermediate portion, so that the effect of the distortion is to bulge the plate in the center. If the plates are not discharged too far and too rapidly, the expansion of the active material is gradual, causing the grid to stretch evenly; this makes the plates "grow," or increase in area, sometimes as much as 10 per cent.

**2742.** The *quantity* of electricity which may be taken from a completely charged cell depends upon the amount (weight) of material altered by the chemical action, as in a primary cell; while the *rate* at which this material is altered, consequently the rate at which the electricity can be taken out (the rate of discharge in amperes), and, to a large extent, the amount of material altered, depends upon the surface of the active material exposed to the chemical action.

**2743.** Cells of this type are then rated at a certain number of *ampere-hours* capacity, depending on both the weight and the surface area of the active material in the cell, and a certain economical *discharge rate* is also recommended, depending on the surface of the plates exposed to the electrolyte.

If this discharge *rate* be continually exceeded, the chemical action goes on too rapidly, the white sulphate is formed in the active material of the positive plate, finally causing disintegration of the active material and buckling of the plates, even if the discharge is not carried beyond the point (1.9 volts E. M. F.) given above. With the ordinary construction, the normal discharge *rate* is about .0165 ampere per sq. in. of surface of positive plate, and the discharge *capacity* about 4.5 ampere-hours per pound of plate (both positive and negative plate included).

**2744.** Fig. 1055 shows the manner in which the E. M. F. of an accumulator falls as the discharge proceeds. In this

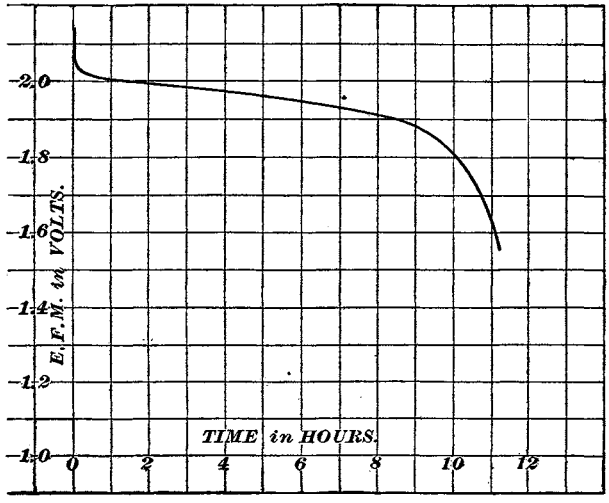


FIG. 1055.

case the cell was connected to a variable external resistance, such that about the normal discharge current, as advised by the manufacturers, was maintained throughout the test in the

external circuit. The oxidation of the slight layer of hydrogen left on the negative plate from the discharge causes the E. M. F. to be high at first, but as this is quickly disposed of, the E. M. F. falls in the first ten minutes or so to 2.04 volts; on continuing the discharge, the E. M. F. falls slowly and evenly until after about $8\frac{1}{2}$ hours of discharging the E. M. F. falls to 1.9 volts. If the discharge is continued beyond this point, the nature of the chemical action changes somewhat, and the fall of E. M. F. becomes more rapid, at 10 hours being 1.8 volts, and at 11 hours being only 1.63 volts.

**2745.** This falling off of the E. M. F. is due to the weakening of the acid solution and to the gradual reduction of all the spongy lead on the one plate and the peroxide on the other to sulphate.

As this reduction can only go on at the points where the acid is in contact with the spongy lead or the peroxide, it is evident that the interior portions of the active material are affected much more slowly than the surface, as the acid penetrates the active material only at a comparatively slow rate.

On this account, discharging at slow rates allows the active material to be more uniformly and thoroughly reduced, thus giving a greater output.

This also accounts for the fact that on discontinuing the discharge at any point the E. M. F. will soon rise to practically its original value, 2.04 volts; for unless the cell is entirely discharged there is always some unconverted active material in the interior of the plate, which serves to give the original E. M. F. when reached by the acid. If the discharge is resumed, this acid is soon exhausted, and the E. M. F. rapidly falls to the value it had when the discharge was stopped.

**2746.** In the above case, the product of the amperes and the hours will give the output of the accumulator in ampere-hours; if the discharge *rate* had been greater, the output in ampere-hours would have been diminished, the discharge being continued until the E. M. F. falls to the

same value in each case. Conversely, if the discharge rate had been lower, the output would have been increased.

For example, assume the limiting E. M. F. to be 1.9 volts. In a certain cell, with a discharge current of 30 amperes, the E. M. F. reaches its limit in 10 hours, giving an output of 300 ampere-hours.

If the discharge current were 40 amperes, the limiting E. M. F. would be reached in about $6\frac{1}{2}$ hours, giving an output of only 260 ampere-hours; while if it were 20 amperes, the limiting E. M. F. would not be reached for about $17\frac{1}{2}$ hours, giving an output of 350 ampere-hours.

For the sake of uniformity, the rating of the capacity of accumulators is made on the basis of a discharge current which will cause the E. M. F. to fall to 1.8 volts in 10 hours, although most manufacturers give tables showing the comparative capacity of the various sizes of cells at other rates of discharge.

**2747.** The *rate* of charge (charging current) for accumulators of this class should be about the same as the normal (10-hour) discharge rate, although much smaller currents, continued for a proportionately longer time, may be used.

**2748.** Although "storage-batteries" do not store *electricity*, they certainly do store energy by converting the *kinetic energy* of the electric current into *chemical potential energy*, which may be realized as kinetic energy again. The *efficiency* of the accumulator (or of any other means of storing or transforming energy) is the *output* divided by the *input*. This quotient is always less than 1, as the accumulator is not a *perfect* storer of energy; that is, there are certain losses in the transformation of kinetic electrical to potential chemical energy, and *vice versa*, besides the loss of the energy required to force the current through the cell, that is, the loss due to the resistance of the plates and electrolyte.

**2749.** The input and output of an accumulator may be expressed either in ampere-hours (the *quantity* of

electricity) or in watts (the *rate of doing work* of the current). If secondary cells of this class be fully charged at normal rate, after a discharge to 1.8 volts, and then discharged to the same point, also at normal rate, the *ampere-hour efficiency* will be ordinarily from .87 to .93, or 87% to 93%. If charged and discharged to the same point at very slow rates, this efficiency may rise to 96% or 97%.

**2750.** The *watt efficiency* at normal rates of charge and discharge is lower, being from 65% to 80%, depending on the construction of the cell. In larger cells of modern construction, the watt efficiency is as high as 84%.

**2751.** The cause of the loss represented by the foregoing figures is, for the ampere-hour efficiency, due to the fact that the charging current must perform several chemical decompositions, of which the elements either do not recombine in the cell or, recombining, do not give up their potential energy in the form of electrical energy. This loss varies with the rate of charge and discharge, as indicated by the figures given, but for a given rate it is practically fixed, the mechanical arrangement of the cells having little effect upon it.

**2752.** The greater loss shown in the watt efficiency figures is due to the fact that the E. M. F. of charge is higher than that of discharge, due in part to the E. M. F. required to perform the wasteful chemical actions referred to above, but largely to the drop in volts caused by the passage of the current against the resistance of the plates and electrolyte. This drop *adds* to the E. M. F. required to perform the chemical decomposition in charging, and *subtracts* from the E. M. F. due to the chemical recompositions, and its amount depends more on the construction of the cell than does the loss represented by the ampere-hour efficiency, as it varies with the shape and size of the plates, their distance apart, their state of charge (on account of variations of the resistance of the electrolyte as the percentage of acid varies) and other conditions.

This loss due to the internal resistance in well-designed

cells usually amounts to about 8%, at normal rates of charge and discharge; the loss is correspondingly less at low rates and more at high rates, being proportional to the *square* of the current flowing.

In a good modern cell exposing about 1,100 sq. in. of positive plate surface, the internal resistance is about .005 ohm when charged. Cells of greater capacity than the above (which is listed as 350 ampere-hours) would have a proportionately lower resistance.

**2753.** The above efficiency figures, as stated, are given for a discharge to 1.8 volts E. M. F., the usual manufacturers' rating; if the cells are not discharged to so great an extent, both ampere-hour and watt efficiencies are higher.

**2754.** The E. M. F. required to send a given charging current through a secondary cell varies with the state of

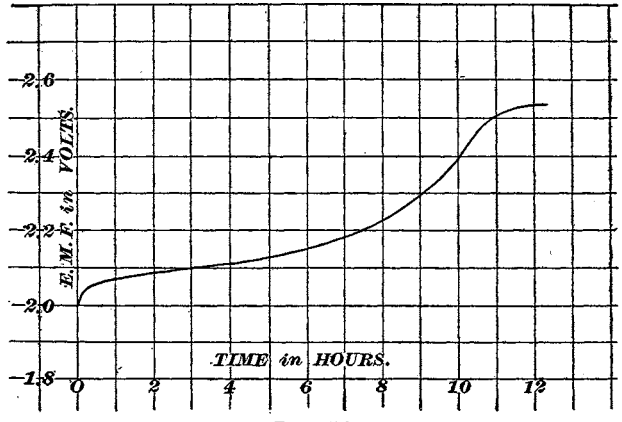


FIG. 1056.

charge of the cell. Fig. 1056 shows the E. M. F. required to charge the same cell that gave the discharge E. M. F. curve (Fig. 1055), being in this case charged at the same rate as previously discharged.

This curve shows that the charging E. M. F., after a quick rise in the first few minutes to about 2.06 volts, gradually rises during the first 6 or 7 hours, after which the rise is more rapid, until after 11 hours of charging it becomes

2.5 volts; at this point gasing begins and the cell is practically charged. On continuing the charging current, the E. M. F. rises a little more, and then remains practically constant at about 2.55 volts; as the only action which now takes place is the decomposition of the electrolyte, giving off gas, further charging would only result in a waste of energy; although long-continued overcharging at a moderate rate will gradually remove any formations of white sulphate that may exist. (See Arts. **2734** and **2736.**)

**2755.** From this curve it appears that the cell became completely charged in practically 11 hours; as the discharge curve (Fig. 1055) shows that with the same number of amperes the discharge is complete (to 1.8 volts) in 10 hours, the *ampere-hour efficiency* of this cell is $\frac{10}{11}$, or 91%, practically.

**2756.** If an accumulator of this class is not discharged at an excessive rate nor to more than 1.9 volts E. M. F., the positive plates should last for about 1,200 or more discharges; while if discharged each time to below 1.8 volts, or at excessive rates, the life of the positive plate will not ordinarily be more than 400 or 500 discharges. The negative plates, with good care, will usually outlast four or five positive plates.

Some of the more modern cells of this class will show better results than the above, which, however, are good average figures.

**2757.** The usual construction of cells of this class is as follows:

The plates and electrolyte are contained in a vessel of approximately cubical form; this vessel is of glass, if the cells are not intended to be portable, the glass allowing the examination of the condition of the plates while the cell is in operation. If the cells are intended to be portable, the vessel is usually made of hard rubber or gutta-percha, or of wood lined with hard rubber or lead. Very large accumulators for central-station use are usually set up in lead-lined wooden tanks.

**2758.** The plates are usually approximately square, and from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick, according to size. To get a large surface area without using single large plates, and to allow of one size of plate being used for cells of various capacities, each cell contains a number of positive and negative plates, arranged alternately side by side a short distance apart. The number of negative plates is always one more than the number of positive plates, so that *each side* of each positive plate has presented to it the surface of a negative. All the positive plates are connected together by a connecting strip, usually at one corner of the plate, and all the negatives are similarly connected. The arrangement of a typical accumulator cell is represented in Fig. 1057, where $N, N, N, N, N$ are the negative plates and $P, P, P, P$ the positive. From a corner of each plate a lug projects; the lugs on the negative plates are joined to a connecting strip, as represented at $T$, and the lugs on the positive plates are similarly joined to a connecting strip $T'$. The joints are made by a process called "burning," which consists in melting the lugs and strip together by a flame of hydrogen. This hydrogen flame absorbs the oxygen from the film of lead oxide with which the lead is usually covered, thus making a clean and solid joint. These connecting strips are extended beyond the limits of the cell, and serve to connect the various cells of the battery together, as shown at $C$, the connection being made by a brass bolt, which clamps the connecting strips together firmly.

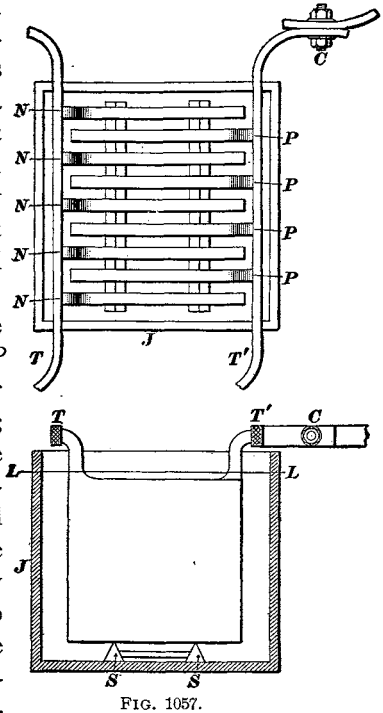

FIG. 1057.

**2759.** The plates are placed in the jar *J*, resting on a wooden support made from two strips of wood (usually boiled in paraffin) of triangular section *S*, *S*. These support the plates at such a height that any loosened particles of active material fall below the level of the bottom of the plates, thus preventing possible short-circuiting. When in position, the electrolyte is poured in until it reaches the line *L L*, thus covering the plates. To prevent the plates from touching each other, it is usually the practice to separate them by blocks or strips of insulating material, the exact arrangement varying with the different manufacturers.

**2760.** Owing to the expense of *forming* the plates by the Planté process, cells of the construction invented by Faure, known as "pasted plate" cells, have been very extensively used. Those principally used abroad are known as the *Faure-Sellon-Volkmar* cells, from the company owning the principal French patents.

**2761.** Sections of the grids principally used by this company are shown in Figs. 1058 and 1059. The first is cast of lead alloyed with a little antimony to give stiffness

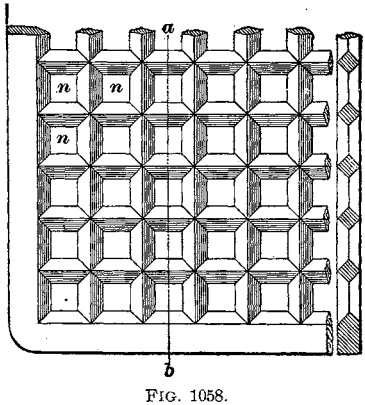

FIG. 1058.

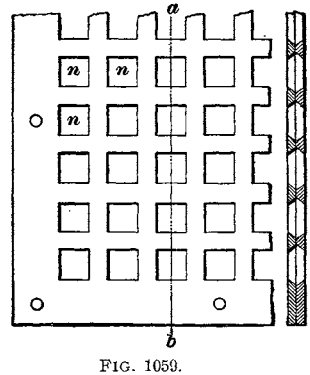

FIG. 1059.

to the grid, and oxide paste is forced into the openings in the grid (*n*, *n*, *n*). The section, taken at the line *a b*, shows the shape of these openings.

**2762.** The second grid is made of two plates cast separately and afterwards riveted together with lead rivets. In this grid, as shown by the section, the openings for the paste (*n*, *n*, *n*) are larger in the center of the plates than at the faces, thus securely holding the plugs of active materials.

**2763.** Grids similar to those shown in Fig. 1057 are used in the E. P. S. accumulator in England and in the cells made by the Electric Accumulator Co., the Julien Co., in the United States, and by other manufacturers.

**2764.** In Germany, where the accumulator has been most extensively employed, more complicated forms of grids are used. One of these is shown in Fig. 1060; it consists of

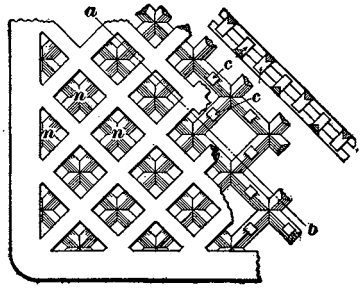


FIG. 1060.

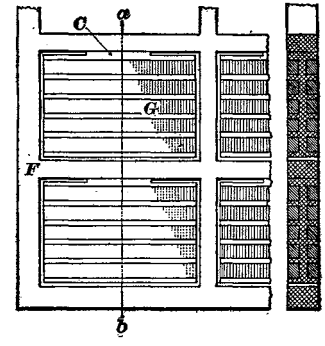


FIG. 1061.

a double lattice united at the edges of the plate, and kept at a little distance apart, as shown in the section, by small columns at the points where the members of the two lattices cross, as represented at *c c*. This plate is cast at one operation. This form of plate holds a large quantity of active material, and is quite stiff. Even more complicated grids are used, some consisting of three layers of lattice-work, separated by columns, as in the grid just described.

**2765.** Fig. 1061 represents a section of the **Tudor** grid, a form of pasted-plate grid which has many good features; it is composed of a number of small square or rectangular grooved grids *G*, about 6 inches square, with

the active material pasted or forced in the grooves as in the ordinary form (see section, Fig. 1061). Six or more of these small grids are then fastened by a lug on one edge, as at *C*, to the bars of a cast lead supporting frame *F*, which has openings between the bars slightly larger than the small grids which they enclose. The small grids are thus free to expand or contract without interfering with the plate as a whole, thus preventing to a large extent buckling and disintegrating of the plate, and any damaged grid may be replaced without disturbing those remaining.

**2766.** Accumulators employing this form of grid are largely used in central stations in Germany, and also form one of the largest accumulator installations in the United States, that of the Edison Electric Illuminating Co., of Boston, Mass., which consists of two sets of 70 cells each, each set having a capacity of about 3,500 ampere-hours. Other forms of grids are also made by the same company, and are also known as Tudor grids.

**2767.** Fig. 1062 illustrates the grid used in the **Sorley** cell, made in the United States. It is made of strips of lead *s*, *s*, *s* of uniform width and thickness, which are bent into the shapes shown, and are held in place by other strips around the edge of the plate. These strips are led out at the upper edge to form a terminal. The oxide paste is forced into the openings between the strips at *n*, *n*, *n*, as in the cast grids. The advantage claimed for this type of grid is that it allows of free contraction and expansion of the active material.

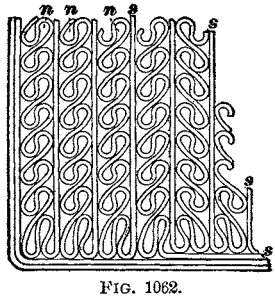

FIG. 1062.

**2768.** A form of grid which is cast around the plugs of active material is represented in Fig. 1063. This grid was invented by **Reckenzaun** for use in street-car propulsion; the active material is prepared in cylindrical plugs,

shown at *c*, which are laid in a corrugated mold, and the melted lead alloy poured in around them. They are thus held quite firmly in place, while exposing a considerable surface to the electrolyte. As can be seen from the section, taken along the line *a b*, the cylindrical form of the plugs holds them in place, even if the plate be bent considerably.

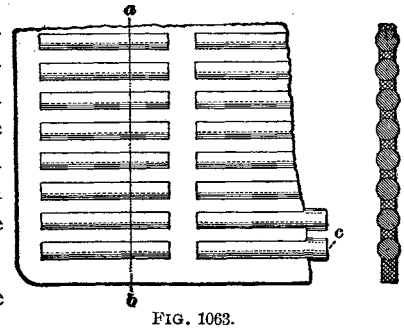

FIG. 1063.

**2769.** None of the pasted-plate cells, however, is as substantial as those in which the active material is formed from the plate itself, as in the Planté cell.

The principal objection to the Planté process being the length of time required to alter the surface of the plates from a smooth to a spongy condition, attempts have been made to construct plates which are porous at the start, such as compressing lead dust, or fine threads of lead made by blowing a stream of air through melted lead, etc., deeply grooving or even slitting the plates to increase the surface; none of these processes has resulted in a plate which is substantial enough for commercial use.

**2770.** A form of cell in which it is claimed the plates combine the cheapness of preparation of the pasted plate with the greater solidity and longer life of the Planté plate is the **chloride** accumulator made in this country by the Electric Storage Battery Co., of Philadelphia.

**2771.** The plates of this type of cell are made as follows: A mixture of zinc chloride and lead chloride is melted and run into molds, which form it into cylindrical pellets or pastilles, which have a bevel $\wedge$ shaped edge, being thus larger in the center than at the faces. These pellets are placed in a second mold, being held in position by steel pins, and an alloy of lead and antimony is melted and forced in between the pellets under heavy pressure. When this

cools it forms a plate, binding all the pellets of zinc and lead chloride together.

**2772.** This plate can not be used in this form in an accumulator; a number of these are first set up in a bath of dilute zinc chloride with plates of zinc, to which the lead plates are connected. These plates then act as the elements of a primary battery, and the resulting chemical action dissolves out the zinc chloride from the pellets, and converts the lead chloride into metallic lead, which assumes a crystalline form. The plate is now practically a continuous lead plate, solid and dense in some parts and porous in others.

**2773.** The plates in this condition are suitable for negative plates; those required for positive plates are then set up with plain lead plates in a bath of dilute sulphuric acid, and a forming current sent through them from the prepared plates to the plain.

This current causes the porous parts of the plates to be formed into lead peroxide and sulphate; the plate is now the equivalent of a pasted plate, and is an improvement through having its active material firmly bound in place in the compressed grid. Fig. 1064 shows a part of one of these plates; the section, taken along the line *a b*, shows the shape of these plugs. The holes in the plugs are caused by the pins by which they are supported in the mold.

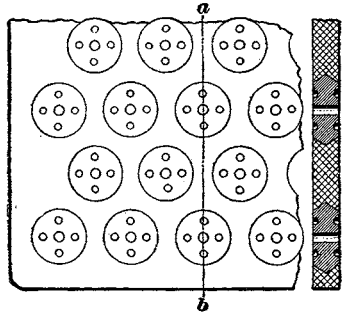

FIG. 1064.

**2774.** The requisite number of these prepared plates are then set up together to form a cell, alternate positives and negatives being connected to common conductors, as in other types of cells. (See Fig. 1057.)

The plates are each surrounded by a sheet of asbestos paper, and are separated from each other by a thin wooden

strip so thoroughly perforated with large holes that it really fills little of the space between the plates; this wooden strip serves as a distance-piece, keeping the plates a certain fixed distance apart.

**2775.** The E. M. F. and action of this form of accumulator are the same as that of the Faure (pasted) type or the Planté. It is claimed by the manufacturers that, from the solidity of the construction, buckling and loosening of the active material are practically impossible, so that the cells may be discharged to a low E. M. F. or at high rates without serious injury. Its output per pound of element is greater than that usually assigned to lead accumulators, being about 5 ampere-hours per pound of plates (both positive and negative) at normal discharge rates.

**2776.** Most of the larger installations of accumulators in central stations in this country have been of this type of cell, and they are in use in France on street-cars, and also in England. The majority of German installations are of the pasted-plate type.

**2777.** There are, as in primary cells, a great number of forms of accumulators in use, both of the Planté type and the Faure; they differ from those described only in details of construction, such as the arrangement of the plates, vertically or horizontally, the form of the grids, etc., and need not be described here.

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## BIMETALLIC ACCUMULATORS.

**2778.** In this class of cells the elements consist of two different metals, the electrolyte being a salt of one of the metals.

There have been several combinations of materials proposed for cells of this type, but the only cells which have actually been used to any extent are the zinc-lead, copper-lead, and copper-zinc cells.

**2779.** The zinc-lead cell usually consists of plates of zinc and lead in a solution of zinc sulphate. On sending a

charging current through this cell (the zinc being the negative plate) the zinc sulphate is decomposed, depositing zinc on the zinc plate and forming free sulphuric acid with the hydrogen of the water, which is also decomposed, its oxygen uniting with the lead plate, forming peroxide of lead. On open circuit and while charging, the free sulphuric acid in the solution slowly attacks the deposited zinc, reforming zinc sulphate, so that the efficiency of this form of cell is low, and it will not retain a charge more than a few days. The E. M. F. is high, being about 2.35 volts.

**2780.** The more modern forms of this cell employ a tinned-iron plate, amalgamated, or a lead plate, in place of the zinc plate. On charging the cell the zinc is deposited on the surface of the tinned-iron or lead plate, where it acts as the negative plate on discharge. (See Art. **2726.**)

**2781.** By substituting copper sulphate for zinc sulphate, and copper plates for the zinc or other negative plates in this type of cell, the acid formed during charge can not attack the copper, so that this loss is obviated; the E. M. F., however, is but 1.25 volts under these circumstances, so the watt output is materially reduced.

**2782.** Owing to the variations in the composition of the electrolyte, the internal resistance of cells of the types before described is variable, being lowest when charged and increasing during discharge as the sulphuric acid forms sulphate of copper or zinc.

**2783.** The copper-zinc accumulators are in greater commercial use than the other forms of bimetallic cells, the best known being the **Phillips-Entz** accumulator, which was made by the Waddell-Entz Electric Company. This accumulator employs the same active materials as the Lalande-Chaperon or Edison-Lalande primary cell (see Arts. **2683** and **2684**), modified in mechanical construction to adapt them for accumulator use.

**2784.** The positive plate is made of porous copper on a solid foundation, prepared in the following manner: A

copper wire is surrounded with a paste made of finely ground copper oxide and sulphur; around this is woven a netting of fine copper wire, and the whole is then heated nearly to red heat, which causes the sulphur to unite with the oxygen of the copper oxide and pass off as gas, leaving the copper on the central wire in a very porous state. This cable is covered with a thin layer of loosely woven cotton thread, which forms a porous partition, and is then wound or braided into a mat or plate, forming the positive plate, the negative plate being a thin sheet of steel, thoroughly amalgamated; a number of these plates are mounted, alternately positive and negative, in a jar made of sheet steel, and surrounded by the electrolyte, which is a solution of *potassium zincate* and *potassium hydrate.* (See Arts. **2683** and **2689.**)

The jar is covered with an air-tight steel cover, to prevent the carbon dioxide (carbonic acid gas) in the air from coming in contact with the potassium hydrate solution; this cover is provided with a gas-valve or allow the gases formed in the cell to pass off.

**2785.** On charging the cell as thus constructed, the chemical reactions are complicated, but result in the deposition of the zinc from the potassium zincate on the steel plate and the sides of the jar, and the oxidation of the porous copper. On discharge the action is the same as in the Lalande-Chaperon primary cells; that is, the zinc is dissolved, the potassium zincate is reformed, and the copper oxide reduced to metallic (spongy) copper.

**2786.** The efficiency of this type of accumulator is about the same as that of the lead accumulators, while its output is very much greater, weight for weight, the ampere-hour output being about 5 times that of a lead cell, or about 20 ampere-hours per pound of plates. The E. M. F. of this form of accumulator being much lower than that of the lead accumulator, averaging 0.75 volt during discharge, the comparison on a basis of watt output is not so favorable; still, the zinc-copper accumulator will show an output of about 15 watt-hours per pound of plates, while the less

accumulators seldom exceed an output of from 7 to 10 watt-hours per pound of plates, the latter figure being seldom reached at normal rates of discharge.

**2787.** The efficiency and internal resistance of the copper-zinc accumulator vary quite largely with the temperature, on account of the considerable variations in the density of the electrolyte; on this account the cells are ordinarily charged and discharged at a temperature of about 54° C. (130° F.), at which point the resistance is about the same as in a similar lead accumulator.

**2788.** These cells are not much affected by the rate of discharge, there being no such occurrence as sulphating or buckling; but on account of the difficulty of depositing the zinc in a solid form, the charging must be done at a slow rate, and the action of the cells is improved by intermittent charging. The E. M. F. required to charge one of these cells varies from 0.90 volt at the start to 1.05 volts at the finish.

**2789.** In spite of the porous partition (cotton thread) which surrounds the positive plate, local action is liable to occur, on open circuit, so that these cells will not retain their charge for more than a few days, while a lead accumulator will scarcely lose 25% of its charge in as many months.

**2790.** On account of these features the copper-zinc accumulator can be successfully used only in installations where it is charged and discharged daily, thus preventing local action, and when it can have the necessary appliances, care and attention in charging, to insure proper charging rate, temperature, etc.; so, in spite of its large output per unit of weight, it can hardly come into general use. However, for traction work, that is, for use on street-cars and other vehicles in constant use, where the accumulators must be able to stand variable and very frequently heavy discharge rates, and must also be as light as possible, this form of accumulator possesses especial advantages, and is, con-

sequently, better suited to the work than the lead accumulator.

**2791.** Other forms of bimetallic accumulators have been proposed, and in some cases used, among which may be classed several forms of primary cells, such as the Daniell, Leclanche, and others, which may be "regenerated" by passing a current through them; these have never been of commercial value, and do not require further attention.

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## THE USES OF ACCUMULATORS.

**2792.** In central stations furnishing electric current for lighting and other purposes, the demand for current varies very largely at different periods in the day; for example, a lighting station in a large city would probably be called upon to furnish, from 7 to 8 P. M., 10 times the amount of current that was required from 7 to 8 A. M., and in smaller stations the disproportion is even greater. As economy of operation demands that the engines and dynamos be worked at or near their full capacity, especially if the engines be compound or triple expansion, these conditions can both be met only by dividing the machinery into a large number of small units, or by having some system of storage of the electrical energy. In the first case, the small units require more attention, and are much less efficient than larger ones, and most modern large stations have their machinery divided into a few large units, employing large compound or triple-expansion engines.

**2793.** In these stations accumulators are being introduced on a large scale, and are installed according to one of two plans, as follows:

1. The dynamos and engines are not capable of carrying the full current required at certain parts of the day, for example, in the evening, but are of a size sufficient to furnish the current for the *average* rate required during the 24 hours. In this case, accumulators are installed which have a capacity sufficient to furnish the required excess of

current over the average. At times when the output of the station is less than the average rate, the current is used to charge the accumulators, thus keeping the output of the engines and dynamos at its maximum, which is the condition of greatest economy in operation. On account of the loss in charging and discharging the accumulators, the machinery must really have a capacity slightly greater than the average output of the station; but in any case the total amount of machinery, including engines, boilers, and dynamos, that must be installed is far less than if accumulators were not used, as in such case the total capacity of the machinery must evidently equal the maximum output of the station.

2. The second plan is to install accumulators of sufficient capacity to furnish all the current of the station for a part of the day when the output is less than the average; in this case, the engines are shut down for a considerable part of the day, the accumulators furnishing the entire output of the station during this time; when the demand for current begins to increase, the machinery is started up, and then furnishes the entire output of the station for the balance of the day, charging the accumulators when the station output is less than the capacity of the machinery. In this case the capacity of the accumulator plant is relatively less than in the former, and as the cost of accumulators is high, this may cause a saving over the first plan, although the mechanical efficiency of the station may be somewhat lower than in the first case.

**2794.** The result of applying accumulators to a large station is shown in Figs. 1065 and 1066. In both, the continuous line represents the actual output in amperes of a certain large station in New York, for a certain day.

**2795.** If this station were designed to use accumulators according to the first plan, the result would be about as represented in Fig. 1065. Here the dotted line represents the output of the dynamos (in amperes); the difference between the ampere output of the dynamos and that

of the station is either absorbed or given out by the accumulators, as the station output is less or greater than the dynamo output. From the curve it appears that the accumulators are absorbing current (that is, being charged) from about 11.45 P. M. to about 4.30 P. M. (of the next day), while during the balance of the 24 hours the accumulators are giving out current, that is, discharging. The output of the dynamos is nearly constant, at about 850 amperes, the

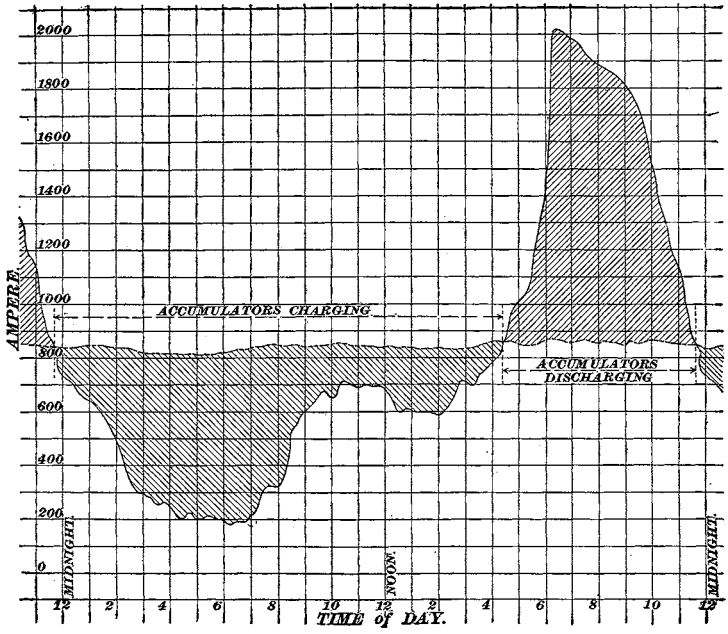


FIG. 1065.

output for the 24 hours being about 20,400 ampere-hours. The output of the station is 20,000 ampere-hours, the *average* output being about 835 amperes. This shows a loss in charging of 400 ampere-hours, which, allowing for slight overcharging, etc., is about right, as the capacity of the accumulator plant is 5,000 ampere-hours, about. This station would probably have installed three dynamos, each of about 450 amperes output, two of which would be kept running

all the time. To allow of cleaning, inspection, etc., one machine would be replaced from time to time by the machine which had been previously idle, so that all three machines would come in for an equal amount of work. In case of accident to one, the other two would be kept running until repairs were made; the accumulators would then furnish the current for such brief shut-downs of the dynamos as would be necessary if made at periods of light load.

**2796.** If the accumulators were installed according to the second plan, the output curve would be represented by Fig. 1066. Here all the dynamos would be shut down from

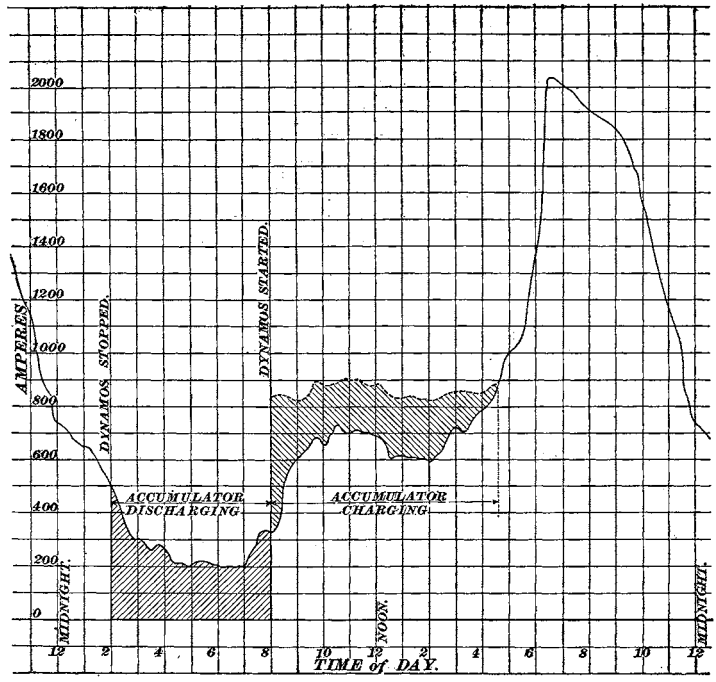


FIG. 1066.

2 until 8 A. M., the previously charged accumulators furnishing the output of the station during that time. At 8 A. M., in this case, the dynamos would be started, supplying both

the output of the station and sufficient current to recharge the accumulators. When the accumulators are fully charged, they are disconnected from the circuit until required the next day. In this case, this is done at about 4.40 P. M., the output of the station from this time being furnished by the dynamos, more being connected in circuit to furnish the extra output during the evening. In this particular case, the station would probably have installed five dynamos, each of a capacity of about 500 amperes; two of these would be of sufficient capacity to run the station from 8 A. M. until about 5 P. M., at which time two more would be switched in; the first two would then be shut down when the output was reduced sufficiently to permit; in this case one would be shut down at about 10 P. M. and the other at about 11.30. The extra dynamo is provided to use in case one of the others becomes disabled. The station output is, as before, 20,000 ampere-hours; the dynamo output is about 20,150 ampere-hours,the loss in charging being 150 ampere-hours. The capacity of the accumulator plant, in this instance, is evidently much smaller than before, being but about 1,600 ampere-hours; the dynamo plant is rather more than proportionately larger, as the machines do not run under so uniform a load as in the previous case.

In this arrangement the dynamos do not operate quite so economically as in the first, but the accumulators operate more economically, being charged and discharged at fairly uniform rates, while in the previous case the accumulators are discharged at a more rapid rate than they are charged, and the *maximum* discharge rate is much higher than the *average*. This either results in a short life for the accumulators, consequently a high allowance for depreciation, or necessitates a larger accumulator plant than the output in ampere-hours would seem to require, which makes the first cost high; again, in the first case, the firemen, engineers, etc., would be required to be in attendance during the whole of the 24 hours, which would probably be done by having three "shifts," or three separate gangs of men, while in the second case no firemen or engineers are required during the

time (from 2 until 8 A. M.) that the engines and dynamos are shut down, so two "shifts" of men would be sufficient; hence, it would appear that for the station which gave this particular output curve the second plan of installing the accumulators would be preferable.

**2797.** Whether or not it would pay to install accumulators in any particular station depends on various circumstances, but it can generally be determined by the output curve, actual or calculated, from which may also be determined the size of the dynamos and accumulator plants, and the proper time for charging and discharging the battery, which features will vary largely in different stations.

**2798.** In railway power stations, where the wide variations in the output occur from second to second, instead of from hour to hour, as in lighting stations, accumulators would serve to greatly steady the load on the generators, acting on somewhat the same principle as does a heavy fly-wheel on an engine; the accumulators would remain at about the same state of charge continually, if properly installed, supplying current to the line when the demand for current is heavy, and absorbing energy when the demand grows light.

**2799.** Accumulators would be especially useful if the source of power was a water-wheel, since they would make the load on the water-wheel so nearly uniform that its regulation would be good, which is not the case if the load is irregular.

**2800.** Electrically operated street-cars, in which the source of the current required is a battery of accumulators, carried upon the cars, have many advantages over the trolley system, overhead or underground; the disadvantages, however, are so serious that very few commercially successful systems of this kind have been operated in this country, although several lines are running in France and in other parts of Europe.

**2801.** The advantages of this system are the absence of the overhead wires or underground conduit of the trolley roads, the complete independence of each car, and the ability of the dynamos which charge the batteries to run uniformly at their full output.

**2802.** A sufficient number of accumulators are usually carried on one car to run it about 30 miles, or for about six hours, with one charging. Such a battery weighs about 4,000 to 4,500 lb., increasing very materially the weight of the car, which ordinarily weighs, with passengers, about 10,000 lb. The power required to propel this extra weight must be provided, and the wear of the tracks and car-trucks is increased.

**2803.** In order that the cars shall not stand idle while its battery is being charged, several sets (about 3 sets to each car) are provided, which makes an expensive equipment, and the cost of handling the heavy batteries, when moving them into and out of the cars, is considerable.

**2804.** The chief disadvantage, however, is the rapid deterioration of the plates. On starting the car, and in ascending steep grades and rounding curves, the accumulators are called upon to furnish currents far in excess of their normal discharge rate, which, added to the continual jolting to which they are subject, makes the disintegration of the positive plates very rapid indeed; and only when the plants have been under the charge of skilled experts has accumulator traction been at all successful in this country.

**2805.** The Waddell-Entz accumulator would seem to be especially suited to traction work, on account of its light weight and capacity for high rates of discharge; but to operate efficiently, this accumulator must be charged and discharged under special conditions (see Art **2790**), which makes its cost of operation high.

**2806.** Accumulators have been very successfully applied to launches and other small boats, in which the propeller is driven by a suitably connected motor; the battery is

located under the seats or in lockers, and is usually of sufficient size to furnish current for running the boat at a speed of seven or eight miles an hour for about 40 miles; higher rates of speed can be obtained, but the total distance covered is then lessened.

**2807.** In general, accumulators have been more or less successfully applied (*a*) where it is desired to supply a variable demand for current and at the same time keep the output of the source of the power approximately onstant; (*b*) where it is desired to utilize an electric current at a point where it is objectionable or impossible to obtain the current directly from dynamo machines; (*c*) where it is desired to obtain a comparatively small but continuous current from a source of a considerable current, which can be utilized only a short time and at infrequent intervals, and (*d*) where a perfectly steady current is required for certain applications, where the current from dynamo machines, which is always slightly irregular, would be unsuitable.

**2808.** Under (*a*) would be classed the various lighting and power station installations, the principles of which have been described (Art. **2792**). An extension of the plan of such stations has been adopted abroad, in cases where a considerable demand for current from a (direct current) central station occurs in some particular district, at a distance from the station. It is evident that if this demand is met by sending the current directly from the station, the wires for carrying the current must be large enough to carry the *maximum* current required, although this maximum only continues for a few hours in each day. If an accumulator plant be installed in this district, the wires from the station need only be large enough to carry the *average* current required for that district, the battery furnishing the additional current during the period of heavy load and charging when the load is less than the average, just as in the first plan for installing accumulators in central stations. (See Arts. **2792** and **2793.**) Aside from the saving in the wire,

there are other advantages of this method of current distribution, which will be treated of in another section.

**2809.** Another application which comes under this same head, although carried out on a much smaller scale than the examples given, is made in places where a current of considerable strength is required only occasionally, with considerable intervals between; primary cells might be directly applied in such cases, but on account of their high internal resistance a considerable number of cells or a few very large cells would be required to furnish the necessary current, or else local action would soon render them useless; if, however, primary cells, say of the "gravity" or other type giving a constant E. M. F., be used to charge secondary cells, the charging can go on continuously day and night at a slow rate, and at any time the secondary cells may be drawn upon for a considerable current far beyond the capacity of the primary cells themselves. This method is often adopted in surgeons' offices, where a considerable current is occasionally required for heating cauteries and for similar work. (See Arts. **2712** and **2714.**)

**2810.** Under class (*b*) would be included such applications of accumulators as in propelling street-cars and small boats, the main features of which have been given. (See Arts. **2800** and **2806.**)

**2811.** Under this same head would also be classed the transporting of electrical energy by means of charged accumulators; these are usually charged at some central station, and are then carried to the point where it is desired to use the current. Thus far this has been done only on a comparatively small scale, principally for furnishing current to the motors which drive the phonographs and kinetoscopes and similar machines, which are so generally on exhibition, often in localities where electric-light circuits are not available, or are not of the right character.

**2812.** Under class (*c*) may be included several of the more important of the minor applications of accumulators,

as follows: The electric lighting of railroad-cars, the charging current for the accumulators being obtained from dynamo machines driven from one of the axles of the car, which source of power is obviously intermittent and irregular; the lighting of houses, at a distance from electric-light stations, such as country residences, where the power for driving the charging dynamos is obtained from windmills or the action of the waves or tides, which sources of power are very variable. Special devices are usually used in such plants which automatically disconnect the dynamo from the accumulators when the source of power has stopped, or is insufficient to furnish the requisite current for charging. The lighting and furnishing of small amounts of power to the offices or such other departments of mills or factories as are obliged to be in operation when the main engine or other source of power is shut down, the accumulators being charged during the day, when the main engine is running, also comes under this head.

**2813.** The amount of current required for lighting an ordinary house is comparatively little, and a very small engine and dynamo would readily furnish it; but the noise and trouble of operating such a small plant at the time when the current was required would make it objectionable. In such a case an accumulator plant may be installed, of sufficient capacity when charged to furnish the current for lighting for several days or even weeks; then, by installing an engine and dynamo of proper size, the battery may be charged once a week or month, as the case may be, with comparatively little trouble and expense, and the time for charging may be chosen so that the noise or other features would not be objectionable. Such a plant would be classed under this same head, (*c*).

**2814.** Under (*d*) would be classed the special application of accumulators in testing and in telephone work. Their action, as regards the steadiness of the current, is no more favorable than that of a good primary cell; but for a given output the accumulator is more compact, requires less at-

tention, and its elements do not need to be replaced when exhausted, but renewed by a charging current. Consequently, accumulators are coming into use for telephone central stations, where three or four good-sized cells may replace several hundred primary cells; they are usually installed in conjunction with suitable charging apparatus, usually small dynamos, the operation of charging being gone through with whenever necessary.

**2815.** The specific applications of accumulators cover many more cases than have been given; but they may be all classed under these several heads.

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## THE INSTALLATION OF ACCUMULATORS.

**2816.** As stated in Art. **2757,** accumulators are usually of approximately cubical form, and the jars are usually of glass or hard rubber, in ordinary sizes; for special applications, such as portable cells and batteries for street-car and launch use, special jars are provided to suit the conditions. For ordinary installations for lighting purposes, the glass jar is best suited, as it permits the examination of the interior of each cell at any time, and any cells in which the active material shows signs of buckling or disintegrating may be attended to before the fault becomes serious.

**2817.** Accumulators should be placed on racks or shelves, and if the number of cells be large, it is usually advantageous to place them in several tiers. Plenty of room should be allowed between the tiers, to allow of making connections, taking out or replacing plates or the electrolyte, etc.

**2818.** If the cells are located in a room where the air is warm and moist, water will collect on the surface of the jars and shelves, and will cause an appreciable leakage of the current; to obviate this, each cell should be supported on a small shelf, which should rest on porcelain or glass insulators, and the jars of adjacent cells should not be allowed to touch.

**2819.** If exhaust steam is to be had for heating purposes, a double line of pipes, running under the shelves on which the cells rest, will be beneficial, as the heat will cause a circulation of the electrolyte, and will decrease its resistance. Such an arrangement is very necessary for cells of the Waddell-Entz type (see Art. **2783**), but for ordinary lead accumulators the advantage is not sufficient to warrant any great outlay for such heating.

**2820.** The space to be allowed for a battery depends on the make and type, and may usually be found in the catalogues of the manufacturers. Lead accumulators of ordinary size will usually have a capacity of 2.5 to 4 ampere-hours per square inch of floor space that they occupy; for large accumulators in lead-lined boxes, such as are installed in central stations, this value may be increased to 5. A good average figure for cells of 200 to 500 ampere-hours capacity is 3 ampere-hours per square inch of floor space occupied.

The output per cubic inch of volume is rather more constant, being about .25 to .3 ampere-hour. The weight of a battery of accumulators is considerable, and the shelves or other supports intended to hold them should be made amply strong, for if they sag or bend, the glass jars are liable to be broken.

**2821.** The electrolyte of an accumulator will not freeze until exposed to a temperature of about — 11° C. (about 13° F.); freezing should be avoided, as it is very liable to break the jars.

**2822.** The number of cells required for any given installation depends upon the E. M. F. desired; ordinary lighting plants are usually designed for an E. M. F. of 50 to 55 or 100 to 120 volts. The number of accumulators required may be found by dividing the E. M. F. required by the average E. M. F. of the cell during discharge, which is usually taken (for lead accumulators) as 1.9 volts; a 55-volt installation would then require $\frac{55}{1.9} = 29$ cells (obviously, fractional cells are an impossibility).

**2823.** When only partially discharged, the E. M. F. of such a battery would be higher than that required; this may be reduced by placing a suitable resistance in series with the battery, and adjusting this as the E. M. F. diminishes, to keep a constant E. M. F. at the lamps, or arranging the connections so that one or more cells may be cut into circuit from time to time, to effect the same result.

Manufacturers of electrical apparatus furnish devices which will automatically perform the above operations as the E. M. F. of the battery changes.

**2824.** To allow for possible accidents to one or more cells, and for the drop in the wiring and connections, one or two extra cells may be provided, and so arranged that they may be cut into the circuit at any time.

**2825.** The size of each cell in such an installation depends upon the strength of the current which it is desired to use, and the length of time (number of hours) the current is required; thus, to furnish a current of 10 amperes for 10 hours with one charging would require cells of a capacity of $10 \times 10 = 100$ ampere-hours each.

**2826.** The current required for operating incandescent lamps, the average number of hours per day that they are lighted, etc., will be treated of later, and from the values given, the size and number of accumulators which should be installed to furnish the current for lighting a building may be determined.

**2827.** The method of procedure in setting up the ordinary forms of cells is about as follows:

Having prepared the shelves or supports for the cells, unpack and thoroughly clean the jars, and place them in position on the shelves, with the support for the plates (*S*, *S*, Fig. 1057) in place. The plates should then be thoroughly cleaned of the sawdust in which they were packed, and placed in position in the jars. They should rest evenly on the supports which raise them from the bottom of the jar, and the blocks or strips of insulating material which

separate the plates should be properly placed in position between them. In some makes of cells pieces of rubber or glass tubing are used for this purpose.

**2828.** The plates should be so placed in the jars that the connecting strips will come into the proper position for connecting the positive plates of one cell to the negative of the next, and so on.

The joints between the connecting strips should then be made bright and smooth, for which purpose a fine file or sandpaper is best; the connecting bolts should be set up with a good pressure, so that these bright surfaces will be squeezed together firmly, insuring good contact.

**2829.** The electrolyte should be prepared in a lead-lined or stoneware tank, and the sulphuric acid should be slowly poured into the water and thoroughly stirred until the solution is of the proper density (1.17 sp. gr.). It is well to note that water should never be poured into sulphuric acid; as the two liquids combine with considerable heat, the small quantity of water which first reaches the acid is instantly converted into steam, resulting in an explosion, which, by scattering the acid about, is liable to cause serious injury. Therefore, in preparing the electrolyte, *always pour the acid into the water.*

In case a considerable quantity of solution is to be prepared, blocks of *pure* ice (manufactured ice is best) may be used in place of water. The heat generated by the dilution of the acid is then absorbed in melting the ice.

**2830.** When all connections are made and preparation for charging completed, the electrolyte should be poured into the cells until the plates are covered to a depth of half an inch or so, and as soon as possible thereafter the cells should be charged. If allowed to stand uncharged in the acid, the plates are liable to become sulphated (see Art. **2736**). Care should be taken that the charging current is of the right polarity; that is, that the current flows *from* the positive *to* the negative plates through the cell; if this is reversed, the cells will be reversed, and a great deal of

trouble will be experienced in getting them back to the proper condition.

The first charging should be long continued and at a low rate, to remove any sulphate that may exist.

**2831.** In charging an accumulator, as has been shown, only a small part (about 8%) of the E. M. F. required to force the current through the cell is expended in overcoming the resistance of the plates and electrolyte; the remainder is expended in overcoming the E. M. F. of the chemical action of the cell. It follows, then, that if the *applied* E. M. F. be just equal to the E. M. F. of the cell no current will flow (see Art. **2504**), so that the E. M. F. of the cell itself may be considered as a *counter* E. M. F., opposing that of the charging current. To apply Ohm's law $\left(C = \frac{E}{R}\right)$ to this case, the $E$ must be considered as representing the *algebraic sum* of the applied and the counter E. M. F., or $E$ = applied E. M. F. − counter E. M. F. This is merely another way of stating that the E. M. F. *required to drive the charging current through the cell* is only that required to overcome its ohmic resistance; but to this must be added an E. M. F. equal and opposite to the E. M. F. of the cell itself, due to the chemical affinity of the substances of which it is composed.

In charging, then, if from any cause the E. M. F. of the charging current be changed by a small amount, the charging current will be altered in a much greater degree, depending on the ratio between the applied E. M. F. and the difference between the applied and counter E. M. F. For example, consider a cell which has been discharged until its E. M. F. is 1.925 volts (on open circuit). The resistance of the cell is .005 ohm and its normal charging current is 35 amperes. The drop due to this current is $35 \times .005 = .175$ volt; the applied E. M. F. must then be $1.925 + .175 = 2.10$ volts, to cause 35 amperes to flow. Now, if the applied E. M. F. drops to 2.0 volts, it is evident that, the counter E. M. F. being the same, the drop is equal

to $2.0 - 1.925 = .075$ volt, and the current which would cause this drop when flowing against .005 ohm resistance is $C = \frac{E}{R} = \frac{.075}{.005} = 15$ amperes. Thus, a drop in the applied E. M. F. of $\frac{.1}{2.1}$, or about 5%, causes the current to fall off more than 50%.

This shows the necessity for having the source of the charging current so arranged that the E. M. F. may be closely adjusted in order that the charging current may be maintained at its proper value.

In all accumulator plants of any considerable capacity the source of the charging current is a dynamo, and the methods of attaining this adjustment therewith will be given later. In any case, the maximum E. M. F. of the source of the charging current must be higher than the highest counter E. M. F. that the battery can give.

**2832.** With every accumulator plant a *hydrometer* (see Art. **995**) should be included, as the electrolyte should be kept at the proper density. The state of charge of the cell can be approximately determined by the density of the electrolyte (see Art. **2737**).

**2833.** The volume of the electrolyte will gradually diminish during the operation of the cell, due to evaporation and to the evolution of gas when the cell is charged; this loss should be made up by occasionally adding pure water, or acid, if the density as indicated by the hydrometer is too low.

**2834.** A portable voltmeter should also be provided, which shall have a capacity such that the E. M. F. of a single cell may be accurately measured, so that if the action of any cell seems to be irregular, its condition may be determined by measuring its E. M. F. and comparing it with that of the other cells. Some instrument makers furnish portable voltmeters with two scales, one a tenth or a twentieth the value of the other; these are very convenient for accumulator work, as by selecting the proper scale the

E. M. F. of the entire battery or of single cells may be accurately determined.

**2835.** Accumulators should not be installed near any apparatus which has bright metal surfaces, such as an engine, as the fumes from the acid will corrode such surfaces unless they are protected by a coating of grease or varnish; all connectors and other brass pieces used around the cell should be coated with varnish or grease for the same reason. Vaseline is especially applicable for this purpose.

This effect may be largely prevented by providing the cells with covers, which also prevents evaporation to a large extent. Covering the liquid with a layer of heavy oil has also been proposed, but this plan involves a great deal of troublesome dirtiness, as the bubbling of the escaping gas causes the oil to spatter.

**2836.** The principal reason why so many accumulator plants in this country have been failures is that they have been installed without any "factor of safety"; that is, they have been made as small and as light as possible, to economize space and weight, and have been daily made to yield their entire output; that is, have been heavily charged and discharged. As has been pointed out, this leads to rapid deterioration of the positive plates, and is liable to destroy whole cells from the buckling of one or more of the plates, besides materially reducing the efficiency of the cells.

Under certain conditions, any accumulator installation whatever would not pay; but, generally speaking, *if properly installed*, an accumulator plant forms an economical and reliable means of storing electrical energy.

# APPLIED ELECTRICITY.

## TELEGRAPHY.

**2837. Electric telegraphy** is the art of transmitting intelligible signals or signs between distant points by means of electric impulses moving between those points.

Intelligence may be transmitted in this manner by audible or visible signals, or by signs, both methods being largely used.

### THE MORSE SYSTEM.

#### THE TELEGRAPH CIRCUIT.

**2838.** The instruments used on the simplest form of Morse telegraph circuit, one of each kind at each station, are a key and a sounder.

**2839.** The **key** is an instrument for manually opening and closing the circuit, for sending various combinations of long and short current impulses over the circuit.

**2840.** The **sounder** is an instrument consisting of an electromagnet and a pivoted armature, adapted to give forth sounds corresponding to the currents passing through its magnet-coils.

**2841.** The simplest form of a telegraphic circuit is shown in Fig. 1067. $L$ represents the line wire connecting the two stations $W$ and $E$; $K$ and $K'$ are keys; $B$ is a battery; $S$ and $S'$ are sounders for receiving messages; $G$ and $G'$ are points where the wire is connected with the earth, or *grounded*, as it is usually termed.

The circuit is traced as follows: When both keys $K$ and $K'$ are closed, the current starts from the plus pole of the battery $B$ and passes to the key $K$; thence through the sounder $S$ to the line, and through the sounder $S'$ and key

$K'$ at station $E$, then to $G'$ and through the earth to $G$ and the minus pole of battery $B$. The earth is commonly used instead of a return wire, and may for all practical purposes

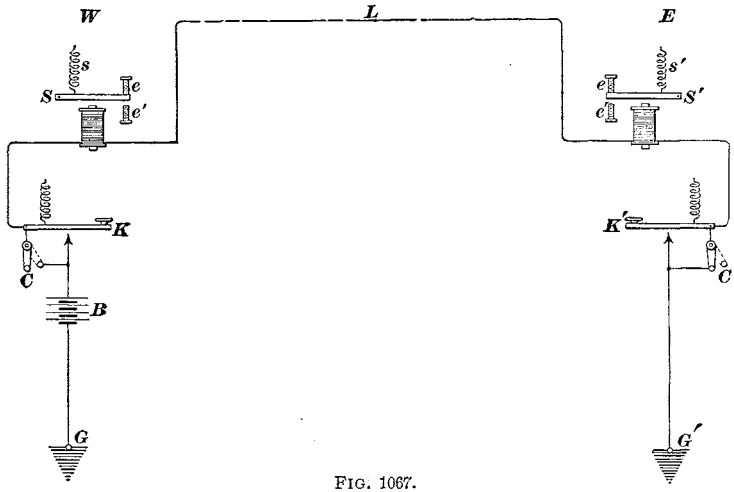


FIG. 1067.

be considered as a conductor of very small resistance, for, although it is comparatively a *poor conductor*, *its practically unlimited area renders its resistance almost nothing.*

When both keys are closed, a continuous current will flow around the circuit, so that the electromagnets of the sounders will attract their armatures. If, now, one key is opened the current will be interrupted, and the electromagnets will therefore release their armatures and allow them to be drawn upwards by the springs $s$ and $s'$. If the key be closed again, both armatures will be drawn down as before. The motions of the armatures are limited by the stops $e$ and $e'$. The downward movement of the armature causes a sound distinguishable from that made by the upward movement, and these movements are called the *down* and *up* strokes, and by certain combinations of these strokes messages are received by sound.

**2842.** When the line is not in use the circuit is left closed, and for this purpose small switches $C$ and $C'$ are

provided for every key. Closure of one of these switches accomplishes exactly the same result as depressing the key. It saves the operator the inconvenience of having to hold down his key when he wishes to leave the circuit at his station closed for some time. In Fig. 1067 station *W* is in the position for *sending* to station *E*. The switch *C* or *C'* at the receiving station must be closed, and that at the sending station open. When the line is idle, both switches must be closed. The necessity for these rules concerning the use of the switches will be appreciated by supposing that the operator at *E* has left his switch open. It will then be impossible for the operator at *W* to control the sounder at *E* at all, for no matter whether the circuit is open or closed at *W* it is open at *E*, and therefore no current can pass over the line.

### THE RELAY CIRCUIT.

**2843.** When the telegraph-line is of considerable length, it becomes difficult to render the current in it strong enough to operate the somewhat heavy armatures of the sounders. An instrument called a relay is then inserted in the line-wire in place of the sounder. The relay has a very light armature and a coil with a great number of turns of fine wire. The armature of the relay carries a contact point, which opens and closes a *local circuit* containing a sounder and a local battery.

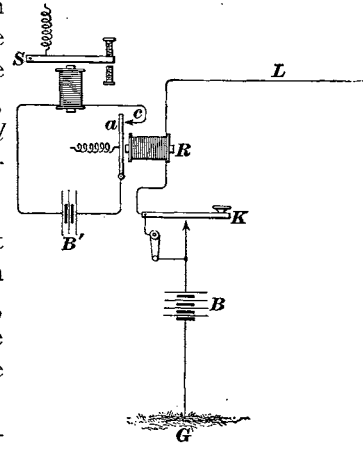

FIG. 1068

**2844.** This arrangement is illustrated in Fig. 1068, in which *R* is the relay, *K* the key, *B* and *B'*, respectively, the line and local batteries, *S* the sounder, and *G* the ground. Currents coming over the line-wire pass through the magnet of the relay and to ground in precisely the same manner as

through the sounder in Fig. 1067. The armature thus makes and breaks the circuit with its contact $c$, thus acting as a key in the local circuit containing the sounder and the local battery $B'$. As many cells of battery as are desired may be used in the local circuit, and thus the sounder may be made to produce a loud sound even though the currents in the line-wire are exceedingly feeble.

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### TELEGRAPH-INSTRUMENTS.

**2845. The Key.**—The key, as has already been defined, is the instrument for making and breaking the circuit. A form very widely used is shown in Fig. 1069, and consists of a steel lever $l$ pivoted in trunnion screws $c$, mounted in standards projecting upwards from the base-plate $m$ of brass. Locknuts $c'$ serve to bind the trunnion screws in any position to which they have been adjusted. A coiled spring $u$, the compression in which may be adjusted by the screw $y$ and locknut $y'$, serves to keep the forward end of the lever in a raised position. The upward movement of the forward end of the lever is regulated by the screw $j$ and its locknut $j'$. As the knob $x$ is pressed down, a platinum contact point $v$ carried on the under side of the key makes contact with a point of similar material carried on, but insulated from, the base $m$. This lower contact point is in metallic connection by means of strip $s$ with the binding-post $d$, which is also insulated from the base-plate $m$. The other binding-post $d'$ is connected directly to the base-plate. These binding-posts $d$ and $d'$ form the terminals of the key, and the path through the instrument may be traced as follows: From post $d$, by strip $s$, to the lower contact point; then, when the key is depressed, to the upper contact point $v$; thence by the trunnions and spring $u$ to the base-plate $m$, and to the other binding-post $d'$. The switch-handle $z$ is connected with a metallic

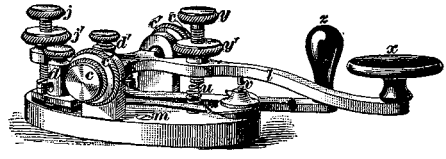

FIG. 1069.

lever pivoted directly on the base *m*, and when pressed towards the key lever makes contact with an extension of the strip *s*, thus short-circuiting the key. This switch will be easily recognized as performing the same functions as the switch *C* in Fig. 1067 and that in Fig. 1068.

**2846.** The contacts on the key are made of platinum, because of the ability of that metal to resist the corroding and fusing action of the electric arc which is always formed at the *break*. It may be well to state that the down stroke of the key is often called the *make* and the up stroke the *break*, referring, of course, to the making and breaking of the circuit.

**2847. The Sounder.**—The sounder is shown in Fig. 1070. It consists of the electromagnets having the coils *m* and *m'* and the armature *a* of soft iron, the latter mounted on a brass or aluminum lever *l* pivoted between the trunnion screws *k*. The armature is normally held in its upper position by means of the coiled spring *s* bearing down on the short end of the lever *l*, the compression of the spring being regulated by the thumb-screw *h*. The down stroke of the lever is limited by the screw *g* striking against the anvil *n*, and the up stroke by the lever striking against the screw *f*. The play of the armature can therefore be adjusted by means of the screws *f* and *g*, and after the proper adjustment is obtained it can be made permanent by the locknuts *f'* and *g'*. The binding-posts *b*, *b* form the terminals of the circuit through the coils, the current passing through them in series. The sounds given out by the sounder may be augmented by mounting the instrument on a sounding-board. The base-plate and the board *c* on which the instrument is mounted are usually constructed

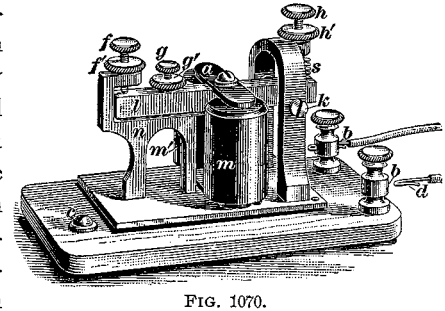

FIG. 1070.

with this idea in view. The magnets are usually wound with No. 23 B. & S. gauge copper wire when the instrument is to be used with a relay, and with No. 30 wire when the sounder is in a main circuit, in which case it is called a **main-line sounder.**

**2848. The Register.**—Fig. 1071 shows a **register,** or an instrument for automatically transcribing the signals sent by the current. Its action is similar to the sounder, as will be seen. The currents passing through the magnets *m*

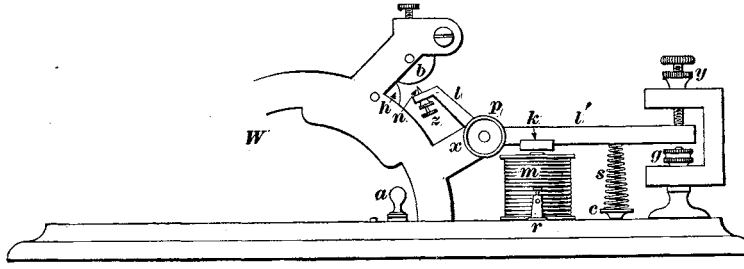


FIG. 1071.

attract the armature affixed to the lever *l'*. The travel of the lever *l'* is limited by the adjustable screws *g* and *y*. When no current passes through the magnets *m*, the compression spring *s* forces up the lever *l'* and the armature *k*. The lever *l'* is pivoted by an arbor at *p*, and has its continuation in *l*, which carries at its end a steel point *n*. The arbor and steel point may be adjusted by screws *x* and *z*; *b* is a roller against which, when a current is flowing in the magnets, the steel point *n* presses. A strip of paper passes between the rollers *h* and *b* and covers a slight groove cut around the roller *b*. The steel style *n* is adjusted just over this groove. One end of the line-wire is connected to a post *r*, while the other end is connected to a post hidden from view back of *m*. Thus the current passes only through the two electromagnets, as in a sounder. As the key is pressed at the distant station, a current flows in *m*, the armature *k* is attracted, and the style *n* makes a raised impression upon the paper. These impressions are given in dots and dashes,

which represent by their combinations the letters of the alphabet, and are determined by the length of time the key is depressed. When the circuit is open, the style is forced away from the paper by the action of spring *s*, which is adjusted by screw *c*. The rollers *b* and *h* are moved by clockwork at *W*, which is started and stopped by the brake *a*. This register, when wound with No. 30 wire, will act for a line *not more than twenty miles long*. If, however, as is usual, there is leakage in the line, or the distance is so great that the current is too feeble to influence the register, a *relay* is used in the same manner as with a sounder.

The first Morse telegraph was operated with registers of this type, but vastly more clumsy, it not being known at that time that it would be possible to receive by sound.

**2849. The Relay.**—This instrument, as has already been stated, consists of an electromagnet, which, by its action upon an armature, opens and closes the circuit of a local battery powerful enough to influence the sounder or register. The magnet must, of course, be wound with a very long and thin wire, in order that it may have a requisite number of turns to enable a feeble current to act upon the armature.

A diagram of a *relay* is shown in Fig. 1072. At *m* there are two electromagnets, which attract the armature *e* upon the lever *l* when a current traverses the coils. At the end

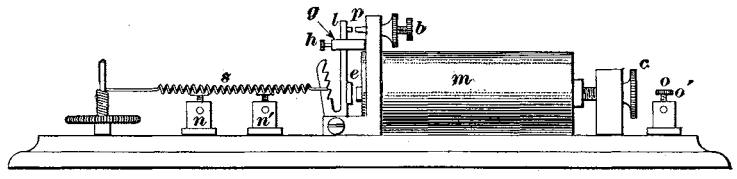


FIG. 1072.

of the lever is a platinum point *p*. The lever passes through a slit in the piece *g*, and is held against a screw *h* by a spring *s*, when there is no current in the magnets.

The ends of the main wire are connected to the two binding-posts *o* and *o'*, which are connected to the respective ends of the wire around the magnets. This wire is usually of

No. 36 B. & S. gauge silk-insulated copper, the total resistance of the two spools being about 150 ohms. The screw *c* adjusts the cores of the magnets towards or away from the armature *e*. The post *n* is connected to the screw *b* through the frame, and *n'* is connected to the lever *l*, so that the ends of the local circuit being connected respectively to these posts, the local battery is brought into action upon the contact of *p* and *b*.

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### RELAYS ON THE LINE AND THEIR ADJUSTMENT.

**2850.** The resistance of a relay used for ordinary lines should be about 150 ohms.

**Rule I.**—*The combined resistances of all the relays on the same line should equal the combined resistances of the lines and batteries.*

**Rule II.**—*All the relays in any one line should have equal resistances.*

**Rule III.**—*The armature of a relay should not move through a space of more than one thirty-second of an inch.*

When the signals are confused, evidence is given that the relay needs adjustment. The cores of the magnets should be moved nearer the armature when the current is too feeble, and farther away when it is too strong. In a case where the insulation of the line is defective, or in stormy weather, a certain small part of the current escapes to the ground. When the key at the farther station is opened, the escaping current forms a circuit from the wire to the ground and to the grounded pole of the battery. On this account a small magnetic force remains in the magnets after the key at the farther station has been opened. To avoid the effect of this magnetism, the magnets are moved farther away from their armature.

**Rule IV.**—*In a case where the sounder does not act while the relay responds to a current in the line, there is some fault in the local circuit. The relay points should be closed with the fingers; if the sounder still does not respond, the condition of the relay points and the connections should be carefully*

*looked after, and the E. M. F. of the batteries tested with a millivoltmeter to see if they come up to the standard. If the sounder can not now be made to respond by closing the relay points, the trouble is in the magnets of the sounder.*

**2851. Batteries.**—The standard battery in the United States for telegraphic purposes is the gravity. The crowfoot gravity is that adopted by the Western Union Telegraph Company, and is for that reason called The Western Union. It furnishes a working E. M. F. of one volt and a maximum current of two amperes. For continuous working, the economic current output is about $\frac{1}{4}$ ampere.

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### THE MORSE CODE.

**2852.** The Morse code consists of combinations of dots, dashes, and spaces. The combinations for the various letters of the alphabet, figures, and punctuation marks now in use in this country are the same as those originally devised by Morse, while those used in Europe have been modified to some extent.

**2853.** The dot is formed by a short, quick pressure on the key, and its immediate release. On the sounder a dot is indicated by a down stroke, *immediately* followed by an up stroke.

**2854.** The dash is formed by depressing the key and holding it down for a short interval of time. On the sounder a dash is indicated by a down stroke, followed, *after a brief interval of time*, by an up stroke.

**2855.** The space is formed by leaving the key in its raised position for a brief interval, and is indicated on the sounder by the interval between the up stroke of a dot or dash and the down stroke of the next succeeding dot or dash.

**2856.** The dot is taken as the unit by which the lengths of the dashes and spaces are measured.

The following table gives the relative lengths of the different dashes and spaces:

| Signal. | | Duration of Signal. |
|---|---|---|
| *Dot* | | *1 unit.* |
| *Space between parts of a letter* | ___1___ | *1 unit.* |
| *Space in space letter* | ___2___ | *2 units.* |
| *Space between letters* | ___3___ | *3 units.* |
| *Space between words* | ___ 6 ___ | *6 units.* |
| *The short dash* | 3 | *3 units.* |
| *The long dash* | 6 | *6 units.* |

It will be noticed that there are four lengths of spaces and two of dashes. An extra long dash, 9 units long, occurs in the numerals, and represents 0 (zero).

**2857.** The accompanying is the Morse code as now used in America.

**2858.** There are several suggestions of value in aiding to memorize the alphabet, and by grouping the letters in the following manner the task is much facilitated.

Dot signs:
*e, i, s, h, p, 6.*

Dash signs:
*t, l, m, 0* (zero), *5.*

Space signs:
*o, c, r, y, z, &.*

Reversals:
*a, n; b, v; c, r; d, u; g, w; j,* , (comma); *q, x; z, &; 4, 8.*

Opposites:
*f, k; 1, 9.*

MORSE ALPHABET.

| | | |
|---|---|---|
| *A*·— | *O*— — — | *1*·— — — — |
| *B*— ··· | *P*·— — — · | *2*·· — — — |
| *C*— ·— · | *Q*— — ·— | *3*··· — — |
| *D*— ·· | *R*·— · | *4*···· — |
| *E*· | *S*··· | *5*····· |
| *F*·· — · | *T*— | *6*— ···· |
| *G*— — · | *U*·· — | *7*— — ··· |
| *H*···· | *V*···— | *8*— — — ·· |
| *I*·· | *W*·— — | *9*— — — — · |
| *J*·— — — | *X*— ·· — | *0*— — — — — |
| *K*— ·— | *Y*— ·— — | |
| *L*·— ·· | *Z*— — ·· | |
| *M*— — | *&*·— ··· | |
| *N*— · | | |

| | |
|---|---|
| *Period* | ·— ·— ·— |
| *Comma* | — — ·· — — |
| *Colon (K O)* | — — — ··· |
| *Semicolon* | — ·— ·— · |
| *or (S I)* | — ·— ·— |
| *Interrogation* | ·· — — ·· |
| *Exclamation* | — ·— ·— — |
| *Parenthesis* | — ·— — ·— |
| *or at beginning (P N)* | — ·— — ·· |
| *at end (P Y)* | — ·— — ·— — |
| *Paragraph* | ·— ·— ·— ·— |
| *Quotation* | ·— ·· — ·— ·— |
| *or at beginning (Q N)* | ·— ·· — ·· |
| *at end (Q J)* | ·— ·· — ·— ·— |
| *Quotation within Quotation (Q X)* | ·— ·· — ·— ·· — |
| *Underline* | ·· — — ·— ·— |
| *or at beginning (U X)* | ·· — — ·· — |
| *at end (U J)* | ·· — — ·— ·— |
| *Dash (D X)* | — ···· — |
| *Hyphen (H X)* | — ···· — |
| *Dollar sign (S X)* | ··· — ··· — |
| *Decimal point* | ·— ·— ·— |

### METHOD OF HOLDING KEY.

**2859.** The proper position for holding the key is indicated in Fig. 1073. The forefinger should be placed on top of the knob and the edges of the knob grasped lightly by the thumb and middle finger. Care should be taken not to grasp the knob tightly, as this quickly tires the hand and destroys control of the key. In telegraphy, as in writing, a free, easy movement of the hand and arm is far better than a cramped movement of the fingers alone.

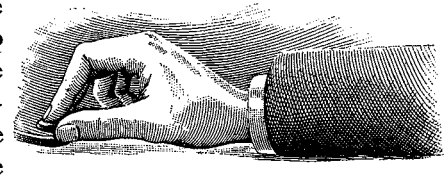

FIG. 1073.

## CIRCUIT ACCESSORIES.

**2860.** Before passing to the discussion of the more complex systems of telegraphy, the appliances with which the various connections are effected, the protective devices, and the batteries will be considered.

### SWITCHES.

**2861.** The switches used in a telegraphic circuit must, above all things, be substantial and of such form that they may be readily cleaned, *for much depends upon the quality of connections.* A faulty connection at any point will often cause a fluctuating current, and will render the adjustment of the springs governing relay armatures, etc., exceedingly difficult, if not impossible.

**2862. The Plug Switch.**—This is a form much used, and commends itself both on account of its reliability and its simplicity. This form of switch is shown in Fig. 1074. It is made up of alternate rows of brass plates $P$, $P_1$, etc., and brass buttons $B$, $B_2$, etc. This board is erected in a vertical position, and the buttons in each horizontal row are connected together. Thus any one wire from the horizontal

side may be connected to any one upon the vertical by inserting a plug, such as is shown at *M*, into the proper

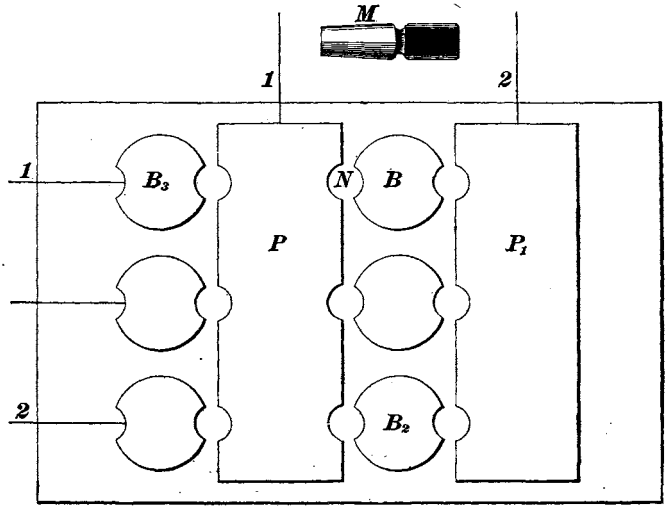


FIG. 1074.

aperture, such as at *N*. The lower part of the plug *M* is of brass, while the upper part is of hard rubber. The circuits in a large station are all appropriately numbered, so that wires *1* and *1*, for instance, as well as *2* and *2*, may be connected together by inserting plugs at the junction of $B_3$ and $P$, and at the junction of $B_2$ and $P_1$.

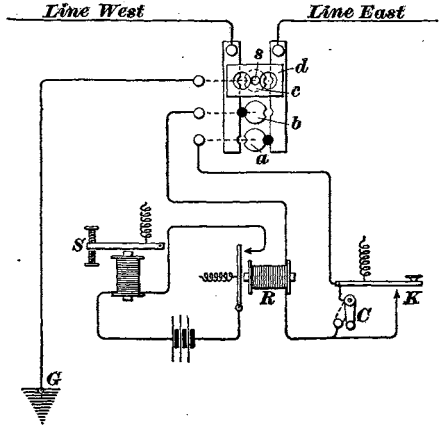


FIG. 1075.

**2863.** Fig. 1075 shows how one of these switches is used at a way station operating but one wire and one set of instruments. The

upper contact button *c* is connected with earth. This button carries a plate *d* held in place by a screw *s*. The plate overlaps the vertical bars, which are connected with the line-wires leading East and West, and is separated from the bars by a layer of thin paper, mica, or a corresponding air-gap. Holes through the plate allow the insertion of plugs between the bars and button *c* in the manner already described.

The two lower buttons *a* and *b* are connected with the wires leading to the key *K* and relay *R*, as shown.

**2864.** The normal operating condition of the circuits is that shown; that is, with a plug in the left-hand hole of *b* and right-hand hole of *a*. The circuit may now be traced from line west, left-hand bar, through plug to button *b*, relay *R*, key *K*, and through plug to button *a* and right-hand bar to line east. In this position a charge of lightning passing along the wire is far more likely to jump the small air-gap to plate *d* and pass to ground than to pass through the high resistance instruments. This device, therefore, serves as a protector of the instruments against all high-pressure charges.

**2865.** When it is desired to cut off either side of the line, a plug is inserted in the right or left hole of button *c*, leaving the other holes plugged as before. Suppose the right-hand hole of *c* to be plugged. Then current will pass from line west through the instrument as before, and to ground through button *c*. Line east will pass directly to ground. Thus the line will be divided into two circuits, one containing the instruments at this station. Inserting the plug in the left-hand hole of plate *c* instead of the right will accomplish the same results, except that the instruments will be in line east instead of line west.

To cut out the instrument entirely, leaving the line continuous, simply plug both holes of button *a* or of button *b*.

**2866.** Fig. 1076 shows a convenient form of switch upon which nearly all desired connections may be obtained. Each small brass plate has, projecting underneath the table,

a binding-screw to which wires may be attached. Thus various combinations may be formed by inserting plugs in

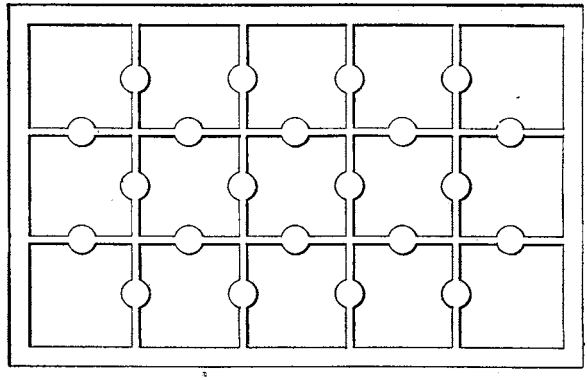

FIG. 1076.

the proper apertures. The plugs should be pressed down with a screwing motion, so as to make complete connection.

**2867. The Spring-Jack Switch.**—The spring-jack, shown in Fig. 1077, is a convenient switch, or cut-out, for introducing into the main circuit, *without breaking the connection*, a measuring instrument or the wires of a way station.

$S$ is a flexible strip of brass fixed at $T$ and carrying a projection at $P_1$ which presses firmly against a stationary projection carried by $P$, so as to make a good connection.

The pressure of the spring is regulated by the screw $M$, which works in the stationary brass piece $c$. Between the two pieces $P$ and $P_1$ a wedge plug (shown at $W$) may be inserted. The plug consists of an insulating hard rubber strip $b$, provided with a handle of the same material, on either side of which there are two brass strips $a$ and $a_1$. The two wires from an instrument or way station are respectively connected with these brass strips.

The stationary part $T$ of the spring is connected to a binding-post $A$, while $P$ is connected to the binding-post $C$.

A lightning-arrester may be provided for way stations, as at $L$. In this case the wire from $A$ to $T$ passes through plate $x$, while that from $C$ to $P$ passes through plate $y$. Plate $z$ is connected to $B$, and should be grounded. The object of these points is to afford a ready path for the lightning

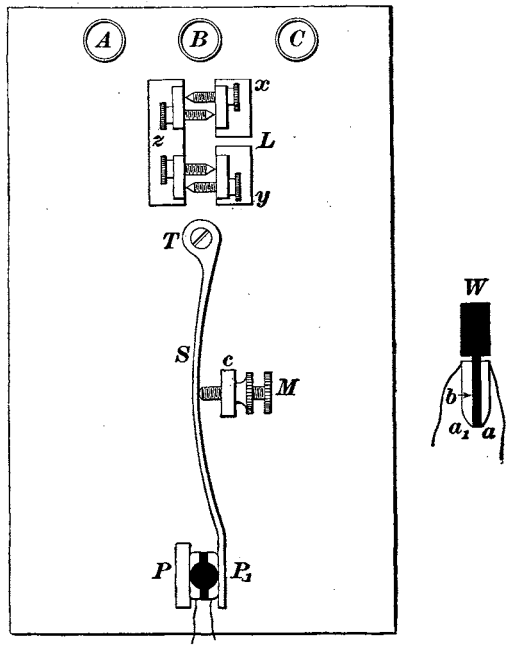


FIG. 1077.

charge coming in over either line to plate $x$ or $y$, to jump to the ground-plate $z$. When plug $W$ is inserted, the connection between $P$ and $P_1$ is broken, and $a$ and $a_1$, respectively, connect with $P$ and $P_1$. It will be seen that this is done without breaking the main circuit.

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### LIGHTNING-ARRESTERS.

**2868.** The **lightning-arrester** is used to avert the danger of the burning out of instruments when an electric storm occurs. There are two forms of these instruments, which depend upon the following facts: *the first, that lightning, having a very high tension, prefers to leap over a short*

*space separating two metallic plates, rather than to run through a long wire; and, second, that lightning escapes readily from a point to a plate.*

**2869. The Plate Arrester.**—This form of arrester is largely used in this country and is built in a great variety of forms. That shown in Fig. 1075, in connection with the way-station switchboard, is one of the most efficient and convenient forms. Mica is the best form of insulation between the plates, as it may be divided into sheets of extreme thinness, and, moreover, it does not carbonize under the effect of sparking.

**2870. The Point or Saw-Tooth Arrester.**—One form of point arrester was shown in connection with the spring-jack switch in Fig. 1077. Another very common form of arrester depending on the ready discharge from points is shown in Fig. 1078. In this the line-wires $a'$ and $b'$ are attached to the upper binding-posts on the plates $y$ and $z$, respectively, and the wires $a$ and $b$ leading to the local instruments are attached to the lower posts on the same plates. The center plate $p$ is grounded by wire $g$. The circuit is thus normally complete through the instruments, but if a plug be inserted in $x$ the line will still be continuous, but the instruments cut out. This is the condition in which the office should be left while the operator is away. A ground may be thrown on either side of the line by placing the plug in one of the holes at the right or left hand side of the ground-plate.

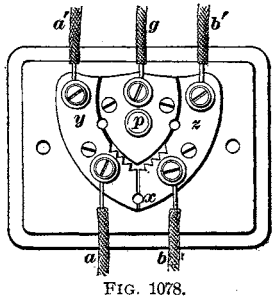

FIG. 1078.

## REPEATERS.

**2871.** As there is leakage in all telegraph-lines, and faults in most, the current at the end of a line extending several hundred miles becomes very feeble, because of this leakage and of the high line resistance. But if a very small

current arrives at the distant end of the wire, this may be made to close a new circuit containing another main battery, and thus repeat the message. These repeating devices require the services of an operator at about each 500 miles of line.

The repeaters most used in the United States are the button repeaters of Wood and Edison and the automatic repeater of Milliken.

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### WOOD'S BUTTON REPEATER.

**2872.** The arrangement of Wood's button repeater is shown in Fig. 1079.

*M* is a switch so arranged that the lever *k*, which is pivoted at the center, is always in contact with one or both of the

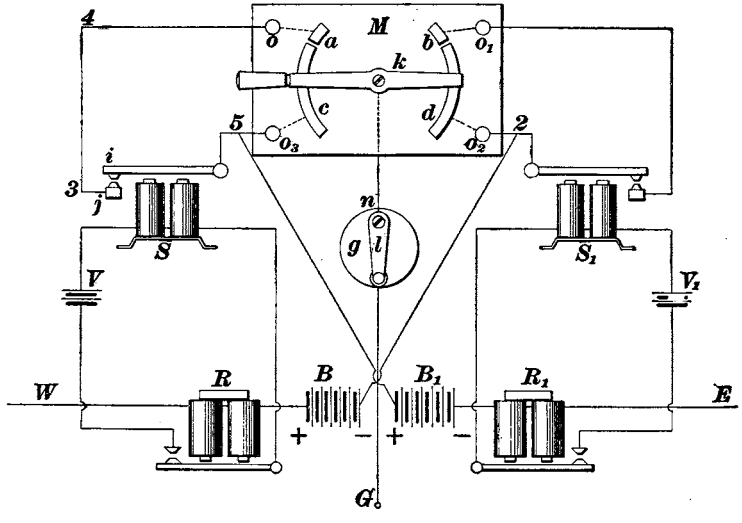


FIG. 1079.

brass pieces *c* and *d*; *o*, $o_1$, $o_2$, and $o_3$ are binding-posts, each joined to the respective brass pieces *a*, *b*, *d*, and *c*; *g* is a ground switch connecting the lever *k* of the switch *M* with the ground at *G*; *W* is the western and *E* the eastern main line; *R* and $R_1$ are the western and eastern relays; *S* and $S_1$ the western and eastern sounders, and *B* and $B_1$ the

western and eastern main-line batteries. $B$ and $B_1$ *must be arranged in series*, the plus pole of one being connected to the minus pole of the other, for this arrangement allows the line to be connected straight across, as will be explained later. $V$ and $V_1$ are the local batteries.

**2873.** If the ground switch $g$ is closed and lever $k$ is placed from $d$ to $a$, the western circuit will repeat into the eastern. The circuit may be traced around as follows: The western key is closed. A current proceeds from the plus pole of battery $B$, goes through the magnets of the relay $R$, then to the western station, where the line is grounded, back through the earth to $G$, through switch $g$ to lever $k$, to $d$, $o_2$, 2, and to the minus pole of battery $B$. By this current, relay $R$ is caused to close its local circuit, which causes sounder $S$ to act and close the circuit of battery $B_1$. This circuit may be traced as follows: From the plus pole of battery $B_1$ through points $i$, $j$, 3, 4, and $o$ to lever $k$, through switch $g$ to the earth at $G$. Then, through the earth to the eastern station, and back through the magnets of eastern relay $R_1$. This acts upon relay $S_1$ and repeats the message. No circuit is closed, however, by the armature of relay $S_1$, as there is a break between $b$ and $k$. It, therefore, acts as a sounder.

If the lever $k$ be placed from $c$ to $b$ while switch $g$ is closed, the eastern circuit will repeat into the western, and the circuits may be traced as before. The single ground at $G$ will serve for both eastern and western circuits.

If the lever $k$ connects $c$ and $d$ and switch $g$ is opened, the eastern and western circuits are connected straight across. This circuit is as follows: From the plus pole of battery $B$, through relay $R$ to the western station, through the earth to the eastern station, then to relay $R_1$, and to the minus pole of battery $B_1$. Batteries $B$ and $B_1$ are connected as one battery in series through $5$-$o_3$-$c$-$k$-$d$-$o_2$-2.

If $k$ connects $c$ and $d$ and switch $g$ is closed, two independent circuits are formed, namely, $B$-$R$-$W$-$G$-$g$-$k$-$o_2$-2 and $B_1$-5-$o_3$-$c$-$k$-$g$-$G$-$E$-$R_1$.

**2874.** In this arrangement, if the two sounders do not work in unison, the lever $k$ must be instantly turned by the operator in attendance so that the person receiving may be able to break and become the sender.

The term button has been applied to these repeaters because of the form of changing switch originally used in their operation.

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### EDISON'S BUTTON REPEATER.

**2875.** The simplest form of the button repeater is Edison's. It requires only the use of instruments in ordinary service at a station, and is operated by means of a simple ground switch. The connections are shown in Fig. 1080.

$R$ and $R_1$ are relays, $S$ is the single sounder, $B$ the local battery, $g$ a ground switch, $G$ the earth, $W$ the western main

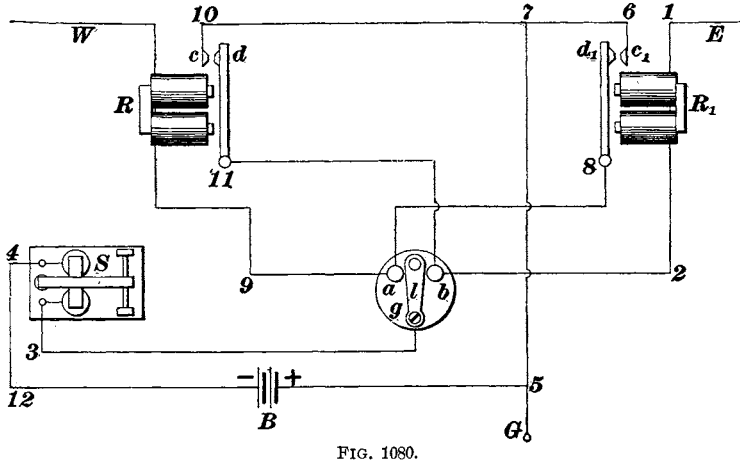


FIG. 1080.

line, and $E$ the eastern main line. The lever $l$ of the ground switch is not connected directly with the ground.

If the lever $l$ is moved to contact $b$, the eastern circuit will repeat into the western. The circuits are traced as follows:

When the key at the eastern station is closed, a current flows through the line-wire to magnets $R_1$, to $b$ and $l$, to sounder $S$, to battery $B$, to $G$, and back through the earth

to the station battery of the eastern circuit. The relay $R_1$ acts by this current to bring the points $d_1$ and $c_1$ together, and a current proceeds from the western battery to $W$, to magnets $R$, to $a$, to $8$-$d_1$-$c_1$, to the earth at $G$, and back to the western station. Thus the message is repeated. If a current at a low E. M. F. passes through a magnet of low resistance and then through one of comparatively high resistance, the attraction of the low-resistance magnet for its armature is quite feeble as compared to that of the high-resistance magnet. Therefore, the current proceeding from $E$ will not affect the low-resistance sounder $S$. The relay $R$ will, however, cause the sounder to act through the circuit *B-5-7-10-c-d-11-b-l-3-S-4-12* by closing points $c$ and $d$. Thus the sounder is really in a circuit common to that of the line east and to the local circuit of relay $R$. It will work, however, only when the latter circuit is closed.

**2876.** If the lever $l$ is moved to $a$, the western circuit repeats into the eastern, and the relay $R_1$ of the eastern circuit works the sounder.

It is well, though not necessary, to have the plus poles of the station battery to line; as, when the current passes through $B$, it is better to have the two batteries act together in series than to have them oppose each other.

**2877.** In button repeaters, as each circuit is closed, a short delay occurs in the transmission of a message, for each armature moves over a short distance before the circuit is complete. This shortens the dots and dashes in proportion to the number of contacts to be closed, and thus the dots are sometimes wholly lost. Therefore, in operating such a circuit, the dots and the dashes should be made longer, or, as operators term it, the "sending should be heavy."

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### MILLIKEN'S AUTOMATIC REPEATER.

**2878.** Automatic repeaters are those which will act in either direction without the need of a switch being turned. An operator, however, is always needed to adjust the armatures of the relays and sounders and to care for the batteries,

but, of course, his time may be largely devoted to other duties.

Milliken's automatic repeater is shown in Fig. 1081. $R$ and $R_1$ are relays, $S$ and $S_1$ are sounders, $M$ and $M_1$ are extra local magnets with armatures, $B$ and $B_1$ are extra local batteries, $P$ and $P_1$ are **U**-shaped springs which prevent, to a certain extent, the shortening of the signals, as will be explained, and $l$ and $l_1$ are levers pivoted at $z$ and $z_1$, carrying at one end of each an armature and at the other end a contact point. $G$ and $G_1$ are grounds, $W$ the western

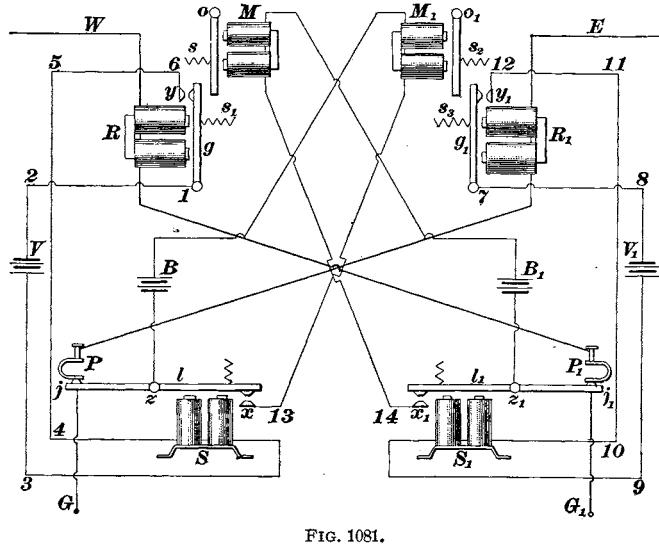


FIG. 1081.

main line and $E$ the eastern, and $V$ and $V_1$ are local batteries.

The western main circuit is through $W$-$R$-$P_1$-$j_1$-$G_1$ and back to the western battery. The eastern main circuit is through $E$-$R_1$-$P$-$j$-$G$ and back to the eastern battery. The local circuit of $R$ is $V$-2-1-$g$-$y$-6-5-4-$S$-3 and back to $V$. The local circuit of $R_1$ is $V_1$-8-7-$g_1$-$y_1$-12-11-10-$S_1$-9 and back to $V_1$. The extra circuits for magnets $M$ and $M_1$ are, respectively, $B_1$-$z_1$-$l_1$-$x_1$-14-$M$, back to $B_1$, and $B$-$z$-$l$-$x$-13-$M_1$, back to $B$.

**2879.** Suppose, in starting, that all circuits are closed. If, now, the western key be opened, the relay $R$ will break its local circuit, and the lever of sounder $S$ will first break the extra circuit of $M_1$, between $l$ and $x$, and then the eastern main circuit between $P$ and $j$; so that, first, $M_1$ is demagnetized and lever $o_1$ is drawn back upon the end of lever $g_1$ by spring $s_2$, and, second, magnet $R_1$ is demagnetized. Lever $g_1$, however, does not leave contact point $y_1$, as it is held by the armature of $M_1$, spring $s_2$ being adjusted to overcome the pull of spring $s_3$. Thus, it can be seen that when the western key is closed, a signal is sent into the eastern circuit by the closing of points $P$ and $j$; and, therefore, the western circuit repeats into the eastern. However, the eastern relay and sounder will remain quiet, because the circuit through $M_1$ is always opened slightly before that through $R_1$, and $R_1$, therefore, always keeps its contacts $g_1, y_1$ closed while the eastern line is receiving. Now it may be seen that, as only two contacts are made, and as that at $P$ does not require much time, and as the breaking at $P$ is delayed by the action of the spring, there is very little shortening of the signals.

## MULTIPLEX TELEGRAPHY.

**2880.** Thus far, methods for transmitting only single messages over a line have been discussed. It is quite obvious that, if instruments can be arranged so that two simultaneous messages can be sent through the same wire, the work of the system is equal to that of two lines. If four messages can be sent simultaneously over the same line, the system is equivalent to a four-wire system. In these two cases a ground return is assumed. If, then, one line can be made to do the work of four lines, the expense of erection and maintenance of three lines is avoided.

**2881.** The transmission of two telegraphic messages simultaneously in opposite directions over the same wire is called the *duplex system*.

**2882.** The simultaneous transmission of four independent messages, two in one direction and two in the other, is termed the *quadruplex system.*

**2883.** There are two general systems of duplex telegraphy, the **differential** and the **bridge.** The fitting signification of each of these words will be apparent as the action of each system is explained.

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### THE DIFFERENTIAL DUPLEX SYSTEM.

**2884.** The differential duplex system is shown in Fig. 1082. *W* and *E* are two stations, which may be many miles apart, similarly equipped and joined by the earth and line

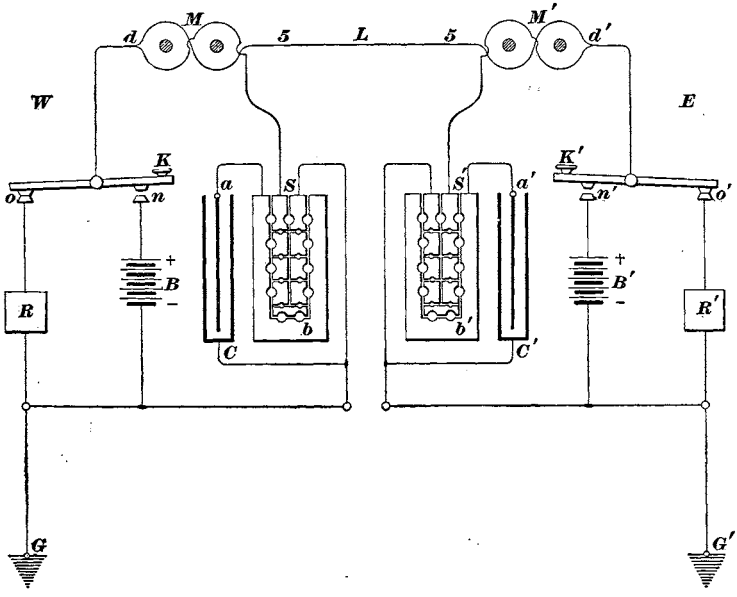


FIG. 1082.

*L.* *M* and *M'* are relays having the customary local circuits, but differing from the ordinary relay in that the magnets have two separate windings in opposite directions. These are not polarized relays, but *differential relays*, so called from the fact that their windings have a differential

or opposing effect. The system, therefore, obtains the title **differential duplex.** The keys $K$ and $K'$ are so constructed that the circuit is always complete, either through the battery $B$ or $B'$ or through the resistance $R$ or $R'$. $S$ and $S'$ are resistances, each of which is adjustable and made equal to the line resistance.

**2885.** The action is as follows: When the key $K$ is pressed, current from the battery $B$ flows through $K$, divides at $d$, one half passing around the magnet $M$ in one direction, and the other half around it in the opposite direction. The relay $M$, therefore, does not operate. The two currents pass on, one through the resistance $S$ to the earth $G$, and back to the negative (−) terminal of the battery; the other over the line $L$, around the magnet of the relay $M'$, in one direction only, to $K'$ and to the earth $G'$, either through the battery $B'$ or through the resistance $R'$ (depending on the position of the key $K'$) and back to the negative (−) pole of the battery $B$. It is thus evident that either key will not operate its own relay, but will work the relay at the other end of the line, irrespective of the position of the key at that end.

**2886.** Underground wires, submarine cables, and air-lines form condensers, and may be likened to a Leyden jar, as follows: *The wire or cable corresponds to the inside conductor, the insulation or atmosphere corresponds to the glass, and the earth corresponds to the outside conductor.*

Thus, in Fig. 1082, when key $K$ is depressed, the line receives a charge from battery $B$; for the plus pole is connected with one conductor and the minus with the other. When contact is broken at $n$, the two conductors—the line and the earth—are connected by the contact at $o$, and the discharge comes back through relay $M$, giving a false signal. To neutralize this effect upon the relay, the condensers $C$ and $C'$ are used. One terminal of each is connected to a brass rim $b$ or $b'$ which fits around the rheostat, so that, by plugging, this terminal may be connected to any rheostat coil that is in the main circuit. Thus the charges proceeding from these condensers may be adjusted until they are

exactly equal to the back charge from the line. *When a current of electricity is flowing through a wire, the E. M. F. between two points that are near together upon this wire is less than that between two points that are farther apart.* Hence, as the charge that a condenser receives depends upon the E. M. F. at the terminals, the condenser $C$ may be adjusted by connecting the terminal $a$ to different coils of the rheostat $S$. The nearer this connection is made to ground $G$, the less will be the charge of the condenser. When $a$ is connected between $S$ and $G$, the condenser $C$ will receive no charge, as both terminals are connected directly to the earth.

Such a combination of condensers and resistances is termed an **artificial line,** since its purpose is to form a branch to earth having the same electrical properties as the line-wire.

**2887. False Cable.**—With submarine cables, it is advantageous that the capacity in condensers $C$ and $C'$, Fig. 1082, shall have the same *distribution* as that of the cable. For this reason a **false cable** is constructed, which agrees with the cable in capacity and resistance. This false cable consists of insulating plates, one side of which is covered with foil and connected with the earth, while strips of foil with their ends connected to form a zigzag figure, shown in Fig. 1083, are placed upon the other. A great number of these plates are piled together, and the ends of the outside strips upon the plates are connected, so as to form a continuous chain. High resistances are connected from the strips to the earth to represent faults in the cable.

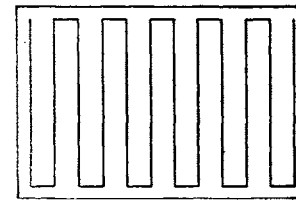

FIG. 1083.

## BRIDGE DUPLEX SYSTEM.

**2888.** The bridge duplex system, shown in Fig. 1084, is similar in its action to a Wheatstone bridge.

$S$ is a slide rheostat, so arranged that as the lever is turned, resistance is taken out of one side of the bridge,

such as *a b*, and is added to another side, as *e d*, and *vice versa*, if the lever is moved in the other direction. One side

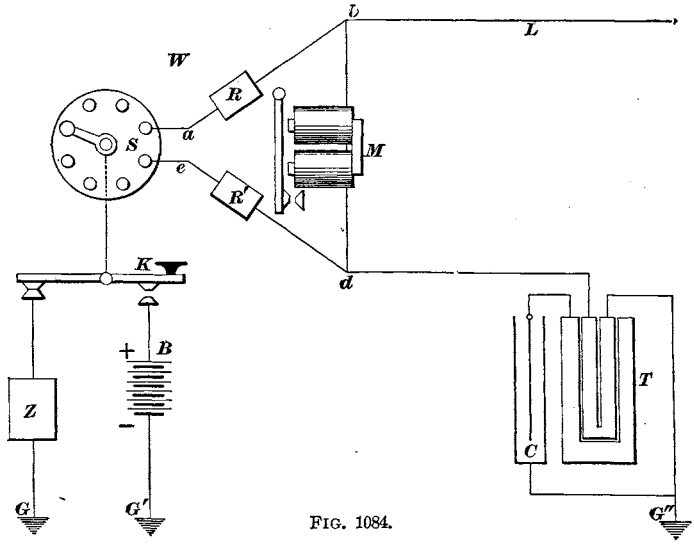


FIG. 1084.

of the bridge is *a b*, *e d* the next, *d G''* the next, and line *L*, with its ground-connection at the other station, the last.

The resistance *Z*, key *K*, battery *B*, resistance-coils *T*, and condenser *C* are arranged to act precisely as in Fig. 1082. Similar connections are made at the other station.

The resistance *Z* equals the resistance of the battery *B*, and the current from station *E*, not shown, passes through this resistance *Z*, instead of *B*, when the key *K* is open at its front contact.

It will be seen that if *a b* bears the same relation to *e d* that line *L* bears to *d G''*, the relay *M*, which in this case corresponds to the galvanometer in a Wheatstone bridge, will not be affected by the outgoing current from battery *B*. If the key at the distant station is depressed, the current will pass along the line-wire *L*, and at the point *b* will divide, a part of it passing through the relay. It is readily seen that the position of the key *K* will in no wise affect this. Thus the relay will be operated only by currents from

the distant station. Adjustment of resistances is made in *a b* and *e d*, first by the resistance-boxes *R* and *R'*, and finally by the rheostat *S*. The resistance of *d G''* is adjusted by the rheostat *T*.

The bridge method is principally used on short lines; but some of the most recent cable-lines are operated by a modified bridge method shown in Fig. 1085.

## BRIDGE METHOD FOR CABLES.

**2889.** Instead of the resistances *R* and *R'* shown in Fig. 1084, condensers *c* and *c'* are introduced. A condenser

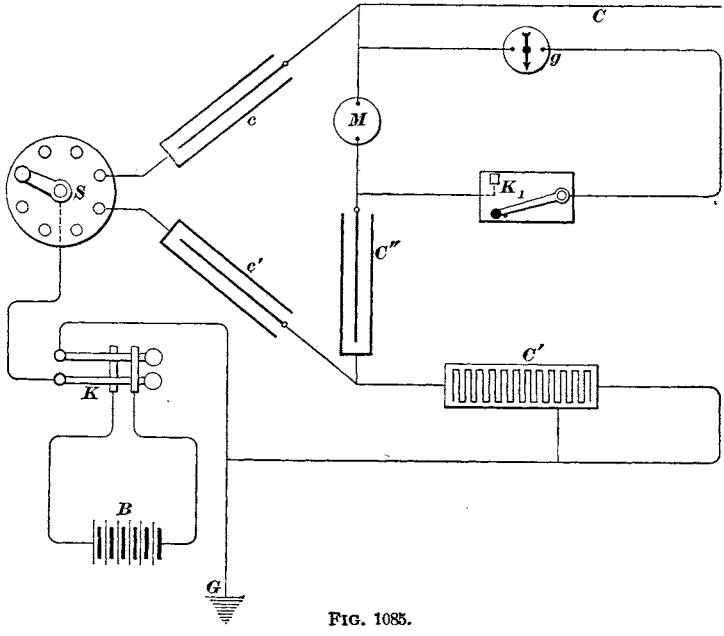


FIG. 1085.

is connected at *C''*, and instead of *T* and *C* in Fig. 1084, the false cable *C'* is used. These condensers, as connected, act in the same way as resistances in a Wheatstone bridge. As connection is made at *K* with one pole or the other of battery *B*, condensers *c* and *c'* are first charged, then cable *C*

and the false cable $C'$. A charge is given to the condenser corresponding to $C''$ at the other station; but *if the charge of c is to the charge of c' as that of C is to that of C'*, there will be no charge given to $C''$, and the receiving-instrument $M$ is not affected.

Key $K$ is so arranged that, by pressing one lever, the plus pole of the battery is put to line, while the minus pole is to earth; and, by pressing the other, the minus pole is put to line, while the plus pole is to earth. Thus, the condensers may be charged in either direction.

**2890.** The receiving-instrument at $M$ is usually a *siphon register*, so placed that a galvanometer $g$ may be switched into circuit by means of the switch $K_1$ should the register be out of order. When the galvanometer is in circuit, a kick is given to the needle in direction corresponding to which lever of $K$ is pressed. One direction is taken as dots and the other as dashes.

**2891. The Siphon Register.**—The **siphon register** consists of a coil of wire swinging upon a pivoted axis between the poles of a magnet. The current passes through this coil and swings it according to the direction of flow. A glass siphon is attached to the coil. One end of this siphon dips into a vessel of ink, and the other spurts ink upon a strip of paper, which is drawn across. The ink is charged positively, while the plate over which the paper passes is given a negative charge. Therefore, the ink is splashed upon the paper, and a record is obtained of the movements of the coil. Later forms of this instrument do not depend upon the attraction of a positive for a negative charge of electricity to cause the ink to flow, but on a mechanical vibration of the siphon-tube.

## QUADRUPLEX SYSTEM.

**2892.** The **quadruplex system** is a means of sending, without interference, two messages in each direction, or a total of four messages over one wire at the same time.

The principles of the method most used are shown in Fig. 1086.

The relays $M$, $M'$ of this system are of peculiar construction, and are called *differential polarized relays.*

A *differential polarized relay* is one whose coils are *differentially wound*, and whose armature is permanently mag-

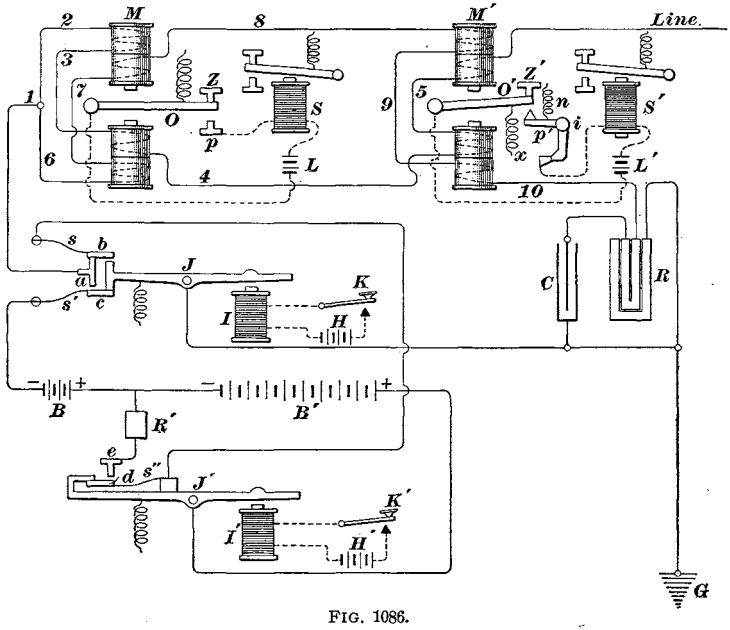


FIG. 1086.

netized so that it will be moved in one direction or the other according to the direction of the current flowing through its coils. Differentially wound means wound as are $M$ and $M'$ in Fig. 1082; that is, so that when equal currents flow in each winding in opposite directions, no effect is produced upon the armature. Thus, in a differentially wound polarized relay, when two currents in opposite directions flow equally through both its windings, no movement of the armature will be produced. When, however, a current flows through only one of the windings, a movement of the armature will result, the direction of this movement depending on the direction of the current.

**2893.** Both relays $M$ and $M'$ are polarized and are provided with armatures $O$, $O'$, permanently magnetized, each swinging between the pole-pieces of two electromagnets.

For positive currents coming from the distant station, the armatures $O$, $O'$ are attracted by the upper magnet of the relays and repelled by the lower, while for negative currents they are repelled by the upper and attracted by the lower, so as to close the local circuits through the sounders $S, S'$. Each magnet of each of the two relays has two windings, making eight windings in all. Four of these, one on each magnet, are connected in series in the line circuit, while the other four are similarly connected in the circuit of a condenser $C$ and rheostat $R$, forming an artificial or false line. Starting at the point *1*, the first of these circuits may be traced through the wires *2*, *3*, *4*, and *5* to line. Similarly, the circuit to the artificial line may be traced from point *1* through wires *6*, *7*, *8*, *9*, and *10* to condenser $C$ and resistance-box $R$ to ground.

**2894.** To explain the working of this system, suppose that this latter circuit through the artificial line is left out. The relays will then respond to keys $K$ and $K'$ exactly as if they were at the other end of the line, provided that the connections of the coils to the line are reversed. With this change, the relays would operate on an outgoing current in the same manner as on an incoming current from the other station, while for purposes of explanation it simplifies the description to have the keys shown in proximity to the relays.

$K$ and $K'$ are keys operating in local circuits with batteries $H$ and $H'$ and electromagnets $I$ and $I'$. These magnets $I$ and $I'$ operate levers $J$ and $J'$, which in turn act in the same manner as keys to make and break contacts in other circuits. The lever $J$ vibrates between contacts $b$ and $c$ carried on springs $s$ and $s'$, and alternately presses them out of engagement with the stationary anvil $a$. It must be noticed, however, that the lever always makes contact with either $b$ or $c$ before causing it to break with $a$. The key $K$ operates upon the lever $J$ to *control the polarity of the current sent to line.* Thus assuming key $K'$ to be open, as shown, lever $J$, when key $K$ is open, will send a posi-

tive current from twelve cells (batteries $B$ and $B'$ in series) to line, and when key $K$ is closed, a current of the same strength, but of negative polarity. By tracing out the circuits, it is easy to see that, irrespective of the position of key $K'$, the lever $J$ will always send a negative current to line when in contact with $b$, and a positive current when in contact with $c$.

**2895.** What, then, is the function of key $K'$, since it has no control over the polarity of the current? It serves to *govern the strength of the current sent to line*, irrespective of the position of key $K$. It operates the lever $J'$ by means of the battery $H'$ and magnet $I'$. $J'$ carries a spring $s''$ insulated from it at its point of support. This spring carries a contact $d$, which, while the key $K'$ is open, makes contact with the lever $J'$, but when the key is closed forms contact with stationary contact $e$ and immediately breaks with $J'$.

Assuming $K$ to be open and $J$, therefore, in the position shown, it will be seen, by tracing the circuits from $G$, that when $K'$ is open $J'$ will allow a current from twelve cells (both batteries $B$ and $B'$ in series) to flow to line, while, when $K'$ is closed, causing $d$ to make contact with $e$, a current from but three cells (battery $B$ alone) will flow to line. It will also be seen that, regardless of the position of key $K$, key $K'$ will always send current from twelve cells to line when open, and from but three cells when closed.

*Key $K$, therefore, controls the polarity of the current and key $K'$ the strength of current, and each key acts independently of the other.*

$S$ and $S'$ are sounders in the local circuits of $M$ and $M'$, operated by the local batteries $L$ and $L'$; $p'$ is a lever pivoted at $i$, and held in such position by spring $n$ that contact is made with an anvil in the local circuit. Let the current given by the battery $B$ of three cells be represented by one unit, and let that given by $B$ and $B'$ together be represented by four units, since there are twelve cells in all, or four times as many as in $B$ alone. These numbers of units with

the signs — or + will be used to represent the currents given to the line.

**2896.** Now, remembering that the circuit through the artificial line is for the present supposed not to exist, we will note the effects on the relays of the currents for all the different positions of the keys.

*Both Keys Open.*—When both keys are open, as shown in the figure, a current +4 units flows to the line. It takes the course *G*, *J*, *c*, *s'*, *B*, *B'*, *J'*, *s''*, *s*, *b*, *a*, *1*, *2*, *3*, *4*, *5* and to the line. This current is sufficient to overcome the pull of spring *x* on relay *M'*, so that both relays are held against their back-stops *Z* and *Z'*, and both sounder circuits are therefore open.

**2897.** *Key K' Pressed Down and K Open.*—A current +1 unit is sent over course *G*, *J*, *c*, *s'*, *B*, *e*, *d*, *s''*, *s*, *b*, *a*, *1*, *2*, *3*, *4*, *5* and to line. This is not sufficient to overcome the pull of spring *x*, so that lever *O'* moves in contact with lever *p'*, but with not enough force to overcome the pull of spring *n*. The circuit of sounder *S'* is closed, but lever *O* is held against *Z*, because the current is in the wrong direction to operate relay *M*. Thus, *S'* is put in action, while *S* is silent.

**2898.** *Key K Pressed Down and K' Open.*—A current —4 units is sent to the line over course *G*, *J*, *b*, *s*, *s''*, *d*, *J'*, *B'*, *B*, *s'*, *c*, *a*, *1*, *2*, *3*, *4*, and *5*. This is sufficient to overcome the pull of spring *n*, and the circuit of sounder *S'* is opened. Lever *O* is pulled against *p*, which causes sounder *S* to be put in action.

**2899.** *Keys K and K' Both Pressed Down.*—A current —1 unit is sent to the line over the course *G*, *J*, *b*, *s*, *s''*, *d*, *e*, *B*, *s'*, *c*, *a*, *1*, *2*, *3*, *4*, and *5*. Contact is made between *O'* and *p'*, but the pull of spring *n* is not overcome by *x*. Therefore, sounder *S'* is set in action. Lever *O* is attracted against anvil *p*, and this closes the circuit of sounder *S*.

These four conditions comprise all the combinations necessary for the simultaneous transmission, in one direction, of two messages over one wire.

**2900.** To change this to quadruplex, it is only necessary that *M* and *M'* be wound differentially, as shown in the figure, by adding the set of windings connected through the course *1*, *6*, *7*, *8*, *9*, *10*, *R* and *C* to *G*, whose resistance, by adjusting rheostat *R*, is made exactly equal—starting from *1*—to the resistance of the line. Resistance *R'* is exactly equal to battery *B'*; so that, when battery *B'* is cut out, the line resistance will remain constant. The condenser *C* is connected as before to neutralize the back kick from the line, as explained in connection with the duplex system.

The opposite end of the line is connected up exactly the same as in Fig. 1086. So the current, starting from *1*, is divided and runs in opposite directions around the relays, producing no effect upon the sounders. But a current proceeds along the line to the other station, and there produces an effect upon the relays precisely similar to that upon *M* and *M'* already described.

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### JONES QUADRUPLEX SYSTEM.

**2901.** The Postal Telegraph Co. of New York City uses to a large extent the quadruplex system. The general principle of its working is the same as that given in Fig. 1086, but many improvements have been made upon the instruments and the method of generating power. The system used is known as the *Jones quadruplex*, and its principal features and circuits are shown in Fig. 1087.

**2902.** Instead of depending on batteries for generating the current for line and local circuits, dynamo machines are used exclusively. For operating the quadruplex line circuits, four machines are used, adapted respectively to deliver to line current at the following pressures: One +100 volts, one −100 volts, one +300 volts, and one −300 volts.

*B* shows the generating machines and their voltages. These machines each have one of their poles connected to a common ground *G*. *P* is a pole-changing lever, worked by a local circuit and corresponding key *K*. This pole-changer

corresponds to the lever *J* of Fig. 1086, and serves simply to control the polarity of current going to line. *P'* is a lever worked by a local circuit and key *K'*; this lever corresponds to the lever *J'* of Fig. 1086, and serves simply to

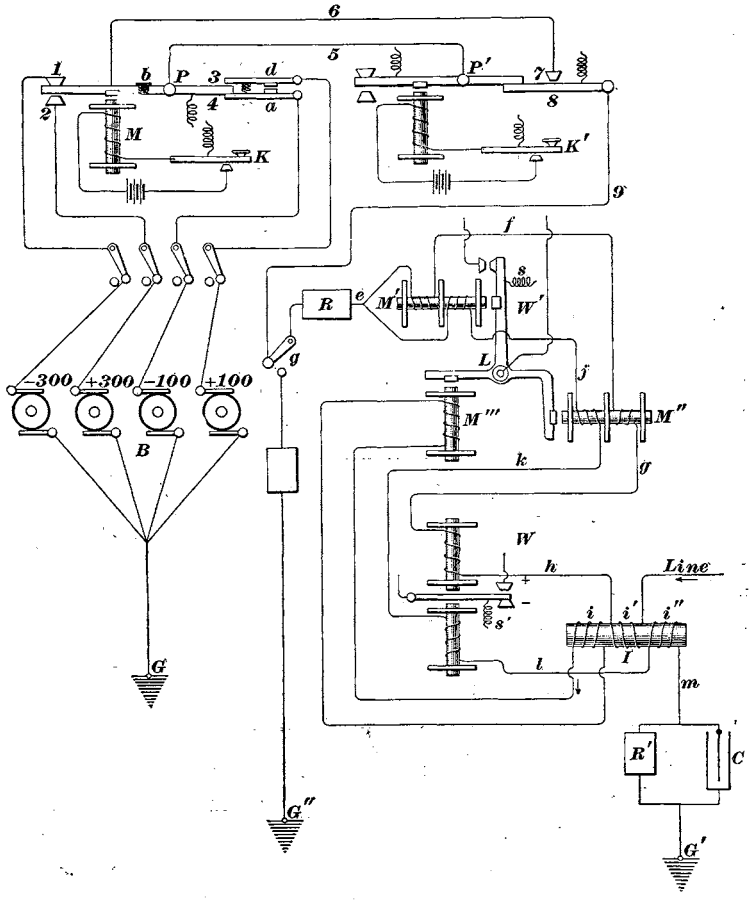


FIG. 1087.

control the strength of current flowing to line, irrespective of its polarity. The two parts of lever *P* are insulated from each other at *b*. This pole-changer makes contact either at *1* and *4* or at *2* and *3*. The two levers *d* and *a* are acted

upon by springs, so that contact is never broken between them when *K* neither touches at *3* nor at *4*, and in this position the two machines *—100* and *+100* are in series, and preserve a continuous circuit. *R* is a rheostat to adjust the E. M. F. of the machines for short lines, when lines of different lengths are operated from one set of dynamos. *W'* is a triple magnet relay, wound differentially, but not polarized, and therefore responding to currents in either direction. The spring *s* on this relay is so strong that currents from the 100-volt dynamos will not operate it. *W* is a differential polarized relay responding to positive currents coming from the distant station, but held against its back-stop by negative currents. *I* is an induction-coil, having two primary coils *i'* and *i''* and one secondary *i*. *M'*, *M''*, the magnets of *W*, and the two coils *i'* and *i''* are all differentially wound in series, so that the winding in one direction goes through coil *i'* to the line, and the winding in the other direction goes through coil *i''* to the earth. Starting at the dividing point *e*, the circuit to line may be traced as follows: *e*, *f*, *g*, *h*, *i'*, and line; and similarly the circuit to the artificial line is from *e* through *j*, *k*, *l*, *i''*, *m*, *R'* and *C* to *G'*. The secondary coil *i* is connected in series circuit with the winding of the magnet *M'''*. An outgoing current, passing differentially around the secondaries of *I*, will therefore produce no effect upon *i*; but an arriving current induces a current and causes *M''* to pull against the spring *s*.

**2903.** When lever *P* acts alone, being pulled down by the closure of key *K*, a current at a pressure of +100 volts is sent to line over the path *G*, *+100*-volt dynamo, *d*, *3*, *P*, *5*, *P'*, *8*, and *9* to point *e*, where it divides. This current will operate relay *W* at the distant station, but is not strong enough to operate relay *W'*.

**2904.** When *P'* acts alone, a current at a pressure of —300 volts is sent to line over the path *G*, *—300*-volt dynamo, *1*, *P*, *6*, *7*, *8*, and *9* to *e*. This will operate the relay *W'* at the distant station, as it is strong enough to overcome spring *s*, but will not operate *W*, because it is in the wrong direction.

**2905.** When both $P$ and $P'$ act together, the current sent to line is at a pressure of +300 volts over the path $G$, +*300*-volt dynamo, *2*, *6*, *7*, *8*, and *9* to point *e*. This current is strong enough to operate $W'$ at the distant station, and is in the right direction to also operate $W$, so that both will act.

**2906.** When neither key is depressed, the current sent to line is at a pressure of −100 volts over the path $G$ −*100*-volt dynamo, *a*, *4*, $P$, *5*, $P'$, *8*, and *9* to *e*. This current is neither strong enough to operate relay $W'$ at the distant station nor in the right direction to operate relay $W$, so that neither will act.

**2907.** The induction-coil $I$ acts only momentarily when a variation in the current in the line from the dynamos at the distant end of the line takes place. One of its objects is to help out the action of the coils $M'$ and $M''$ of the relay $W'$, but its main function is to steady the action of the armature lever $L$ of the relay $W'$, which it does in the following manner: Suppose that lever $P'$ is depressed at the distant station, thus sending a current of 300 volts to line and causing the relay $W'$ at the home station to attract its armature. The fact that the key $P'$ is down ensures that a voltage of 300 is impressed upon the line at the distant station, but whether that voltage is positive or negative depends on whether the lever $P$ is down or up. Suppose, further, that while $P'$ is depressed, as in making a dash, the lever $P$ is changed from its depressed to its raised position. The voltage sent to line will change from +300 to −300, and, therefore, the current through the home relay $W'$ will change in direction, and in so doing will pass through its zero value. This would tend to suddenly release the armature $L$ and reattract it, thus breaking the dash which relay $W'$ should be recording. The change of the incoming current, however, in passing through coil $i'$ will induce a current in the coil $i$, which will pass through the coil $M'''$, and which is a maximum while the current in the line is at zero. This current, therefore, acts on the armature $L$ to prevent

its fluttering when it should keep its local circuit closed. The current induced is always strongest when most needed, that is, when the current on the line is varying most rapidly.

The lever $L$ of $W'$ is of aluminum, and very carefully balanced. $R'$ and $C$ are a rheostat and condenser, respectively, operating the same, as in Fig. 1086.

$W$ and $W'$ close local circuits having sounders. All such circuits are operated by a 40-volt dynamo, one pole of which is put to the ground, while from the other the circuits are branched. The other terminals of the local circuits are to the ground.

**2908.** The switch $g$ is used for grounding the end of the line through the relays, leaving the transmitting apparatuses cut off. This is for the purpose of making tests, and obtaining a proper adjustment of the relays to incoming currents from the line.

**2909.** Fig. 1088 is a greatly simplified diagram of the quadruplex apparatus just described. $B$ represents the

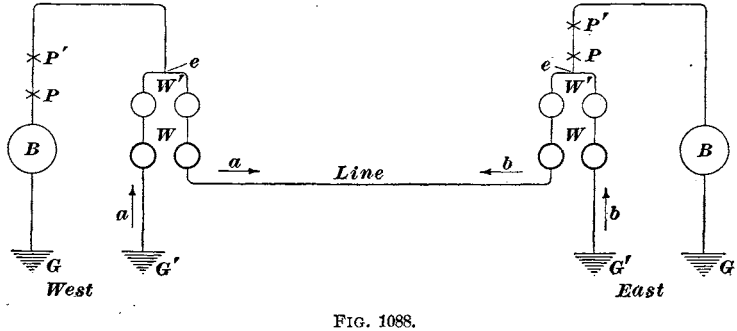


FIG. 1088.

entire group of generators at each end of the line. $W$ and $W'$ refer to the polarized and the three-magnet differential relays, and $P$ and $P'$ to the transmitting levers, $P$ being the one governing the *direction* of current sent to line and $P'$ the one governing the *strength* of the current. The same notation is used throughout, as in Fig. 1087, with the addition of the arrows $a$ and $b$ to indicate the direction of

## TABLE 95.

| | Keys. | | | | Pressure at Point *e*. | | Current in | | | Effective Current. | | Relays Operated. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | West. | | East. | | | | West. | Line. | East. | West. | East. | West. | | East. | |
| | *P.* | *P'.* | *P.* | *P'.* | West. | East. | *R G'.* | *R R.* | *R G'.* | Relays *W* and *W'*. | Relays *W* and *W'*. | *W.* | *W'.* | *W.* | *W'.* |
| 1 | Up | Up | Up | Up | − 100 | − 100 | $\frac{100}{R}(a)$ | 0 | $\frac{100}{R}(b)$ | $\frac{100}{R}(a\ G')$ | $\frac{100}{R}(b\ G')$ | | | | |
| 2 | Down | Up | Up | Up | + 100 | − 100 | $\frac{100}{R}(b)$ | $\frac{200}{R}(a)$ | $\frac{100}{R}(b)$ | $\frac{100}{R}(a\ L)$ | $\frac{100}{R}(a\ L)$ | | | × | |
| 3 | Up | Down | Up | Up | − 300 | − 100 | $\frac{300}{R}(a)$ | $\frac{200}{R}(b)$ | $\frac{100}{R}(b)$ | $\frac{100}{R}(a\ G')$ | $\frac{300}{R}(b\ L)$ | | | | × |
| 4 | Down | Down | Up | Up | + 300 | − 100 | $\frac{300}{R}(b)$ | $\frac{400}{R}(a)$ | $\frac{100}{R}(b)$ | $\frac{100}{R}(a\ L)$ | $\frac{300}{R}(a\ L)$ | | | × | × |
| 5 | Up | Up | Down | Up | − 100 | + 100 | $\frac{100}{R}(a)$ | $\frac{200}{R}(b)$ | $\frac{100}{R}(a)$ | $\frac{100}{R}(b\ L)$ | $\frac{100}{R}(b\ L)$ | × | | | |
| 6 | Down | Up | Down | Up | + 100 | + 100 | $\frac{100}{R}(b)$ | 0 | $\frac{100}{R}(a)$ | $\frac{100}{R}(b\ G')$ | $\frac{100}{R}(a\ G')$ | × | | × | |
| 7 | Up | Down | Down | Up | − 300 | + 100 | $\frac{300}{R}(a)$ | $\frac{400}{R}(b)$ | $\frac{100}{R}(a)$ | $\frac{100}{R}(b\ L)$ | $\frac{300}{R}(b\ L)$ | × | | | × |
| 8 | Down | Down | Down | Up | + 300 | + 100 | $\frac{300}{R}(b)$ | $\frac{200}{R}(a)$ | $\frac{100}{R}(a)$ | $\frac{100}{R}(b\ G')$ | $\frac{300}{R}(a\ L)$ | × | | × | × |
| 9 | Up | Up | Up | Down | | | | | | | | | | | |
| 10 | Down | Up | Up | Down | | | | | | | | | | | |
| 11 | Up | Down | Up | Down | | | | | | | | | | | |
| 12 | Down | Down | Up | Down | | | | | | | | | | | |
| 13 | Up | Up | Down | Down | | | | | | | | | | | |
| 14 | Down | Up | Down | Down | | | | | | | | | | | |
| 15 | Up | Down | Down | Down | | | | | | | | | | | |
| 16 | Down | Down | Down | Down | | | | | | | | | | | |

current in the line and ground branches. This figure is shown in order to make a complete analysis of all currents flowing in the line and ground branches of the relays for each of the sixteen key combinations which may exist.

**2910.** The results of such analysis are shown in part in Table 95. This table has been only partially printed here in order that the student may obtain valuable information and a more comprehensive knowledge of the system by filling in the blank spaces.

The letters in parenthesis, in column "Effective Current," refer to the direction of the current and to the branch carrying the largest current. Thus, $\frac{100}{R}$ ($b$ $G'$) means that the effective current through the coils of the relays is in the direction of the arrow $b$, and is in the ground branch $G'$ instead of in the line $L$.

$R$ in the table refers to the line resistance, that is, the resistance from $e$ at one station to $G$ at the other. It is also equal to the resistance from point $e$ to the point $G'$ at the same station. The resistance of earth return is in each case neglected.

## TELEGRAPH-LINES.

### WIRE.

**2911.** Galvanized iron wire is used for telegraph-lines more than any other, although the use of copper wire for this purpose is rapidly increasing.

The size of iron wire varies from No. 4 B. W. G. (Birmingham Wire Gauge), having a diameter of .238 inch, or 238 mils, as it is usually expressed, to No. 14 B. W. G., having a diameter of 83 mils. Probably a greater amount of No. 8 B. W. G. is in use than any other one size, this having a diameter of 165 mils, a resistance of 12.5 ohms per mile if of good quality, and a weight of 378 pounds per mile.

**2912.** The increasing use of copper for telegraph-line work is largely due to the fact that copper can now be drawn

into wire having very nearly the same tensile strength as iron wire, and having only one-seventh the resistance. The fact that copper wire is practically non-corrosive when exposed to ordinary atmospheric conditions, while even the best grades of galvanized iron wire are always, sooner or later, rendered useless by corrosion, is another very strong argument in favor of copper.

**2913.** The size of copper wire used for telegraph-line work varies from No. 9 American or B. & S. (Brown and Sharpe) gauge, having a diameter of 114 mils and a resistance per mile of .78 ohm, to No. 14 B. & S., having a diameter of 64 mils and a resistance per mile of 2.48 ohms.

**2914.** Various different standards for designating the sizes of wire are in use in this country. These all refer to the sizes of wires by numbers, the smaller numbers referring to the larger wires. The Birmingham Wire Gauge (B.W.G.) and the Brown and Sharpe Gauge (B. & S.) are the ones in most common use. The practice of designating wire by its diameter in mils is, happily, increasing.

**2915. Joints.**—Wires are usually connected in this country by the American telegraph joint, as shown in Fig. 1089. The wires are first placed side by side, and then each

FIG. 1089.

end is wound around the other. The joint should then be soldered, to insure the maintenance of a perfect electrical contact. The joint may be cleaned for soldering by a wash of muriatic acid in which zinc has been dissolved. If the joint is to be covered with insulation, it should not be soldered with acid, but with resin or some soldering compound which contains no acid.

**2916.** Another joint, which is rapidly coming into general use and which should entirely supersede the Ameri-

can telegraph joint, is the McIntire sleeve joint. The ends of the wire are slipped into a double sleeve of copper or iron, shown in Fig. 1090, and the two are then twisted through several turns, making a joint like that shown in Fig. 1091. These joints give excellent service,

FIG. 1090.

FIG. 1091.

always keeping good electrical contact without the use of solder.

### POLES.

**2917.** Overhead telegraph and telephone wires are supported on glass insulators generally on wooden poles, as shown in Fig. 1092, unless appearance or mechanical strength

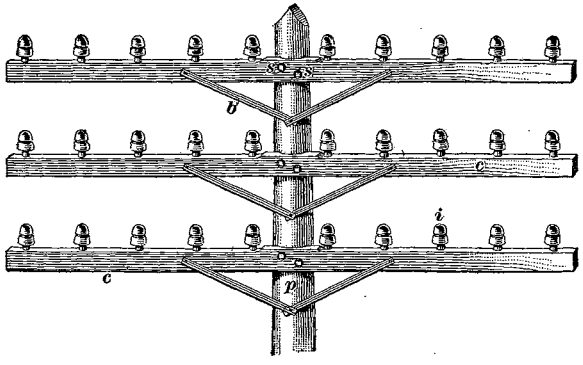


FIG. 1092.

compels the use of an iron pole. Wood is preferable on account of its cheapness and its insulating qualities. The woods used are Norway pine, cypress, red and white cedar, redwood, and chestnut. The last named is best on account of its toughness and elasticity. Poles should be of the best quality, as straight as possible, and well proportioned. Their lengths depend upon the nature of the locality of their erection and the ordinances governing the district. In cities

they should be sufficiently tall, so that the wires will not interfere with the possible work of the fire department, and so that the wires are not dangerously near roofs, fronts, trees, or trolley-wires, which last ought always to be provided with guard wires when passing beneath overhead conductors.

**2918.** It is usually required that poles on which cross arms are to be carried shall have a diameter of not less than seven inches at the top. This dimension is, as a rule, sufficient to specify for any length of pole, for the natural taper of the tree will ensure a proportionately larger diameter at the butt. Larger poles should be used for corners and curves, and when possible should be raked from the inside of the bend.

**2919.** Before erection the poles should be prepared by having the bark peeled and the knots trimmed close ; then they should be cut to the proper lengths, the butts squared, and the tops chamfered or coned. In cities or in conspicuous places, the specifications may call for octagonal or sawn poles. It is in some cases desirable to treat the poles by *creosoting*, or by injecting some preservative into the pores of the wood, after which they may be painted. It is always good practice to coat the butt of the pole with pitch for a distance of six feet.

### CROSS ARMS.

**2920.** The cross arms (*c*, *c* in Fig. 1092) should be made of straight-grained Norway or yellow pine. Their size and length depend on the load each one is to support. They are made from 2 feet long for 2 wires up to 9½ feet long for 10 wires, and 2¾ inches thick and 3¾ inches deep for the shorter lengths, and $3\frac{1}{4}'' \times 4\frac{1}{4}''$ for the longer lengths. The top of the arm is rounded or chamfered, so as to shed water or snow.

**2921.** Gains or slots are cut in the poles at intervals of twenty-four inches. These should be 1½ inches deep and wide enough to fit the cross arm snugly. The gains should be carefully cut, and afterwards painted with white lead or oil paint, to prevent rotting due to the collection of moisture.

In each cross arm are bored two holes for the lag-screws, *s*, *s*, which secure the arm to the pole. The screws with washers are then inserted and screwed up. Lag-screws should never be hammered more than a short distance into the pole, as hammering destroys the holding quality of the fiber of the wood. The screws may also be strengthened by iron braces *b*, which extend from the pole 18 inches below the arm to 19 inches from the pole on each side. The braces are of iron $1\frac{1}{4}$ in. wide, $\frac{1}{4}$ in. thick, and 28 in. long. When the poles are up, the cross arms of adjacent poles should be alternately on the same side and on the opposite side from each other, so that if one arm gives way, either the arm next to it or the next but one will successfully withstand the shock.

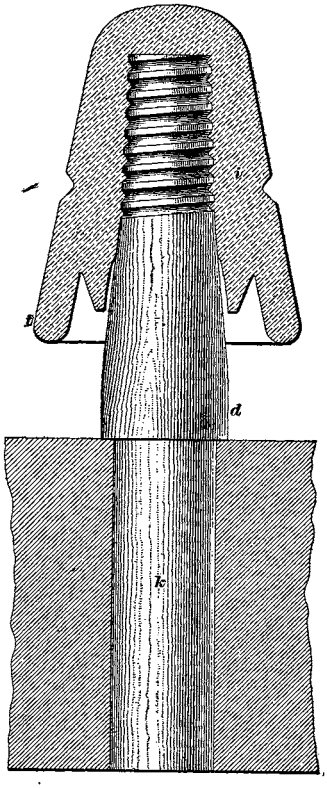

FIG. 1093.

### BRACKETS AND PINS.

**2922.** The **pins** for the insulators (see *d*, *k*, Fig. 1093) should be made of oak or locust. They are turned up, with a coarse thread on one end, on which the insulator is to be screwed. The shank *k* is turned $1\frac{1}{4}''$ or $1\frac{1}{2}''$ in diameter, so as to fit the hole in the arm. If the pins are loose in the hole, they should be fastened by driving a nail through the arm and through the shank of the pin. This is not desirable for a good fitting pin, because if the pin breaks from accident or rot, it may be difficult to extract the nail.

**2923.** If only one wire is to be placed on a pole, a bracket pin (Fig. 1094) is used.

This is so shaped at the lower portion as to lay against

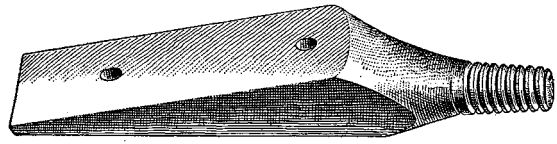

FIG. 1094.

the pole at an angle, and is secured to the pole by two heavy spikes.

### INSULATORS.

**2924. Insulators** in this country are usually made of glass. Porcelain is a better insulator, but is more costly, and under the action of cold the glazed surface becomes cracked. When this happens the moisture soaks into the interior structure, and its insulating quality is greatly impaired, if not rendered useless. The form of insulator shown in Fig. 1093 is much used in telegraph and telephone work. It is bell-shaped, with an interior thread and a single "petticoat" *t*. The resistance offered by insulators follows the same law as the resistance of conductors. The larger the path afforded and the less its cross-section, the greater resistance it will give to leakage from the line. When moisture forms on the glass, it must first cover the outside of the cup, and then proceed up the inner curve before it causes leakage.

In cases where greater insulation resistance is required, double petticoats may be used. The moisture upon such an insulator must extend beyond two inner curves before causing leakage.

**2925.** Fig. 1095 shows the method of attaching the line-wire to the insulator. The line-wire is not passed around the insulator, but is simply laid in the groove and tied there by a short bit of the same size of wire used for the line-wire. In cases where a very heavy line-wire is being used, however, the tie wire may be somewhat smaller.

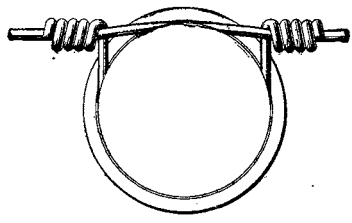

FIG. 1095.

# TELEPHONY.

**2926.** **Telephony** is the art of transmitting articulate speech and other sounds between distant points by means of fluctuations in an electric current flowing between those points.

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## SOUND.

**2927.** **Sound** is produced by molecular vibration. It is usually produced by a vibrating solid, and transmitted through the atmosphere to the drum of the ear. It may, however, be produced by a vibrating liquid or gas. The medium through which sound is transmitted must possess some elasticity, and as all solids, gases, and liquids have this property to a certain extent, transmission may be effected through them with more or less facility. The transmission through air may be explained as follows:

**2928.** In Fig. 1096 $P$ is a thin elastic plate or *diaphragm*, held between two supports $M$ and $N$. Imagine this plate to be in rapid vibration. As it moves to the right there is a condensation of the atmosphere at $C$ and a rarefaction at $R$. The condensation at $C$ is communicated to the particles of air at $A$ at the right of $C$, and by them to the particles of air at their right, and so on. A wave of condensation, therefore, travels through the air, gradually diminishing in intensity, until it is finally lost. In its movement to the left, the plate causes a rarefaction at $C$, and the particles of air from $A$ rush into it, thus causing a rarefaction at $A$, which, in turn, is filled by particles in the space at its right. Thus, a wave of rarefaction follows the wave of condensation, and this, in turn, is followed by another wave of condensation, and so on as long as the plate continues to vibrate. A similar set

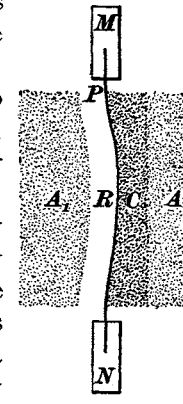

FIG. 1096.

of waves is also sent out in the opposite direction by the other side of the plate. Waves of this description, which are capable of acting on the ear to cause the sensation of sound, are called sound-waves.

### CHARACTERISTICS OF SOUND.

**2929.** All sounds have three characteristics, variations in which enable us to distinguish between different sounds. They are *loudness*, *pitch*, and *timbre*.

**2930.** **Loudness** is that characteristic of sound which depends on the amplitude of the sound-wave. Thus, a certain note on the piano may be loud or soft according to whether we make the string vibrate violently or not. Loudness is the intensity of sound.

**2931.** **Pitch** depends entirely on the rate of vibration of the body producing the sound. A low rate of vibration produces low tones, and a high rate shrill or high tones. The difference between the sounds emitted by long and short strings of the same material and of equal size and tension is one of pitch.

**2932.** **Timbre** is the *quality* of sound, and depends on the form of the sound-wave. The difference between a certain tone on the flute and the same tone on the violin is one of timbre.

### ARTICULATE SPEECH.

**2933.** The successive vibrations of the human voice forming distinguishable and intelligible sounds are called

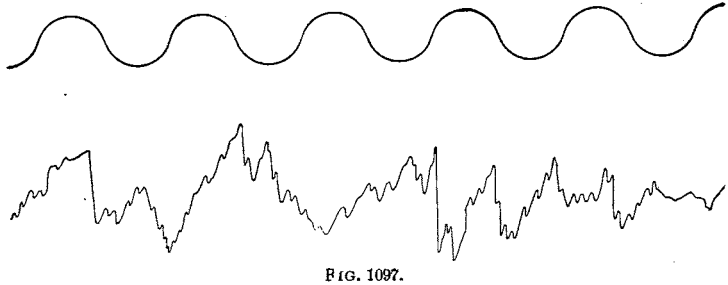

FIG. 1097.

*articulate speech.* The vibrations serving to make up spoken words are probably the most complex in the whole realm of sound. The difference between a simple and a complex series of sound-waves may be comprehended by reference to Fig. 1097, in which the upper line represents the waves of a simple musical sound—as, for instance, that of a tuning-fork—and the lower line represents the vastly more complex waves set up by the human voice.

## ACTION OF THE TELEPHONE.

**2934.** In electric telephony the transmission of sound is accomplished by making one plate or diaphragm at the transmitting end of the line take up or respond to the waves of the sound to be transmitted, and causing by electric means another diaphragm at the receiving end of the line to vibrate in exact accordance with it.

### THE MAGNETO-TELEPHONE.

**2935.** The production of the first successful speaking telephone is usually accredited to Prof. Alexander Graham Bell. The action of Bell's instrument, which is the simplest

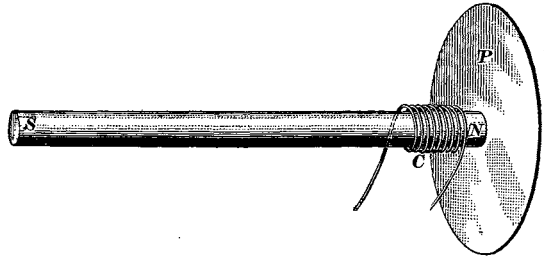


FIG. 1098.

form of electric telephone, will be understood by reference to Fig. 1098 in connection with the following description :

**2936.** A thin diaphragm $P$ of soft iron is mounted close to, but not touching, one pole of the permanent magnet $N S$. A coil of fine insulated wire $C$ is wound about one end

of the magnet, and the terminals of this coil are connected directly in the circuit in which the instrument is to be used.

It is evident that the diaphragm will normally be strained slightly towards the magnet by the attraction of the latter. If a current is sent through the coil in such a direction that the lines of force set up by it coincide with those of the permanent magnet, the strength of the magnet will be increased, and the diaphragm will be pulled still closer to the pole. If, however, a current is sent through the coil in such a direction as to set up lines of force opposing those of the magnet, the strength of the magnet will be diminished and the diaphragm allowed to spring farther away from the pole.

**2937.** If a current which is undulatory, but always in the same direction, is sent through the coil, the lines of force induced by it in the magnet will increase while the current is increasing, and will decrease while it is decreasing. Thus, whether the lines induced by the coil are in the same direction as those of the magnet or not, a varying pull on the diaphragm will cause vibrations in the latter which will be in harmony with the changes in current.

**2938.** Again, if the current is an alternating one—that is, one which flows first in one direction and then in the other—the lines set up by it in the magnet will change their direction every time the current changes its direction. They will thus, while flowing in one direction, add to the strength of the magnet, and while flowing in the other diminish it, thus producing the same effect on the diaphragm as in the case of the undulatory current.

**2939.** In the preceding article we have seen that an alternating current sent through the coil would cause the diaphragm to vibrate. The converse of this statement is true ; for if the diaphragm of the instrument is caused to vibrate by some external means, corresponding alternating currents will be caused to flow in the coil—provided, of course, its circuit is closed. This is true because the movement of the diaphragm towards the pole of the magnet increases the number of lines of force passing through the coil, and, as has

been pointed out in Principles of Electricity and Magnetism, the changing of the number of lines of force through a closed circuit will cause currents to flow in that circuit. Similarly, when the diaphragm moves away from the pole, the number of lines passing through the coil will diminish, and thus cause a current to flow in the opposite direction. Thus, for an outward movement of the diaphragm we will have a current in the coil in one direction, and for an inward movement a current in the other direction.

**2940.** Two instruments like that shown in Fig. 1098, if connected in one circuit, as shown in Fig. 1099, represent

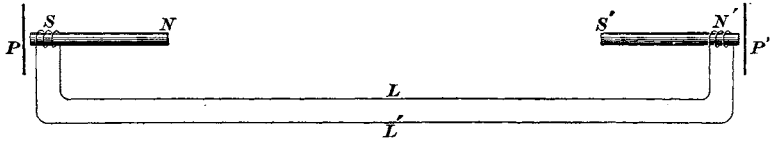


FIG. 1099.

the apparatus by which Bell actually brought about successful telephone transmission.

When the soft iron diaphragm $P$ is spoken to, it takes up the vibrations of the sound-waves, and thus causes changes in the strength of the magnetic field in which the coil lies. These changes, as shown above, cause currents, first in one direction and then in the other, that is, an alternating current, to flow in the circuit. These currents vary in direction, strength, and frequency of alternation in every way in unison with the movements of the diaphragm, and, therefore, have all the characteristics corresponding to the relative loudness, pitch, and timbre of the sound causing the diaphragm to vibrate.

Passing along the line-wire, these feeble currents alternately strengthen and weaken the permanent magnet at the other instrument, and cause it to exert a varying pull on the diaphragm, which thus vibrates in unison with the changes in current, and, therefore, faithfully reproduces the first sound.

The action described as taking place in the instrument *spoken to* is that of a *transmitter*, and that in the instrument which *repeated the sound* is that of a *receiver*.

**2941.** A **telephone transmitter** is an instrument which takes up the vibrations of the sound to be transmitted, and causes corresponding fluctuations of electric current to flow in the circuit in which it is connected.

**2942.** A **telephone receiver** is an instrument which receives fluctuating currents corresponding to sound-waves, and translates them into distinguishable sounds.

**2943.** The single instrument so far described, and consisting of a permanent magnet, a coil, and a vibrating iron diaphragm, is called a *magneto-telephone*. Many forms of this instrument have been devised, but all contained the same essential parts, though frequently these parts were duplicated. As a receiver, the magneto-telephone is marvelously efficient. Currents so small that no other instrument can detect their presence produce sounds readily audible in it. As a transmitter, however, it has not proved generally successful, as the amount of energy derived from the sound-waves is so extremely small that the currents generated by the movements of the diaphragm soon become lost when transmitted over lines of considerable length.

### THE BATTERY TRANSMITTER.

**2944.** To overcome the difficulty due to the weak transmission of the magneto-instrument, a class of instruments depending on an entirely different mode of operation was devised. These instruments, instead of causing the transmitter to act as a generator of electricity, serve to produce variations in the strength of a current already flowing from some other source. The *battery transmitter*, or *microphone*, as instruments of this class are called, depends for its action on the fact first pointed out by Prof. Hughes, that the electrical resistance between two bodies in light or loose contact was made to vary greatly by slight

changes in the pressure between them. All conductors have this property to a greater or less extent, but it is exhibited by carbon in by far the most marked degree of any known substance.

**2945.** In Fig. 1100, $D$ is a diaphragm carrying a carbon button $B$, and $C$ is a similar button carried on a light spring $S$ in such a manner as to bear lightly against the button $B$. The diaphragm and spring form the terminals of wires leading to a receiver $R$, one of which wires includes a battery $B'$. While the instrument is at rest, a steady current flows through the circuit, of which the two carbon buttons and the coil of the receiver form a part. If, however, the

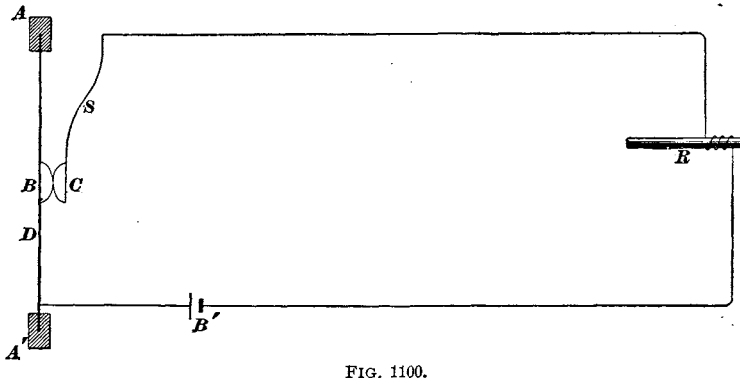


FIG. 1100.

slightest jar is given the diaphragm, a variation in pressure at the point of contact between the buttons will take place, which will cause a corresponding variation in the resistance of the contact. This, in turn, produces a fluctuation in the strength of the current, which, as before, travels along the line-wire and acts on the diaphragm of the receiver. Sounds, such as spoken words, uttered before the diaphragm $D$, will cause it to vary the pressure between the buttons in such a manner as to produce fluctuations in the current flowing in the circuit from the battery $B'$, which fluctuations will be in exact accordance with the sound-waves, and will, therefore, cause the diaphragm of the receiver to vibrate in unison with that of the transmitter. We thus see that

the battery transmitter serves, not as a generator of electricity, but as a valve to control the flow of current from a separate generator in the same circuit.

**2946. Theory of the Battery Transmitter.**— Transmitters which depend for their action on the variation in pressure between two or more electrodes are called microphones. Their action has been the subject of much discussion. Undoubtedly the variation in resistance is due directly to changes in the *area of contact*, brought about by changes in pressure between the electrodes. If two rubber balls be touched lightly together, the area of their contact will be but a mere dot. If the pressure between them be increased, more and more of the surfaces of the balls will be in contact, and the amount of area so in contact will depend on the pressure and on the nature of the material. It is easy to see that in the case of an elastic conducting material like carbon, the surface of contact would vary in the same way with the pressure, though not to such an extent as between the two rubber balls, and that the electrical resistance between them would decrease as the area of contact increased. This is a perfectly satisfactory theory for the phenomena of the microphone, and experiments recently performed tend to show that the variable resistance is due to variation in surface contact entirely, to the exclusion of all the other more complicated theories which have been advanced.

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### THE INDUCTION-COIL IN TELEPHONY.

**2947.** One more step will lead us to understand the principles of all the apparatus actually used in the transmission of speech proper in practice to-day. Assume that in Fig. 1100 the resistance in the entire circuit is normally 1000 ohms, and that the transmitter is capable of producing a change of resistance of 1 ohm. It will be evident that in this case the transmitter will be able to vary the resistance of the entire circuit by only $\frac{1}{1000}$ of its total value, and that the variation of the current flowing will be but $\frac{1}{1000}$ of its value.

Consider, now, what will be the effect if the transmitter $T$ is put in a local circuit containing a battery $B$ and the primary coil $P$ of an induction-coil, as shown in Fig. 1101.

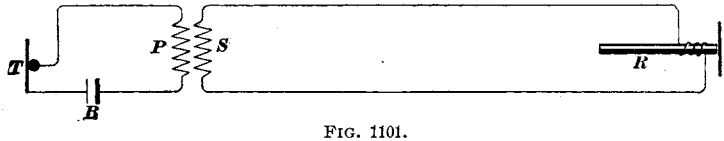


FIG. 1101.

The resistance of the local circuit may be made very low, and we will say that it is 10 ohms. The transmitter is still able to produce a variation in the resistance of the circuit of 1 ohm, from which it follows that the total change of the current value will be $\frac{1}{10}$ of its normal amount, or 100 times as great an amount as in the case of Fig. 1100. When it is considered, in addition to this, that the normal value of the current in the local circuit it far greater with the same battery power, owing to its low resistance, than when the battery is directly in the line, it will be seen that the difference between the two systems is still further augmented. The fluctuations in the current in the local circuit in Fig. 1101 induce corresponding currents in the secondary winding $S$ of the induction-coil, which currents flow over the line circuit and cause the diaphragm of the receiver at the distant station to vibrate.

**2948.** The primary winding of the induction-coil is composed of a small number of turns of comparatively coarse wire, while the secondary winding is composed of a much greater number of turns of fine wire. The electromotive force in the secondary is, therefore, many times that in the primary, thus enabling the secondary currents to overcome great line resistances to better advantage than the low voltage primary currents.

**2949.** The current in the primary or local circuit of a telephone is *undulating, but not alternating.* It never changes its direction. The current in the secondary, however, is *alternating* in character. This fact is usually a little

puzzling to the student, but its explanation is very simple. When the current in the primary increases, the number of lines of force through the core of the induction-coil increases. When the current in the primary decreases, the number of lines of force through the primary decreases. It has been shown in Principles of Electricity and Magnetism that the direction of an induced current in a coil depends on whether the lines of force through that coil are increasing or decreasing—provided, of course, the lines continue in the same direction. In the induction-coil, in the case in hand, the lines of force remain in the same direction, but are constantly increasing and decreasing, and, therefore, the current in the secondary must be alternating.

## RECEIVERS AND TRANSMITTERS.

### THE SINGLE-POLE RECEIVER.

**2950.** The instrument most largely used in this country as a receiver is that shown in Fig. 1102. *M* is a compound magnet composed of two pairs of permanently magnetized steel bars, arranged with *like poles together*. These pairs of bars have clamped between them at one end a soft iron pole-

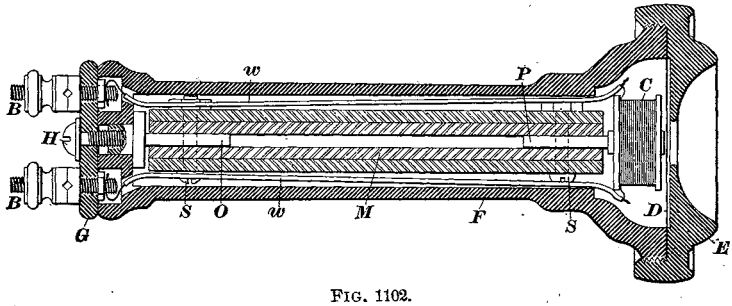


FIG. 1102.

piece *P*, and at the other end a block *O*, also of iron. On the pole-piece is wound a coil *C* of fine insulated copper wire, usually No. 38 B. & S. gauge. The magnet is encased in a shell of hard rubber composed of three parts *E*, *F*, and *G*. Between *E* and *F* is clamped the diaphragm *D* of thin

soft iron, the space left between the diaphragm and the pole-pieces being about $\frac{1}{64}$ of an inch. Two binding-posts $B$, $B$ are secured to the tail-piece $G$ of the shell, and these are connected by heavy wires $w$, $w$ to the terminals of the coil $C$, all connections inside the instrument being soldered. The resistance of these instruments is usually 75 ohms.

### BIPOLAR RECEIVERS.

**2951.** Within the last few years a form of receiver presenting two poles to the diaphragm has come into somewhat extended use, and will undoubtedly eventually supersede the single-pole instrument entirely. In these the magnet is made in substantially horseshoe form, and each pole carries a flat coil, which are brought quite near together and close to the diaphragm. The two coils are connected in series, and usually have a joint resistance of 100 ohms, although for certain purposes it is sometimes made very much lower than this.

### THE BLAKE TRANSMITTER.

**2952.** The Blake transmitter is a form of microphone that has been for the past twenty years in more extensive use in the United States than any other transmitter. This is not because it was better, or even as good as others, but because it was fairly efficient, required little battery power, was cheap, not easily put out of order, and easily repaired when repairs were needed.

**2953.** Referring to Fig. 1103, $O$ is the front board of the transmitter box, having a suitably shaped opening $o$ to receive the sounds. $R$ represents a cast-iron ring, forming a framework for the instrument. It is screwed to the inside of the board $O$, and is provided with two lugs $r$ and $r$, which form parts of the same casting. On a properly turned seat in this ring is mounted the diaphragm $D$ of soft sheet iron, of about double the thickness of that used for receiver diaphragms. Around the edge of the diaphragm is stretched a soft rubber band, serving to insulate it from the ring

and at the same time to allow it to vibrate as a whole. Two damping springs, not shown, tipped with rubber and screwed to the edge of the ring, serve to press the diaphragm against its seat. These also prevent too great an amplitude of vibration of the diaphragm, and keep it from vibrating in separate parts instead of as a whole.

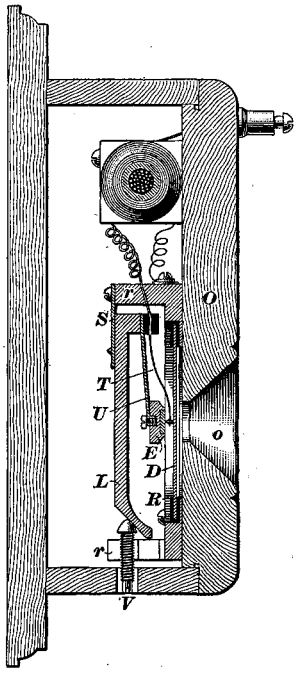


FIG. 1103.

Flexibly mounted on the lug $r$ by the spring $S$ is a bent lever $L$, on the upper extremity of which is mounted on an insulating block a light spring $T$, carrying at its lower end a small piece of platinum, which rests against the center of the diaphragm. On a heavier spring $U$, also mounted on the lever $L$, but not insulated from it, is carried the back electrode $E$, formed of a block of carbon set into a brass block. The platinum piece which forms the front electrode is pressed by its spring $T$ away from the diaphragm, towards the carbon electrode; but the pressure of the spring $U$, which is much the stronger of the two springs, overcomes this and keeps the platinum pressed firmly against the diaphragm. The frame $R$, which is in electrical connection with the back electrode, forms one terminal of this instrument, while the spring $T$ forms the other terminal.

The adjustment of pressure between the electrodes is accomplished by turning the screw $V$, which wedges against the inclined surface on the lower end of the lever $L$ and moves it backwards or forwards in an obvious manner. This transmitter, when in good adjustment, articulates well, and transmits the quality of the voice with wonderful fidelity. It is not very powerful, however, and will not stand more than one cell of battery, as stronger battery power will cause the instrument to give forth a singing or sputtering sound.

### THE HUNNINGS TRANSMITTER.

**2954.** Hunnings introduced the idea of using granulated material, preferably carbon, as the variable resistance medium of transmitters, and all the so-called long-distance instruments are now constructed on this principle. One of the most simple of these transmitters is shown in Fig. 1104. Clamped between the block *B* and the mouthpiece *A* is a thin diaphragm *D*, usually of carbon. Within a chamber behind the diaphragm is mounted a block of carbon *C*, and the space between this and the diaphragm is filled or partially filled with granulated carbon, resembling ordinary gunpowder in all outward appearance. The two binding-posts *E* and *F* are connected, respectively, with the diaphragm and with the carbon block, and the circuit between them is completed by the granulated carbon.

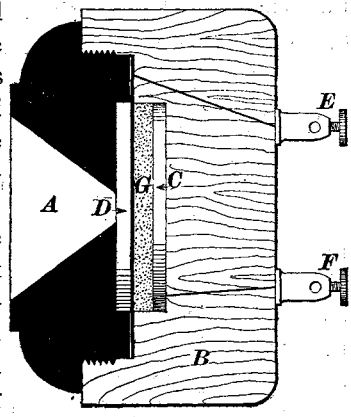

FIG. 1104.

**2955.** The sound-waves entering the mouthpiece produce vibrations in the diaphragm ; this varies the pressure at the multitude of contacts between the granules, and thus varies the resistance of the circuit. In these transmitters it is important that the granules lie loosely in their chamber, and to this end the chambers in many forms of instrument are only half filled.

**2956.** The principal objection to transmitters of the Hunnings type, but one that in recent instruments is almost overcome, is known as *packing*. When an instrument is packed, the granules become wedged between the back block and the diaphragm, thus preventing the free vibration of the latter. Sometimes granules may become packed by reason of some sudden mechanical shock, sometimes by reason of the slow settling down of the small particles between

the large ones, thus forming a compact mass, and sometimes by reason of moisture from the breath or from some other source. When due to the first or second causes, a violent shaking of the transmitter sidewise will usually remedy it; but when due to the third, the instrument should be taken apart and refilled.

### THE SOLID BACK TRANSMITTER.

**2957.** Of the many improvements on the Hunnings type of instrument, the **solid back** or **White transmitter** is in most general use for long-distance work. In this the back electrode is of carbon, and is carried in a heavy brass block mounted on a firm bracket attached to the front plate of the instrument. The chamber in which the back electrode lies also contains the front electrode, also of carbon, which is attached to the diaphragm by a short piston-rod. The space between the electrodes is nearly filled with very fine granules of carbon, and the chamber is then closed by a thin mica diaphragm, through which the piston-rod passes. The main diaphragm is of metal, and is heavily damped by means of rubber-tipped springs, similar to those used in the Blake transmitter.

## CALLING APPARATUS.

**2958.** So far we have considered only the apparatus and methods employed in the actual transmission of speech. Hardly of less importance than these are the means for attracting the attention of a party at a distant station, with whom it is desired to converse. For this purpose the magneto generator and the polarized bell or ringer are almost universally used.

### THE MAGNETO GENERATOR.

**2959.** The magneto generator is in reality the simplest form of dynamo. It consists essentially of an armature of iron, wound with a large number of turns of fine insulated copper wire, and adapted to be rapidly revolved between the poles of a powerful permanent magnet. Its principles

of operation can be readily understood by reference to the left-hand portion of Fig. 1105. *A* represents the armature,

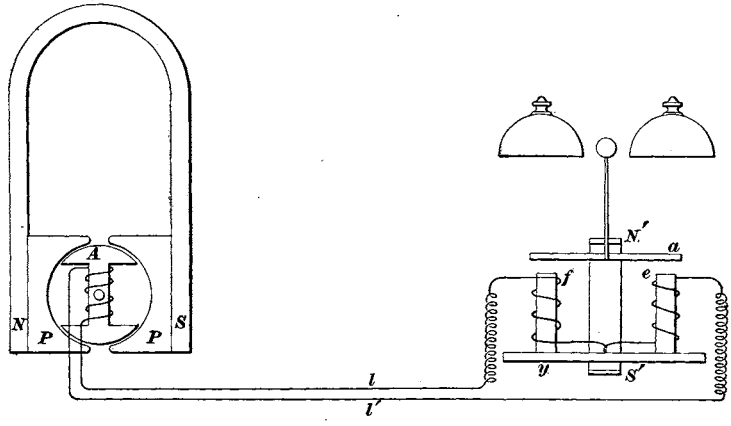


FIG. 1105.

around the shank of which are wound the coils of wire, as shown. *S* and *N* are the south and north poles of the permanent magnet, and *P*, *P* are the pole-pieces, usually of soft cast iron, attached to the magnets and bored out so as to afford a space in which the armature may turn. The armature is seen to be in a rather powerful magnetic field, the lines of force forming which pass from the north to the south pole of the magnet.

When the armature is in a position with its shank horizontal, that is, when turned 90° from the position shown, all the lines of force pass through it, and therefore through the coils, as they follow the path easiest for them to travel. When turned 90° farther, it reaches a point like that shown in Fig. 1105, where no lines pass through the coils, because their plane is parallel to the direction of the lines. Thus we see that in a complete revolution of the armature, starting at a point where the plane of the coils is vertical, the lines of force passing through the coils will decrease from a maximum to zero, and then to a maximum in the other direction, and then decrease to zero and increase to the maximum in the first direction again. We have seen in

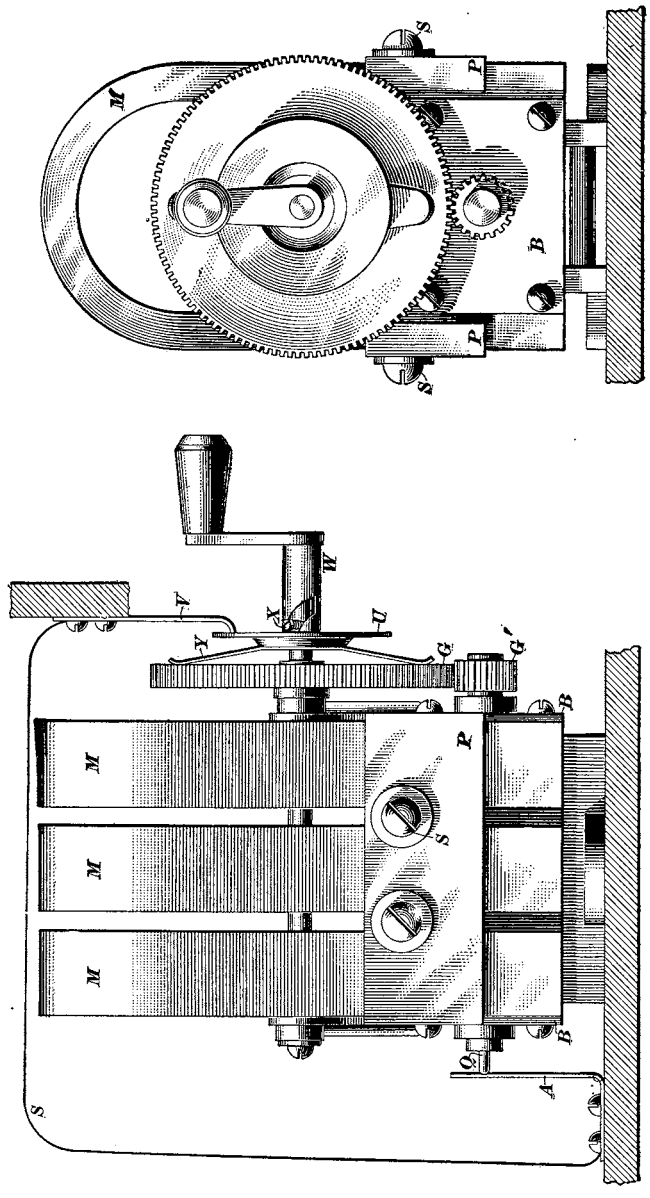


FIG. 1106.

Principles of Electricity and Magnetism that a coil moving in a field of force so as to include within itself more or less of the lines will have induced currents set up in it, and that the direction of this current depends on the direction of the lines through the coil, and on whether they are increasing or diminishing. Now, since during each complete revolution of the armature the number of lines passing through the coil will vary from a maximum in one direction through zero to a maximum in the other direction, and then through zero again to the first maximum, it follows that two impulses of current will flow in the coil, and these impulses will be in opposite directions. The current is, therefore, an alternating one, and is of considerable strength and voltage.

**2960.** A common form of magneto generator is shown in Fig. 1106, in which *M*, *M*, *M* are the permanent magnets, bent into horseshoe form from bar steel especially adapted for the purpose, then hardened flint hard, and magnetized, usually by stroking them across the poles of a powerful electromagnet. These magnets are clamped to their cast-iron pole-pieces by screws *S*, *S* passing through washers and clamping plates *P*, *P*, and then between the magnets, as shown. The end-plates *B* are of brass, secured to the ends of the pole-pieces by screws. These end-plates form bearings for the armature and also for the crank-shaft carrying the large gear-wheel *G*, which engages the small gear-wheel *G'* secured directly to the armature shaft. The pole-pieces are bored out accurately and the armature turned to fit, so that the air-gap between them will not be more than $\frac{1}{64}$ inch. The winding on the armature is usually of No. 36 B. & S. gauge silk-covered wire, and the resistance about 600 ohms. One terminal of the winding is soldered to a pin driven in the armature core, and thus makes contact with the frame of the machine through the bearings. The other end of the winding is fastened to a pin *Q*, driven into the end of the armature spindle, but insulated from it. Connection with this pin is made by the spring *A*, which, therefore, forms the other terminal of the machine.

**2961. The Automatic Shunt.**—A very important adjunct to the magneto generator is the automatic shunt. It is found desirable that while the generator is not in use, the resistance of the armature shall be removed from the circuit by having a path of practically no resistance closed around it. This is accomplished in a variety of ways, but the one shown in Fig. 1106 is a good one. The plate or collar *U* normally bears against the spring *V*, which is connected by a short wire *s* with the spring *A*. This forms a low-resistance shunt or short circuit around the winding of the armature. When the crank of the generator is operated, the slotted sleeve *W*, which is loosely mounted on the shaft, is automatically pressed towards the generator by means of the pin *X* riding on the inclined sides of the slot in the sleeve. This presses the collar *U* away from the spring *V*, thus breaking the shunt. This always happens before the generator starts to turn, and hence always removes the presence of the shunt when the generator is being operated. As soon as the hand is removed from the crank, the spring *Y* presses the collar *U* again into contact with the spring *V*.

There are several reasons why it is desirable to have this shunt around the armature. One is on account of the danger of burn-outs, due to lightning and other causes. The other reasons will be made clear as we progress.

**2962.** The voltage given out by these machines depends on the strength of the magnetic field, on the number of turns of wire on the armature, and on the speed of rotation. At the usual rate of turning by hand, a machine for ordinary service will generate a pressure of from 65 to 75 volts.

## THE POLARIZED BELL.

**2963.** The polarized bell, or ringer, as it is more often called, is a device for receiving the alternating currents generated by a magneto generator and causing them to produce audible signals.

The bell is shown in diagram in Fig. 1105 in connection with a magneto generator and in a complete form in Figs.

1107 and 1108. Referring to the two latter figures *m*, *m* are the coils of an electromagnet, of which *y* is the yoke and *a* the armature. The cores of the magnets, the yoke, and armature should all be of the best grade of annealed soft iron. The bracket *b*, on which the armature is pivoted, is of brass, and is carried on the brass standards *g*, *g*, which also pass through and support the yoke *y*. Carried by the armature is the hammer *h*, consisting of a slender brass rod and a ball for striking the gongs. Carried also on the bracket *b* is the permanent magnet *N S*, bent as shown in Fig. 1108.

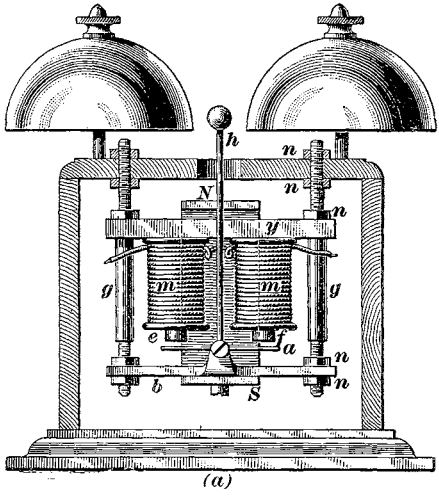


FIG. 1107.

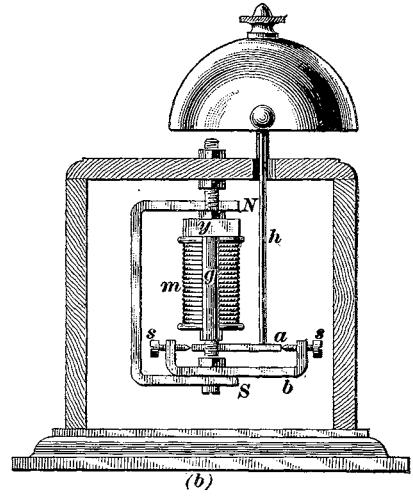


FIG. 1108.

This magnet serves by induction to give the yoke *y*, and consequently the core ends or poles *e* and *f*, a positive polarity and the armature *a* a negative polarity. Each end of the armature will, therefore, be attracted with about equal force by the two poles *e* and *f*, and will adhere to the one it happens to be nearest to. The two coils are wound in opposite directions (see Fig. 1105), so that a current traversing them in series will tend to make one of the poles positive and the other negative. We will say that a current is sent through the coils in such a direction as to make *e* positive and *f* negative. This will strengthen *e* and weaken *f*, and, therefore, *a*

will be attracted by *e*, causing the hammer to strike against the right-hand gong. If the current is reversed, *f* will be made stronger and *e* weaker, and the armature will be attracted by *f*, causing the hammer to strike against the left-hand gong. If the impulse of current is so strong as to entirely reverse the polarity of the pole which it weakens, that pole will then tend to repel its end of the negatively polarized armature, thus aiding the attraction of the other pole.

**2964.** For ordinary purposes the coils are wound with a No. 31 B. & S. gauge silk-covered copper wire to a resistance of 120 ohms. For some purposes, however, they are wound to a much higher resistance—1,000, and even 5,000 ohms.

### COMPLETE MAGNETO-BELLS.

**2965.** The term magneto-bell is usually applied to the combination of a magneto generator and ringer mounted in a box, as in common use in telephone work. A fairly good machine will ring its own bell through a resistance of 10,000 ohms, and this is the test usually applied to them.

## COMPLETE TELEPHONE INSTRUMENTS.

### THE HOOK SWITCH.

**2966.** We have now considered the apparatus for sending and receiving both articulate speech and signal. These two sets of apparatus perform entirely separate functions, and in order that one may not interfere with the other, it has been found necessary to provide means for cutting one set out of circuit while the other is in use. It is evident that during the idle periods of the instrument it is necessary that the ringer should be left in circuit, in order that an incoming call may be received. As soon, however, as a call is received or sent, it is better to cut the calling apparatus out of circuit, so that the telephone, or "voice currents," as they are called, will not have to pass through the high resistance

of the ringer and generator coils. The alternative switching of the talking and calling apparatus into circuit was at first accomplished by ordinary hand switches, but it was soon found that people could not be relied upon to operate them, and a device, now in universal use, was designed to accomplish these changes of circuit automatically, without the volition of the user of the telephone. Such devices are usually termed hook switches.

**2967. The Warner Hook Switch.** — This is the switch most largely used by the Bell Company, and is shown in Fig. 1109. The lever *l*, carrying the hook for the receiver on its outer end, is pivoted to a bracket screwed to the inside of the magneto-box. The hook is held in the position shown, when released from the weight of the receiver, by the action of the spring *e* pressing against the rubber knob *f*. When the hook is depressed, the spring *e* breaks contact with *f*, and establishes contact with the metal pin *h*, which is secured directly to the under side of the lever. The short arm *a* of the lever carries on its under side a hard-rubber block *b*. The springs *c* and *d* press outwardly from the side of the box, and rest against the metal arm *a* when the hook is raised, and against the rubber block *b* when the hook is depressed. The spring *g* always presses against the rounded portion of the lever, so as to ensure a perfect contact between it and the bracket.

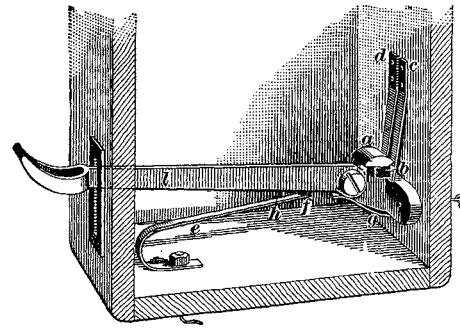

FIG. 1109.

**2968.** The connections with this hook to the various circuits of the telephone are made as follows: One side of the line-wire terminates in the bracket on which the hook is pivoted. The generator and ringer circuit terminates in

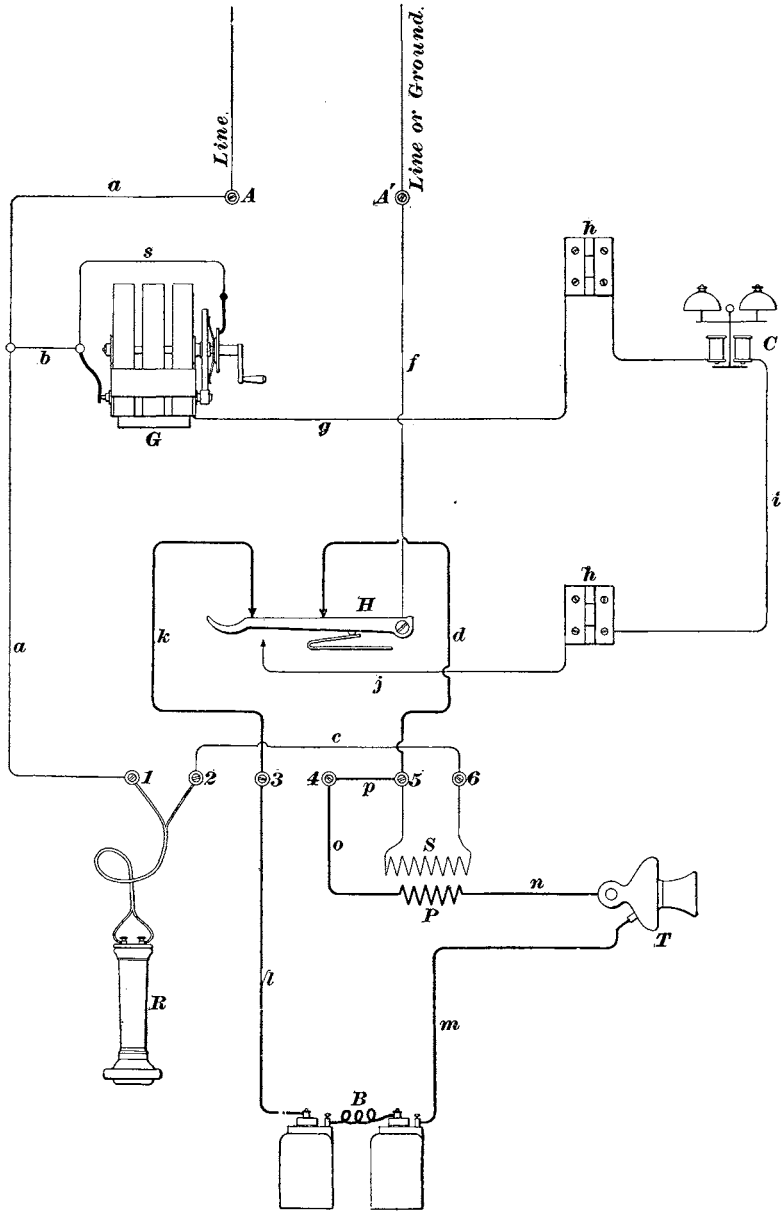


FIG. 1110.

the spring *e*, so that when the hook is depressed, the connection is from line through the calling circuit. One side of the local transmitter circuit terminates in *d*, and one side of the secondary or receiver circuit terminates in *c*, so that when the hook is elevated, the primary circuit will be completed and also the secondary. The action of this switch and of hook switches in general will be more readily understood by considering the circuits of a telephone-instrument.

### CIRCUITS OF A TELEPHONE.

**2969.** In Fig. 1110 is shown the complete organism of an ordinary telephone, such as is used in most exchanges. *G* is the magneto generator, *C* the ringer, or call-bell, *R* the receiver, *T* the transmitter, *H* the hook switch, *B* the battery, and *S* and *P* the secondary and primary, respectively, of the induction-coils. The hook lever is pivoted at its right-hand end, and is free to vibrate between the contacts on its lower and upper sides.

While supporting the receiver, the lever is depressed, against the force of a spring, into engagement with the lower contact. When the receiver is removed, however, the spring immediately moves the lever into engagement with the upper contacts, in which position it is shown.

**2970.** Supposing the receiver to be supported on the hook ; an alternating current from the magneto generator of some distant station may enter the instrument, we will say, by the line-wire terminating at binding-post *A*. It will then pass by wires *a* and *b* to the armature spring of the generator ; two paths will then be presented, one through the armature winding to the frame of the generator and to wire *g*, and the other through the shunt wire *s*, shunt spring and collar on the generator shaft, to frame of the generator and wire *g*. As the latter path is a short circuit of practically no resistance, nearly all the current will pass through it. From the wire *g*, the current will pass through the upper hinge *h* on the lid of the box, thence through the coils of the polarized bell *C*, and thence by wire *i*, lower hinge *h*, and

wire *j* to the lower contact of the switch. As the lever is depressed, the current will pass through the lever and by wire *f* to the return side of the line or to ground, according to whether a double or a single wire is used. This current will cause the gongs to sound, and thus give the desired signal. Let us now suppose that, instead of receiving a signal, the generator is operated to send one. The hook being down, the current from the generator will travel over exactly the same path as that just traced, but there will be no shunt circuit through wire *s*, because the operation of the generator will break the continuity of that circuit between the shunt spring and the collar on the shaft.

**2971.** After having sent or received a signal, the receiver is removed from the hook, and the apparatus is connected as shown in Fig. 1110. It will be noticed that the calling circuit is now open at the lower contact point of the hook switch. The circuits through the talking apparatus have, however, been closed at the upper contacts, and are as follows: Starting at binding-post *A*, a current coming over the line would pass through wire *a*, receiver *R*, wire *c*, secondary winding *S*, wire *d* to upper right-hand contact, to hook lever, and thence by wire *f* to binding-post *A'*. This is called the secondary circuit, and contains only the receiver and secondary coil of the induction-coil. Another circuit is also closed by the rising of the switch-lever. This contains the battery, transmitter, and primary winding of the induction-coil. The wires forming the primary circuit are shown by heavy lines, and, beginning at the battery, may be traced as follows: Battery, wire *m*, transmitter *T*, wire *n*, primary winding *P*, wire *o*, wire *p*, wire *d*, right-hand upper contact, lever, left-hand upper contact, and by wires *k* and *l* back to battery.

In this position the action of the instrument is the same as that already described in Arts. **2944** to **2949,** inclusive. The transmitter causes fluctuations of the current flowing in the primary circuit, and these act inductively on the secondary circuit, causing corresponding alternating currents to pass out over the line.

**2972.** It is usual in modern telephone-instruments to mount the generator, ringer, and hook switch all in the same box. The terminals of the circuits leading from these parts are led to binding-posts *A* and *A'* on the top of the box for the line terminals, and posts *1*, *2*, *3*, *4*, *5*, and *6* on the bottom of the box. The numbered posts on the bottom are for facilitating the connecting of the other parts of the telephone not properly included in the magneto-box. The usual arrangement is that shown, where the two right-hand posts are for the secondary circuit, the two in the middle for primary, and the two on the left for receiver.

**2973.** The greatest care should be observed in making connections in a telephone. All permanent joints should be soldered, and in soldering, acid should not be used as a flux, as this frequently eats off the wires, causing open circuits. Besides this, the appearance of an instrument daubed inside with acid is very untidy.

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### BATTERIES.

**2974.** The battery used with the Blake transmitter is in nearly all cases one Leclanché cell. Two or more cells will, as a rule, cause undue heating between the electrodes and a buzzing or crackling noise. With the various forms of Hunnings transmitters, more battery power is needed. Two cells of any good sal ammoniac battery will, under ordinary circumstances, give good results, and are generally used. In long-distance work, however, the Fuller bichromate battery is coming into favor rapidly, two and sometimes three cells being used. The advantages of this cell are that it does not become exhausted so quickly as the sal ammoniac cell, and that it has a higher E. M. F. and a lower internal resistance, and is, therefore, capable of giving a greater current. Storage-batteries are also used to an increasing extent, and where there are facilities for charging them they give excellent results, on account of their exceedingly low internal resistance, their constancy of E. M. F., and their cleanliness and longevity.

## TELEPHONE EXCHANGES.

### PARTY LINES.

**2975.** When several parties desire intercommunication by telephony, the simplest way is to place the instruments of all on one line circuit. Then, when one party turns his generator crank the bells of all the parties will ring. In order to distinguish between the calls, a code of signals is arranged, usually consisting of various combinations of long and short rings. Lines of this description are called party lines, and really form the simplest type of telephone exchange. Instruments on party lines may be arranged in two different ways, that is, either in series or in multiple.

**2976. Series Party Line.**—When arranged in series, the instruments already described are used with low resistance ringer coils. The line-wire is cut at each station, and the two ends so formed are connected with the two binding-posts at the top of the instrument. The instruments thus form a part of the line circuit, the line circuit entering at one binding-post and going out at the other. Another reason will now be made apparent for the placing of the shunt around the generator armature in each instrument; for if the resistance of the armatures were left directly in the circuit of a party line, it would be necessary for the voice currents of two stations in use to pass through the armature coils of all the stations not in use. Ringing currents would also have to pass through the same path, thereby greatly reducing their effectiveness.

**2977.** So far as the actual ringing of bells is concerned, as many as forty instruments may be placed on a line, but this renders the talking exceedingly poor. Besides this, there is always an incessant ringing of bells, and a consequent annoyance and confusion of signals. As a rule of good practice, not more than ten instruments should be placed on a series line, though, of course, conditions sometimes render a greater number necessary.

**2978. The Bridged Party Line.**—The other method of connecting telephones on a party line is to place them in multiple or bridge connection. Each instrument is in a separate bridge wire between the two sides of the line circuit, that is, either between the two line-wires, where a double line or metallic circuit is used, or between the line-wire and ground, where a grounded circuit is used. In this system the ordinary telephone is modified to adapt it to the multiple connection. The ringer magnets are wound to a high resistance—usually 1,000 ohms—and may be left permanently in the circuit. The great number of turns on the magnets prevents the rapidly alternating voice currents from leaking through, and forces them to pass along the line. The generator at each station is in a normally open bridge wire, which is automatically closed when the generator is operated. Current from any generator in operation on a line passes along the line-wire and divides, passing through all the ringer magnets in multiple. These lines give better service in talking than series lines, and for other reasons are to be preferred. It is not advisable, however, to place more than twelve instruments on a single line, though, of course, it is possible for a much greater number to be used.

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### SWITCHBOARDS.

**2979.** The ordinary form of exchange for handling a larger number of subscribers than can be accommodated on party lines comprises a central office, from which the lines to the various telephone users, or "subscribers," radiate. These lines terminate at the central office in what is termed a switchboard. A switchboard must contain : apparatus for attracting the attention of the operator when a subscriber desires a connection ; means for the operator to connect her telephone with the line of a subscriber, in order to ascertain his wants; means for connecting his line with that of any other subscriber ; means for calling up the subscriber called for; and, lastly, means enabling either subscriber to signal the operator at the close of the conversation.

### LINE DROPS.

**2980.** The apparatus for calling the operator is usually an electromagnetic annunciator, one form of which is shown in Fig. 1111. In this *C* is an electromagnet mounted be-

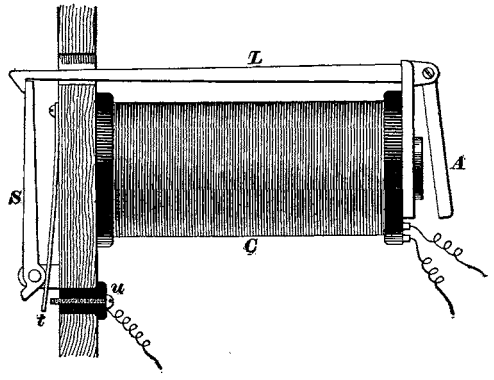


FIG. 1111.

hind the front plate of the switchboard. *S* is a shutter pivoted below and held in its upper position by a catch carried on the lever *L*, rigidly secured to the armature *A*. When a current is sent through the coil *C*, the armature *A* is attracted, thus removing the catch from engagement with the shutter and allowing it to fall. An auxiliary feature, known as a night-alarm attachment, is shown in connection with this drop. When the shutter falls, the small spring *t* is pressed into engagement with the contact point *u*, by the cam projecting from the bottom of the shutter. The spring *t* and contact *u* form the terminals of a circuit containing a battery and an ordinary vibrating bell, and the bell is therefore sounded whenever a drop falls. This arrangement is used only at night, when the exchange is not busy.

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### SPRING-JACK AND PLUG.

**2981.** In Fig. 1112 *J* represents a spring-jack and *P* a connecting plug. The jacks are mounted in the rear of the front panel *B* of the switchboard, below the line drops. *S* is a spring mounted on the frame of the jack, and normally

resting on the pin $p$. When, however, a plug $P$ is inserted into the jack from the front of the board, as shown, the spring makes contact with the metallic portion of the plug, and is lifted thereby from contact with the pin $p$. The plug has an insulating handle of hard rubber or fiber, and from

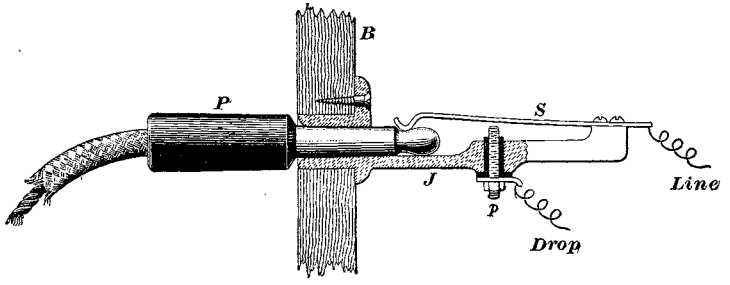



FIG. 1112.

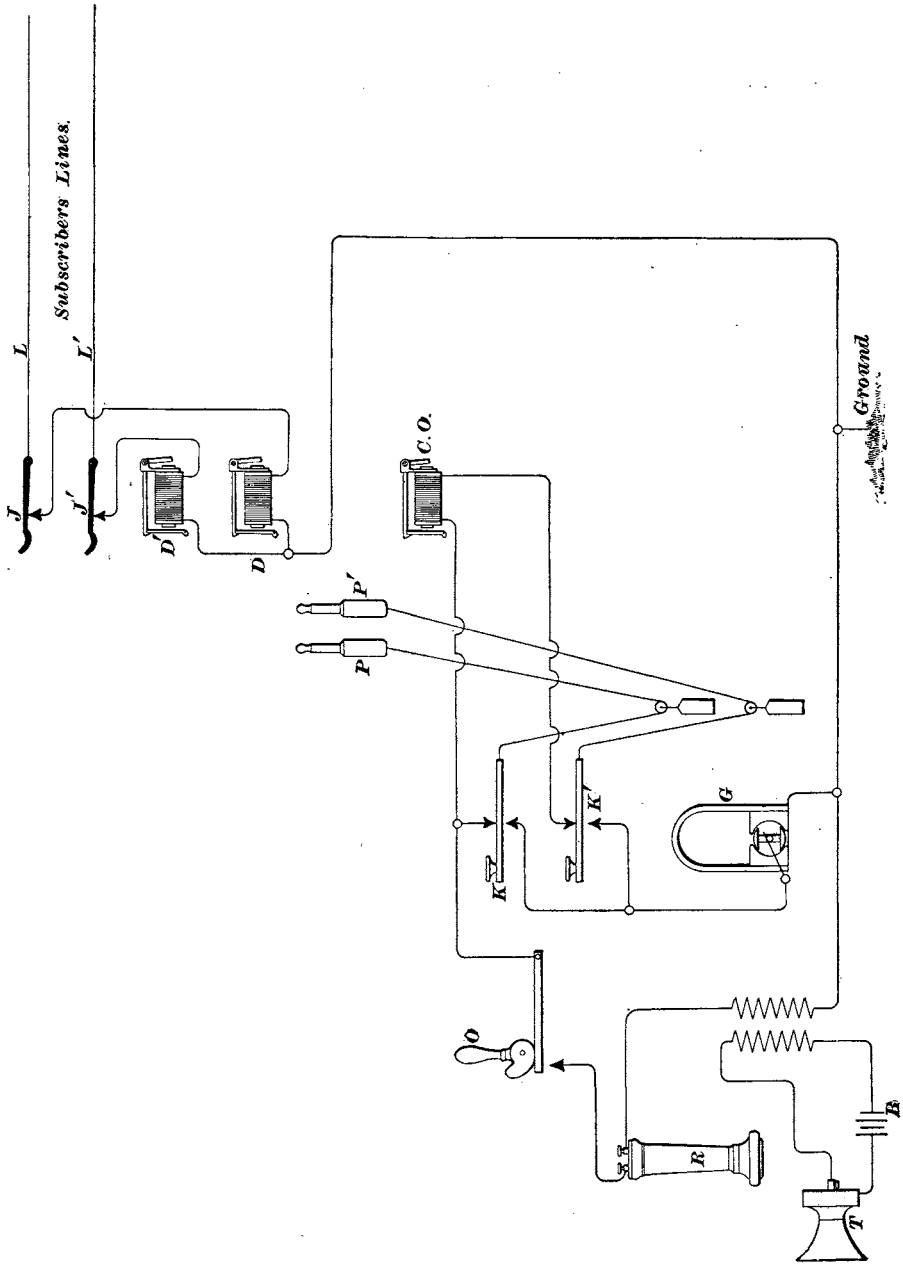
its rear projects the flexible conducting cord, as shown. This cord is usually made up of twisted tinsel or copper strands, covered by one or more braids of linen. Sometimes a spiral spring, closely wound, surrounds the tinsel under the linen, to act as a protecting sheath for the conductor, and still allow great flexibility.

The spring $S$ is connected with the line-wire, and the pin $p$ with one side of the drop magnet, the other side of which is grounded. The jack and plug described are for grounded circuits only; when used for double or metallic circuits another set of contacts must be added.

### OPERATION OF SWITCHBOARD.

**2982.** The operation of telephone systems in general may be most easily understood by considering their most simple type, that is, a system for grounded lines for a number of subscribers not greater than 500.

In Fig. 1113, $J$, $J'$ are spring-jacks connected with subscribers' lines, as shown. The contact pin or anvil of each jack is connected through the magnet of a drop $D$ or $D'$ to ground, so that under normal conditions the circuit of the line passes through the drop and to ground; but when a plug is inserted, the connection through the drop is broken.


Subscribers Lines.
L
L'
J
J'
D'
D
C. O.
Ground
P'
P
K
K'
G
O
R
B
T

**2983.** Suppose, now, that the subscriber on line $L$ sends in a call. The operator will see the shutter $D$ fall, and at once insert one of her plugs $P$ into the corresponding jack $J$. She then turns her cam lever $O$ into such a position as to press its lever into engagement with the contact below, thereby connecting her telephone, set between the line $L$ and the ground. This enables her to converse with the subscriber, and learning that he wishes, we will say, the subscriber on line $L'$, she inserts the plug $P'$ into jack $J'$ and presses down on the lever $K'$. This latter movement connects the constantly operated magneto generator $G$ with the line of the subscriber called for and rings his bell. Upon releasing the key $K'$, the two subscribers are connected together for conversation through the following circuit. From ground at the subscriber of line $L$, line $L$, spring-jack $J$, plug $P$, flexible cord, key $K$, drop $C.\ O.$ key $K'$, flexible cord, plug $P'$, jack $J'$, line $L'$, and to ground at the end of line $L'$.

**2984.** It will be noticed that the drop $C.\ O.$ is in this circuit. This is called the clearing-out drop, and its function, as its name implies, is to convey a signal to the operator when either subscriber operates his generator after conversation to signify that a disconnection is desired. The operator, on seeing this signal, pulls out both plugs, thus restoring the apparatus to its normal condition.

**2985.** In the switchboards of this type, whether for metallic or for grounded circuits, it is customary to wind the drop magnets to a resistance of about 75 ohms. The drops are cut out of circuit when a plug is inserted, for several reasons, the principal one being to prevent one drop acting on another inductively, so as to repeat a conversation from one circuit into another. Another reason is to clear the talking circuit of their resistance. It is very important in all switchboard work that every permanent connection be soldered without the use of acid as a flux.

## TELEPHONE-LINES.

**2986.** The construction of telephone-lines is in general the same as that of telegraph-lines. Certain peculiar conditions are found, however, in telephony which occur in no other class of work.

**2987.** Telephone-lines as first constructed used the earth as the return side of the circuit, in the same manner as is universally done in telegraph work. Such lines are called *grounded lines.* In later years it has been found advisable not to use the ground at all as a part of the circuit, and it has, therefore, become the general practice to use another wire for the return, thus making two separate wires for each line circuit. Such lines are called *metallic circuits.*

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### INDUCTION ON LINES.

**2988.** When a grounded telephone-line runs parallel with another on the same poles for a considerable distance, a very peculiar phenomenon occurs. It is found that although the two wires are entirely separated, and highly insulated from each other, a conversation on one circuit can be distinctly heard in the other. Similarly, a telephone-line running in the vicinity of electric-light, power, telegraph, or trolley lines will have currents set up in it which cause noises in the receivers, always exceedingly annoying, and sometimes so loud as to prevent conversation.

These phenomena are, of course, due to induction, and it has been proved that this induction is electrostatic instead of electromagnetic, as was at first commonly supposed.

**2989. Cross-Talk.**—The phenomenon of overhearing conversation on a circuit other than that over which it is originally conducted is called *cross-talk.* It is very confusing when two or more subscribers are talking at the same time, and was at one time the main difficulty to be overcome in practical work, when a number of circuits were necessarily run in close proximity. The action by which induction is produced may be explained by Fig. 1114, in which a tele-

phone-line *a b*, two or three hundred feet long, contains three Bell receivers, one at each end and one at the center. The two ends of *a b* are connected to the earth at *g* and *g'*. A telephone-line *c d* is supposed to run parallel to *a b* and

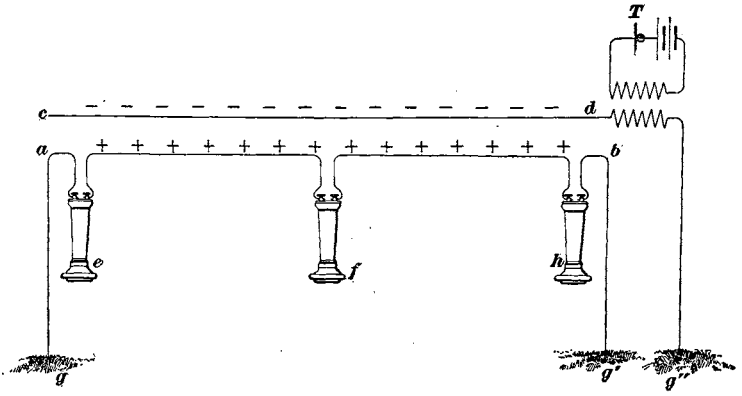


FIG. 1114.

at a uniform distance therefrom of one-eighth of an inch throughout its entire length. One end *c* is open, that is, it is left entirely disconnected, while the other end *d* is connected with earth at *g''*. A transmitter *T* in a local circuit with a battery is connected with this line through an induction-coil in the usual manner.

A sound is produced in front of *T* by a tuning-fork or some other source, and the line *c d* will receive a succession of charges which are alternately plus and minus. This induces charges on *a b* of opposite signs, the two conductors with the air between forming a condenser, the free charges passing off into the ground. Now, if a minus charge be formed on *c d*, as in the figure, a plus charge will be held upon the line *a b*. As the charge on *c d* changes to plus, the positive charge on *a b* is released, and two equal currents pass from the center of line *a b* in both directions to the earth at *g* and *g'*. A plus charge upon *c d* produces the same effect, but the currents are in an opposite direction, and meet at *f*. It will be observed that the sound is heard distinctly by the receivers *e* and *h*, while receiver *f*, for the

reason that no current passes through it, is silent. This shows that the current is produced by electrostatic induction and not by electromagnetic, as, if it were produced by the latter, a sound could be heard in all the receivers.

**2990. Obliterating Cross-Talk.**—When a complete metallic circuit is used, no cross-talk or other induction is developed if the disturbing wire is at equal distance from each of the circuit wires. This fact is explained in Fig. 1115, where the two halves of a complete metallic circuit are at $a$ and $a'$; $r$ and $r'$ represent coils of receivers placed at opposite ends of the circuit, and $c$ $d$ is a disturbing wire placed in such position that all its points will be the same distance from $a$ that they are from $a'$. Alternating charges are pro-

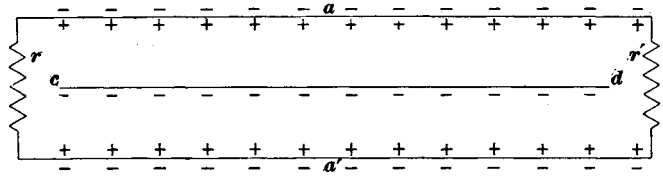


FIG. 1115.

duced upon $c$ $d$ either by a telephone or by any other source, and alternating charges with opposite signs to these are produced upon $a$ and $a'$. When a negative charge is produced upon $c$ $d$, as in the figure, a positive charge is induced upon the sides of $a$ and $a'$ that are nearest $c$ $d$; while upon the other sides negative charges are produced. As the charge on $c$ $d$ reaches zero, a current will flow across each wire, but not lengthwise, for the potential is exactly balanced on each side of the wires $a$ and $a'$. The charges of opposite sign simply come together across the wires. There is no tendency for the free negative charge on $a$, for instance, to flow away, as in the case of a grounded wire, because there is an equal negative charge on the entire circuit. If, however, the wire $c$ $d$ is nearer to $a$ than to $a'$, the free negative charge on $a$ will be greater than that on $a'$, and some current would flow. In this case the lines would be said to be *out of balance*, and some cross-talk or induction would take place.

**2991.** It may be readily perceived that only four wires forming two complete circuits can be placed so as to fulfil the condition shown in Fig. 1115. Their position is shown in Fig. 1116, in which $a$ and $a_1$ are the cross-sections of the wire of one circuit, and $b$ and $b_1$ those of the other. It is, therefore, necessary to resort to the method of transpositions shown in the next figure.

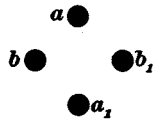

FIG. 1116.

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**TRANSPOSITIONS.**

**2992.** In Fig. 1117 the disturbing wire is $c\,d$ at unequal distances from the two circuit wires $a$ and $a'$, and the resistances $r$ and $r'$ represent the subscribers' instruments. As $c\,d$ is at unequal distances from $a$ and $a'$, the induced poten-

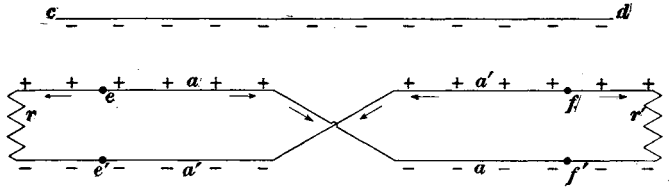

FIG. 1117.

tials will not be balanced, and cross-talk would occur, were it not for the fact that the two wires are transposed, as shown in the figure. This transposition breaks up the charge, so that the resulting currents are too small to seriously affect the telephone. When $c\,d$ receives a negative charge, as in the figure, a positive charge is induced upon the nearer ends of $a$ and $a'$, while a negative is repelled to the farther ends. As the potential on $c\,d$ reaches zero, currents flow from the two points $e$ and $f$ and come together at $e'$ and $f'$. At these points no effect would be produced upon a Bell receiver; and if there were no retardation from resistance and self-induction in the apparatus, they would be in the center of each transposition. However, on account of this retardation, the greater part of the current will flow from the neutral points in a direction away from the apparatus through the part having less retardation. The

neutral points, therefore, are nearer to the apparatus; and this fact enables the transpositions to be the longer as the retardation is increased. The greater the number of transpositions, the smaller will be the charges and, therefore, the resulting currents.

**2993.** Where many wires are used, the transpositions must be carefully planned, since, although for two circuits one may be transposed so that no cross-talk shall occur, for one more circuit the same transposition would cause cross-talk between the second and third. This is shown in Fig. 1118, where it may readily be seen that the average

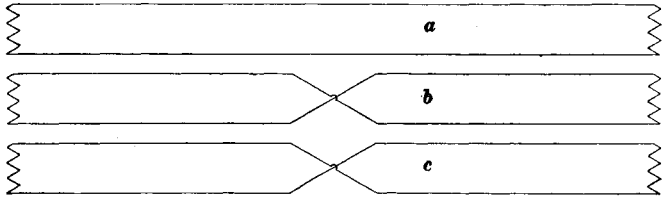


FIG. 1118.

distances of the two wires of *c* from any wire of *b* are not equal to each other. In fact, the circuits *b* and *c* bear the same relation to each other as if they had not been transposed. To overcome this difficulty, twice as many transpositions as there are in the second must be made in the third, and so on, as is shown in Fig. 1119.

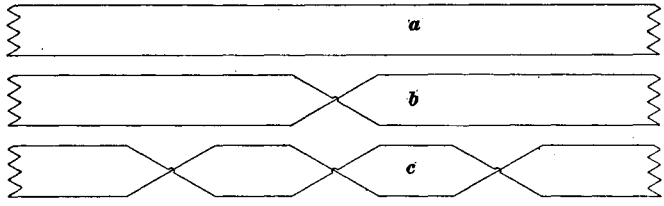


FIG. 1119.

**2994.** It is not necessary in practice, however, to exactly balance the induction effect. The same transposition for every other circuit has been found to work very well.

Fig. 1120 shows the scheme of transposition on the New York-Chicago telephone-line, the poles on which transposi-

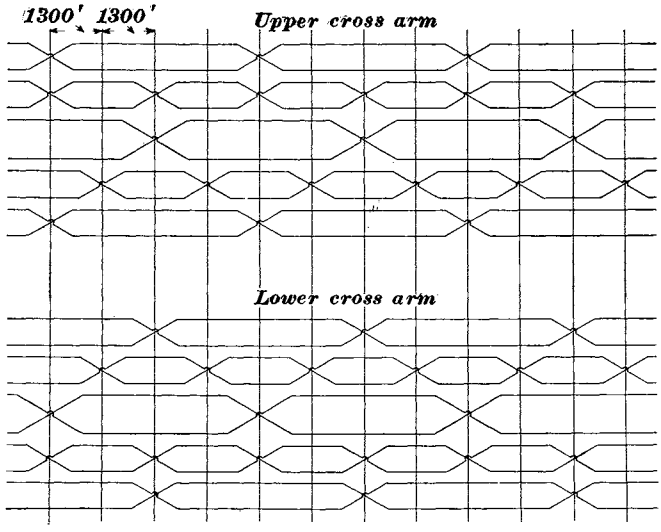


FIG. 1120.

tions are made being 1,300 feet apart. The same scheme of transposition is used on every other set of cross arms.

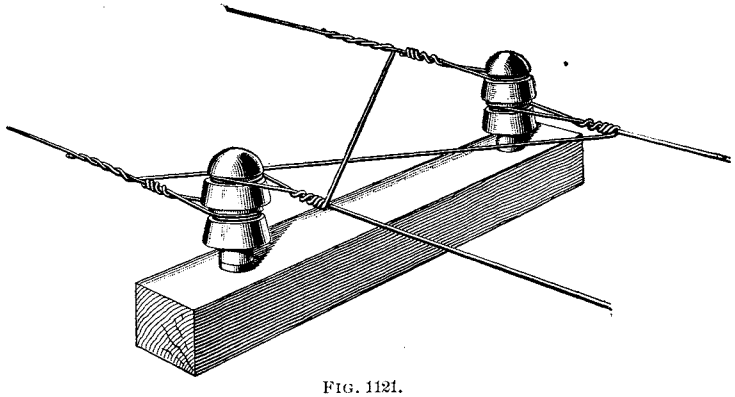

FIG. 1121.

Thus the first line of cross arms at the top of the pole line will be arranged as shown in the upper part of Fig. 1120,

the next set will be arranged as shown in the lower portion of that figure, the third set will be like the first, and the fourth like the second, and so on throughout the entire number of sets of cross arms.

**2995.** The method of making transpositions now generally adopted is that shown in Fig. 1121. The cross-over wires should either be insulated or else so bent as to avoid the possibility of crosses, the latter plan being the more common.

### TELEPHONE-CABLES.

**2996.** When telephone-lines enter cities, it is customary to bunch them into cables, usually containing 52 or 104 pairs, or complete metallic circuits. These wires are usually of No. 19 or 20 B. & S. gauge copper, and are insulated with paper, sometimes dry and sometimes saturated with an insulating compound. The whole cable is usually covered with a lead sheath to keep out moisture and to protect the wires.

In telephone-cables the two wires in each pair forming a complete metallic circuit are twisted together, thus successfully preventing cross-talk. The pairs in each concentric layer are given a twist in a direction opposite to that of the pairs of the next layer. Thus, if any two pairs be considered, and one wire of one of them be taken as the disturbing wire, it will readily be seen that the wires of the other pair are at equal average distances from this disturbing wire. The method of twisting pairs in cables affords the most perfect transposition known.

## ELECTROMETALLURGY.

**2997.** **Electrometallurgy** deals with the separation, by means of an electrical current, of metals from liquids in which they are united with various other elements, and the deposition of them in a pure state upon surfaces that are connected to the negative pole of the source of electrical power.

Electrometallurgy may be divided into three parts, namely, the reduction of metals, electroplating, and electrotyping.

The action of the electric current by which these operations are performed is spoken of as electrolysis. Concerning this subject, enough, perhaps, has already been said in the section on Batteries, so only a few rules will be given here for reference.

**Rule I.**—*The quantity of a metal liberated at a negative electrode in a given time is proportional to the strength of the current passing through the electrolyte.*

**Rule II.**—*The quantity of a metal liberated at a negative electrode per second is equal to the strength of the current in amperes multiplied by the electrochemical equivalent.*

The electrochemical equivalents of metals may be obtained from column 6, Table 89, Art. **2561.**

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## REDUCTION OF METALS.

**2998.** This is really a refining process by which metals are obtained in a state of great purity. The principal metals that are refined by this process are copper, silver, lead, and aluminum. The process consists in suspending in a proper solution thin plates of the pure metal, connected to the negative pole of the source of supply, while from the positive pole are suspended pieces of the impure metal, to be refined and melted into bars of the proper shape. Between each pair of bars a plate of pure metal is usually suspended. This arrangement reduces the resistance of the electrolyte. A current of electricity is, of course, sent through the solution.

The resistance in ohms of the electrolyte being known, as well as the current in amperes, the H. P. to deposit a certain quantity of metal will be proportional to $\frac{C^2 R}{746}$, or, in terms of current and electromotive force, $\frac{C E}{746}$. This term must be multiplied by a coefficient $K$, which depends

in each case upon the quality of the metal under treatment.

Therefore, H. P. $= K \frac{C E}{746}$.

**2999.** The resistance through an electrolyte may be reduced at will by increasing the size of the plates and bars, while the current employed may be reduced by connecting a number of baths in series. Thus, the production may be increased within certain limits with an expenditure of the same electrical power.

If too great an E. M. F. be used in depositing a metal, the quality will be granular and porous, and if too small, the deposit will be too slow. Therefore, an E. M. F. must be determined upon that will give the best results.

The E. M. F.'s and the compositions of the electrolytes for various metals are as follows:

| | |
|---|---|
| COPPER. | The electrolyte is a saturated solution of sulphate of copper, mixed with $\frac{1}{4}$ its volume of water containing about ten per cent. of sulphuric acid for conducting the current. The E. M. F. is from 0.5 to 1 volt. |
| SILVER. | The solution consists of cyanide of silver dissolved in cyanide of potassium. The E. M. F. is from 1 to 2 volts. |
| LEAD. | The solution consists of plumbic sulphate dissolved in sodic acetate. The E. M. F. is from 0.5 to 1 volt. |
| ALUMINUM. | The electrolyte is chloride of aluminum, ammonium, and sodium, but, instead of being in solution, it is used in a melted or fused state. The E. M. F. is from 15 to 20 volts. |
| GOLD. | The solution is cyanide of gold in cyanide of potassium. E. M. F. is from .5 to 3 volts. |
| NICKEL. | The solution is the double sulphate or chloride of nickel and ammonia. E. M. F. is from .5 to 1 volt. |

In the preparation of aluminum, the chloride is heated to nearly 400° F. in a porcelain cup. The positive electrode is a carbon, and the negative a platinum plate. When the current passes through, aluminum and sodic chloride is deposited on the platinum plate. This deposit is afterwards treated to extract the metallic aluminum.

The temperature of a solution affects the deposit to a marked degree. As the temperature is raised, the deposition takes place with greater rapidity.

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## ELECTROPLATING.

**3000.** This is a process by which objects may be coated, either for ornament or for protection, with a thin layer of metal.

The object to be plated is connected to the negative pole of the generator by means of a heavy wire and is suspended in a suitable electrolyte, the positive pole being connected to a plate of the metal to be used as a covering, which also is immersed in the electrolyte. When a current is passed through the solution, a uniform covering is deposited upon the object.

The solutions used in plating always contain a salt of the metal which is to be deposited, and the **anode,** or plate of metal from which the deposit is to be made, is suspended in the solution and connected electrically to the positive pole of the battery or dynamo furnishing current. When the **cathode,** or object to be plated, is suspended in the bath and connected to the negative pole of the battery, the passing current will decompose the metallic salt and deposit it upon the cathode in a layer, the quality and thickness of which depend upon the metal used, the strength of the current, and the time during which it flows. The metal which is thus taken from the solution is immediately replaced, because the acid radical combines with the metal of the anode, this process continuing as long as there is metal in the anode.

It is sometimes desired to plate articles with a layer of metal of varying thickness, as, for example, on silverware, at

those parts which are subject to the greatest amount of wear. This process is called **sectional plating.** To produce this result, the anode is brought close to the cathode, and the deposit at that point becomes heavier. It follows from this, that, when a uniform coating of metal is to be deposited, a certain minimum distance must be maintained between the anode and the cathode. Also, the cathode may be moved occasionally, in order to present another side to the anode, in case the plating bath is very small.

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### COPPER PLATING.

**3001.** The electrolyte for use in copper plating may be a simple acid solution of copper sulphate, or a cyanide of potassium solution with either sulphate or acetate of copper. The acid solution is very easily made, as follows:

**Acid Solution.**—The necessary ingredients are

| | |
|---|---|
| Sulphate of copper | 1 lb. |
| Sulphuric acid | 1 lb. |
| Water | 1 gallon. |

The sulphate of copper is dissolved in hot water, after which cold water is added until the quantity named is made up. The sulphuric acid is then added, and after the solution has become cool, it is poured into the depositing vessel. This may be of glass or of wood, and should be thoroughly cleaned before using.

**3002. Cyanide Solution with Copper Sulphate.**—For this bath 8 ounces of sulphate of copper is dissolved in 1 quart of hot water and set aside to cool. When cold, liquor ammonia, specific gravity .880, is added gradually, the solution being continually stirred with a glass rod or a piece of wood until the precipitate which at first appears is again dissolved. One quart of cold water is then added. A solution of cyanide of potassium, made by dissolving $1\frac{1}{4}$ lb. in 2 quarts of water, is *gradually* mixed in, with constant stirring, until the blue color disappears. Then the remaining cyanide solution is added, and the mixture is allowed to

stand until the clear liquor rises to the top, when it may be siphoned off and is ready for use in the bath. This solution is generally used cold, although a quicker action may be obtained if it is warmed to a temperature approximating 120° F. In using cyanide of potassium, great care must be exercised in handling, as this chemical is a strong poison and very deadly. If the hands are cut or scratched, blood-poisoning will probably result from contact with cyanide, so that the greatest precautions should always be adopted in preparing solutions of which it forms an ingredient.

**3003. Cyanide Solution with Acetate of Copper.**—In making up this bath, the following proportions of ingredients are necessary:

| | |
|---|---|
| Acetate of copper, crystallized... | 20 parts. |
| Carbonate of soda, crystals..... | 20 " |
| Bisulphite of soda ..... | 20 " |
| Cyanide of potassium, pure ..... | 20 " |
| Water..... | 1,000 " |

The acetate of soda is reduced to powder and made into paste with a little water; to this is added the carbonate of soda, previously dissolved in 200 parts of water, and the mixture is well stirred. The bisulphite of soda is then dissolved in 200 parts of water and added to the mixture, when the green precipitate first formed becomes of a yellow color. The cyanide of potassium is dissolved in 600 parts of water and added, the mixture being well stirred. The precipitate will be dissolved by the cyanide and the solution will become clear. Should this not take place, more cyanide should be added. This bath may be used hot or cold.

**3004. Deposition of Copper on Aluminum.**—The trouble usually encountered in copper-plating aluminum will be obviated if a film of copper is first deposited by immersion in a copper sulphate bath; after this film is laid on, electroplating may be proceeded with as in ordinary cases. The process indicated is as follows:

The aluminum article is first cleaned in a solution of potassium or sodium carbonate. Upon removal from this bath, it is washed in clear water and then dipped in a 5 per cent. solution of hydrochloric acid. It is then washed again and placed in a slightly acid solution of copper sulphate until a deposit of copper is formed. When this is sufficiently thick, the article is removed and washed, when it is ready to be placed in the ordinary plating bath.

---

### NICKEL PLATING.

**3005.** In electrodepositing nickel, it is necessary to thoroughly clean the articles to be plated, because the bath is nearly neutral and has no power to remove oxide from the surface of the metal. The first operation is to remove any grease, such, for example, as may be due to handling. A hot potash bath is used for this purpose, made by dissolving ½ lb. of caustic potash in 2 gallons of water. This solution is kept hot by means of a steam-pipe coil at the bottom of the galvanized-iron tank. The strength of the potash gradually lessens while in use, so that, while a few minutes only are necessary to cleanse an article in a fresh bath, a longer time will be required later on. Upon being removed from this bath, the article should be well scoured with pumice and water and rinsed. It may then be placed in the nickel bath, but, since an almost imperceptible film of oxide may have formed upon the surface, it is advisable to dip brass or copper articles for a few seconds in a solution composed of ½ pound cyanide of potassium dissolved in 1 gallon of water. This will ensure the deposit adhering firmly. For steel or iron it is better to use ½ pound hydrochloric acid in 1 gallon of water, contained in a wooden tank. For cast iron the hydrochloric is replaced by sulphuric acid, the solution being used cold. An immersion of fifteen minutes to half an hour will be required in this case, and the casting should be thoroughly scoured. When a bright finish is wanted on cast iron, the proportion of sulphuric acid should be doubled, and 2 ounces of granulated zinc added.

After this dissolves, add ½ pound nitric acid and mix thoroughly.

The plating bath is made as follows:

Double sulphate nickel and ammonia (pure). 12 to 14 oz.
Water ..... 1 gallon.

The nickel salts are put into a wooden tank and hot water is poured upon them until they dissolve, this being hastened by stirring with a clean wooden stick. The liquid may be poured off into the plating tank after a short time, without waiting for all the salts to dissolve; then more hot water is poured upon the salts, this being repeated until the salts are completely dissolved. When this is accomplished, cold water is added to bring the solution to the required measure.

This plating bath has a rather high resistance, and good results may usually be obtained by adding to the solution 10 per cent. of common salt. This has the effect of whitening the nickel deposit and making it more tough, so that the film of metal will not readily strip, and the resistance of the bath is decreased.

The nickel bar or plate used as an anode must be pure, in order to secure good results.

Cast anodes are more readily dissolved by the action of the current than are rolled anodes, and are therefore to be preferred. For small work, however, rolled anodes are more generally used, as they are more easily obtained.

All the water used in plating baths should be distilled, or rain water may be employed if desired.

In order to obtain a good color, the bath should be slightly acid; but if too acid, the deposit will peel off. In working the bath, the anode should present as large a surface as the object to be plated. If it is too small, the solution will be robbed of metal and become too acid, in which case sulphate of nickel (single salts) should be introduced, by dissolving first in water and adding to the solution in the required quantity. If the bath has the full amount of metal, the acidity may be corrected by the addition of carbonate of ammonium dissolved in water. When the bath is alkaline,

add double salts, even if it is necessary, in consequence, to reduce the exposed surface of the anode for the time being.

---

### GOLD PLATING.

**3006.** The electrolyte used in gold plating is made of the following ingredients:

| | |
|---|---|
| Fine gold | 10 parts. |
| Pure cyanide of potassium | 20 " |
| Or, commercial cyanide | 30 to 40 " |
| Distilled water | 1,000 " |

The gold must be formed into chloride in the following manner: The gold is placed in a flask, and a mixture of 2 parts of hydrochloric and 1 part of nitric acid is poured upon it. The proportion of this acid to gold will be about 4 to 1, that is, 4 ounces of mixed acid to 1 ounce of gold, depending, however, upon the quality of the acid, of which too much should not be used. This mixture is then to be evaporated on a hot sand bath until nearly all the acid is driven off and the solution begins to move sluggishly on rocking the dish. It is then allowed to cool. If too much heat has been applied, the gold will be converted into a metallic state. It should in that case be washed with distilled water and redissolved with acid. This chloride of gold is now to be dissolved in about 200 parts of water. The cyanide is dissolved in the remainder of the water. After filtering, the solutions are mixed and then boiled for a short time. This plating bath is generally worked at a temperature of about 120° F., but may be worked cold. The color of the deposit will vary according to the conditions of working, from a pale lemon color to a rich orange. A cold bath, with the same battery power, will give a lighter color than a hot bath. The free cyanide present in the solution will also affect the deposit, which will be pale if too little cyanide is used, and brown if too much is used. Also, a strong current will produce a darker tone than a light current.

### SILVER PLATING.

**3007.** For silver plating the following ingredients are required, in the proportions given:

| | |
|---|---|
| Pure silver | 25 parts. |
| Cyanide of potassium, pure | 50 " |
| Water | 1,000 " |

The pure silver, in granulated form, is first to be converted into silver nitrate, using the following process: Take, say, 2 ounces of silver and put into a flask with 1½ ounces of distilled or rain water, then add about 3 ounces of pure nitric acid. This causes red fumes to be given off, with violent ebullition. As soon as this ceases, the flask is to be heated on a sand bath until the fumes no longer appear. The solution should then be poured off into an evaporating dish, and if any undissolved silver remains, it should be treated in the same manner as described, care being taken not to add an excess of acid. The evaporating dish containing the solution is placed on the sand bath, remaining there until it becomes nearly dry, when there will no longer be any free acid contained.

In preparing the plating solution, 1 ounce of the silver nitrate may be taken and dissolved in about 2 quarts of distilled or rain water, the solution being well stirred. A strong solution of cyanide of potassium is next prepared, about ½ pound of cyanide being dissolved in 1 quart of water. This must be added to the silver solution in small quantities, each addition forming a precipitate of cyanide of silver. The mixture must be continually stirred while the cyanide is being added, a glass rod or a clean piece of wood free from resin serving for this. When further addition of cyanide appears to produce only little effect, no more should be put in, and the solution should be allowed to rest until the precipitate settles to the bottom, when the liquid may be poured into another dish and treated with cyanide to obtain all the cyanide of silver possible. The result of adding more cyanide of potassium than is sufficient to form the precipitate will be that the precipitate will be

redissolved. If this should occur, it would be necessary to add more nitrate of silver until the solution becomes milky again; then proceed with additions of cyanide as before. This may, however, cause waste of silver.

The next operation is to wash the precipitate by pouring water on it, stirring, and leaving to settle, when the water is drawn off. This washing should be repeated two or three times. If the plating bath is to be made up to one gallon, add now half a gallon of rain or distilled water to the moist precipitate. The precipitate is then carefully redissolved with constant stirring in strong cyanide of potassium, making the double cyanide of silver and potassium. The amount of cyanide used in this operation should be noted. It must be added very carefully, and it is advisable, when nearly all the precipitate is dissolved, to pour off the liquid, and then dissolve the remaining precipitate separately. By this means an excess of cyanide of potassium will be avoided. Cyanide should now be added, in quantity equal to about one-fourth as much as was used to dissolve the precipitate. This free cyanide is necessary, as in the gold solution, for the proper working of the bath, but as long as the anode will keep clean, the less free cyanide that is used the better. After a bath has been worked for some time, it will usually require an addition of cyanide, but too much will cause the silver deposit to strip off or blister.

For use as a plating bath, the double cyanide of silver and potassium is diluted to the required volume by the addition of water.

The amount of silver used in the bath varies from $\frac{1}{2}$ ounce to 5 or 6 ounces to 1 gallon of water, but 2 ounces or less will usually give excellent results. It is always advisable to use distilled or rain water for the plating bath, as there are likely to be impurities in river water which may injuriously affect the quality of the deposit.

When only small baths are required, it is better to buy the cyanide of silver and dissolve as here described. To 1 gallon of water use 2 ounces cyanide of silver and about twice that amount of cyanide of potassium.

### CURRENT DENSITY USED IN PLATING.

**3008.** The usual densities for different metals are:

| | | |
|---|---|---|
| Copper, acid bath..... | 5 to 10 | amperes per sq. foot. |
| " cyanide bath.... | 3 to 5 | " " " " |
| Nickel, double sulphate.. | 6 to 8 | " " " " |
| Gold, chloride in cyanide. | 1 to 2 | " " " " |
| Silver, double cyanide... | 2 to 5 | " " " " |

In general, a low-current density produces a hard, close-grained surface, and a high-current density a softer, more open deposit, which may even become of a powdery appearance.

---

## ELECTROTYPING.

**3009.** This is a process by which reproductions are obtained of printer's type and cuts, to be used on the printing-press in place of the original, which may thus be preserved in good condition. The forms of type, after having been prepared in the usual manner, are placed in a press and forced down on a sheet of wax which has previously been dusted over with fine graphite. On removing the type an impression in reverse will be found on the surface of the wax, which is again coated lightly with graphite, all superfluous particles being blown off. The wax sheet, or case, as it is called, is then coated with a solution of iron filings and vitriol, which forms a thin and smooth face of copper on the mold, ensuring a uniform deposit. A connection is now made between the wax sheet and rods leading to the terminals of the dynamo. This serves to make electrical contact between the conducting surface and the dynamo. The wax mold is immersed in a plating bath, which deposits a coating of copper upon the wax. The thickness of this coating of copper, or shell, as it is termed, depends upon the length of time the mold is acted upon by the plating solution. A sufficient thickness of copper deposit may be obtained in some cases after about half an hour, but a longer time is usually required, depending, of course, upon conditions of operation. Upon removal from the bath, the shell is

separated from the wax sheet and filled in with electrotype metal to give a firm backing.

Careful manipulation is necessary in preparing the wax sheet and in making the impression, as the resulting electrotype may otherwise be wanting in fineness.

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### GLYPHOGRAPHY.

**3010.** This is an ingenious method of preparing cuts for illustrations. A copper plate is stained black, and covered with a white, opaque substance resembling wax. The drawing is copied upon this plate by means of points that pierce the white composition. Thus the black plate shows through, and constitutes the lines of the drawing. The plate is then brought in contact with a substance having chemical affinity for the white composition, which is thus raised to the required thickness. Some parts, where much light occurs in the drawing, are now thickened by mechanical means; and the plate is ready to receive a deposit of copper. This deposit is removed, and is given its proper backing of pewter, solder, and lead.

Formerly, it was the custom to use batteries for all processes involving electrolysis; but to-day specially constructed dynamos are almost universally used.

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## ELECTRIC WELDING.

**3011. Electric welding** consists in passing a current of great volume through two pieces of metal while they are tightly pressed together by mechanical means. This current heats the pieces to such a temperature that they are welded together.

The usual welding process consists in heating in a blacksmith's fire two pieces of the same metal until they are nearly at a white heat, and at about the same temperature. They are then hammered together; if the surfaces are clean, a joint is made as if they were one continuous piece. If two pieces be thus properly welded, the junction is nearly if not quite as strong as the unbroken metal.

In electric welding the two pieces are heated much nearer to the same temperature by the passage of a large current of electricity. The pressure being applied at the time of heating, the current being regulated to produce exactly the proper degree of heating, and there being no time for the surface of contact to become oxidized, a perfect weld is produced. Dissimilar metals, that can not be welded by any other process, have been firmly joined by this method.

The pieces to be welded are each firmly fixed in a massive clamp of copper or bronze. The two clamps are then brought together by turning a screw, by hydraulic pressure, or by the falling of a weight. At the same time, the current is sent from one clamp to the other through the pieces to be welded. Such volumes of current are sent through that the resistance of the metal at the point of contact between the two pieces is sufficient to bring each molecule through which the current passes up to the desired temperature.

**3012.** In this process the time may be shortened and the power increased for a weld, without a porportional increase in the waste of power, and when the machine is not in use the power may be shut off. With a fire, to increase the rate of heating, a proportional (or more) increase is made in the waste, and when pieces are not heating the fire continues to burn with a loss of heat.

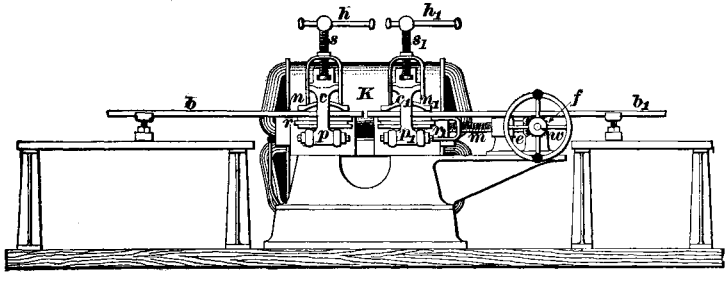


FIG. 1122.

Fig. 1122 is a diagram of Thomson's welder. At $b$ and $b_1$ are the pieces to be welded. They are clamped by the

levers $c$ and $c_1$, carrying clamping pieces $n$ and $n_1$. Underneath the pieces are the supporting plates $r$ and $r_1$, which carry two pieces to fit under $b$ and $b_1$. The levers $c$ and $c_1$ are clamped down by the screws $s$ and $s_1$, which are turned by handles $h$ and $h_1$. The levers are pivoted at $p$ and $p_1$. One clamping piece is brought up against the other by turning the hand-wheel $w$. Upon the shaft of $w$ is a gear-wheel $f$, which gears with a wheel $e$. This last wheel operates the screw $m$, which passes through the clamping piece. The current enters at one clamping piece, then passes through $b$ and $b_1$ to the other clamping piece and out.

At the back part of the machine may be seen the converter $K$. As alternating currents are generally used in all electric welding processes, a high E. M. F. and small current may be changed to a low E. M. F. and very large current. Sometimes as much as 60,000 amperes are used. The two clamping pieces are, of course, connected in with the secondary coil of the converter, while the generator is in the primary. The secondary coil consists of a few turns of very low resistance. In cases where small welds, such as that of pipes, are made, the current may be received directly from the generator.

It has sometimes been found necessary in practice, on account of the excessive heat produced, to pass streams of water through the most massive parts of the clamping pieces. Also some harder bronze—although possessing greater resistance—has been found more useful for these clamps than pure copper. The bronze does not so readily fuse and wear away by the sparking at the points of contact.

The current is regulated by switches, and by a reactive coil, the principle of which will be explained later, in connection with converters or transformers.

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### POWER FOR ELECTRIC WELDING.

**3013.** The greater the power employed, the shorter will be the time of making a weld, and, conversely, the less the power, the greater will be the time. These matters are regulated according to the material to be welded. Copper,

brass, tool steel, and other metals that are deteriorated by being heated must be welded rapidly. Thus no time is given for the metal to change its nature. That part of the metal where deterioration has occurred is pushed out from the weld by the pressure applied. Other materials must be heated very slowly, to prevent bad effects from one heating.

The accompanying is a table given by the Thomson Electro-Welding Co. for the power used in welding iron, copper, and brass, of varying cross-sections. The distance between clamps was twice the diameter of the iron pieces to be welded, three times the diameter for brass, and four times the diameter for copper.

The loss of heat that occurs is due only to radiation and conduction. This amounts to about 25%.

On account of the power lost in the engine and dynamo, the cost of fuel for electric welding for continuous work is at least equal to, if not more than, the cost of welding by fire. For work at intervals, the cost is less for electric welding.

**3014. Welding Rails.**—A use has been recently found for these machines in welding electric street-railway rails, so that the track consists of one continuous piece. The machine for this purpose is carried at the front of a special car. Within this car is a motor dynamo, a machine which takes the power from the road circuit at about 500 volts and 275 amperes and transforms it into 300 average volts and 650 amperes. This power enters the converter and is transformed into the large current needed at a low voltage. The rails are first put in contact, and then two pieces are welded on either side over the joint.

The necessary pressure upon the weld is furnished by the hydraulic method. A continuous 70-pound rail is required to bear about 150,000 pounds to withstand the maximum stress put upon it by the variations in temperature from winter to summer, while an electric weld breaks only at 279,000 pounds stress. The conductivity of the joint is as great as that of the rail itself.

## TABLE 96.

| Iron and Steel. | | | | | Brass. | | | | | Copper. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area in Sq. In. | Watts in Primary of Welders. | Time in Seconds. | H. P. Applied to Dynamos. | Foot-Pounds. | Area in Sq. In. | Watts in Primary of Welders. | Time in Seconds. | H. P. Applied to Dynamos. | Foot-Pounds. | Area in Sq. In. | Watts in Primary of Welders. | Time in Seconds. | H. P. Applied to Dynamos. | Foot-Pounds. |
| .5 | 8,550 | 33 | 14.4 | 260,000 | .25 | 7,500 | 17 | 12.6 | 117,000 | .125 | 6,000 | 8 | 10.0 | 44,000 |
| 1.0 | 16,700 | 45 | 28.0 | 692,000 | .5 | 13,500 | 22 | 22.6 | 281,000 | .250 | 14,000 | 11 | 23.4 | 142,000 |
| 1.5 | 23,500 | 55 | 39.4 | 1,191,000 | .75 | 19,000 | 29 | 31.8 | 508,000 | .375 | 19,000 | 13 | 31.8 | 227,000 |
| 2.0 | 29,000 | 65 | 48.6 | 1,738,000 | 1.00 | 25,000 | 33 | 42.0 | 760,000 | .500 | 25,000 | 16 | 42.0 | 369,000 |
| 2.5 | 34,000 | 70 | 57.0 | 2,194,000 | 1.25 | 31,000 | 38 | 52.0 | 1,087,000 | .625 | 31,000 | 18 | 51.9 | 513,000 |
| 3.0 | 39,000 | 78 | 65.4 | 2,804,000 | 1.50 | 36,000 | 42 | 60.3 | 1,390,000 | .750 | 36,500 | 21 | 61.2 | 700,000 |
| 3.5 | 44,000 | 85 | 73.7 | 3,447,000 | 1.75 | 40,000 | 45 | 67.0 | 1,659,000 | .875 | 43,000 | 22 | 72.9 | 872,000 |
| 4.0 | 50,000 | 90 | 83.8 | 4,148,000 | 2.00 | 44,000 | 48 | 73.7 | 1,947,000 | 1.000 | 49,000 | 23 | 82.1 | 1,039,000 |

# APPLIED ELECTRICITY.

(CONTINUED.)

## THEORY OF THE DYNAMO.

**3015.** In order that a current may flow through a circuit, and thereby be available for doing work, it is necessary that a difference of potential be established between two points in that circuit, and in order that the resulting current may be maintained, it is necessary to maintain the difference of potential between these points. (See Art. **2237.**)

This difference of potential may be established and maintained in a variety of ways, some of which—the chemical action of certain liquids on certain other substances, for example—have already been explained.

Generating an E. M. F. in a conductor by moving the conductor in a magnetic field in such a direction that it cuts the lines of force of the field, is by far the most extensively used method of establishing the required difference of potential, and a machine for generating and maintaining an E. M. F. by the movement of one or more conductors across the lines of force of a magnetic field is called a **dynamo.**

**3016.** The amount of the E. M. F. generated in a moving conductor depends upon the rate at which the conductor cuts the lines of force. (Art. **2449.**) With practicable values for the length of the conductor, for its velocity, and for the extent and density of the magnetic field, the E. M. F. which can be generated in a single conductor is not sufficient for most of the applications of the electric current. However, by joining a number of conductors in series, in such a

manner that the E. M. F.'s generated in them are added together, any desired E. M. F. may be obtained.

The *character* of the E. M. F. of a dynamo depends upon the grouping of the various conductors with respect to the magnetic field, and to the method of connecting these conductors with the external circuit.

The part of the dynamo in which the E. M. F. is generated, consisting of the conductors, the means of supporting and moving them, and the device for connecting them with the external circuit, is called the **armature,** and the conductors, in their various arrangements and connections, constitute the **armature winding.**

The effect of the various methods of arranging and connecting armature windings upon the character of the E. M. F. produced may best be studied by developing them from the simplest form, a straight conductor moving in a straight line through a uniform magnetic field, as will be explained later.

**3017.** The principal sources of magnetic fields are permanent magnets, such as the earth, masses of lodestone, or hard-steel magnets, and electromagnets.

As the E. M. F. generated in a moving conductor is proportional to the density of the field in which it moves, other conditions remaining the same, it is obvious that a field of considerable density is desirable. For this reason the earth's field or that of permanent magnets, either natural or artificial, is seldom used in dynamo-electric machinery, since the density of such a field is low compared with that possible to obtain with suitably designed electromagnets, so that, in spite of the fact that electrical energy must be continually expended in order to keep up the magnetizing force of the electromagnet, this last form is almost universally used.

The design of electromagnets for dynamo-electric machinery will be discussed later; for the present it is sufficient to consider that the magnetic field exists in the space between one or more pairs of poles, the balance of the magnetic circuit not being considered.

## GENERATION OF E. M. F.

**3018.** If any straight conductor $a\ b$, the direction of whose length is at right angles to the lines of force, is moved in a uniform magnetic field in a direction at right angles to the lines of force of the field and to its own length, and at such a uniform velocity that at the end of unit time (1 second) it reaches the position $a'\ b'$, as represented in Fig. 1123, the following conclusions result :

The *velocity* of the conductor may be represented by the length of the line $a\,a'$ (or $b\,b'$), as the conductor moves over this distance in unit time. The total number of lines cut by the conductor is evidently that number enclosed in the area $a\,a'\,b'\,b$; the lines $a\,a'$ and $a\,b$ (or $b\,b'$ and $a'\,b'$) being at right angles to each other, the area enclosed by $a\,a'\,b'\,b$ is the product of the *length of the conductor* $a\,b$, and the *length of its path* $a\,a'$ (or $b\,b'$). Formula **447,** given in Art. **2449,** $E = \frac{N}{10^8\,t}$, may be modified to fit this case,

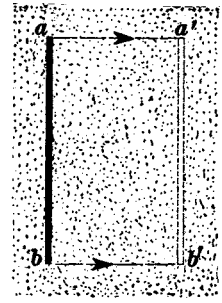

FIG. 1123.

as follows: Let $\mathbf{B}$ = the density of the magnetic field, $L$ = the length of the conductor, and $M$ = the length of its path, or its velocity. Then, the area moved over by the conductor (in unit time) is $L\,M$, and the total number of lines cut by the conductor is $\mathbf{B}\,L\,M$. Then, substituting this value for $N$ in the above formula, $E = \frac{\mathbf{B}\,L\,M}{10^8\,t}$. As in this case $t = 1$, unit time being assumed, this may be written

$$E = \frac{\mathbf{B}\,L\,M}{10^8}, \qquad \textbf{(473.)}$$

which gives an expression whereby the E. M. F. generated in a conductor moving in a magnetic field *under the conditions given above* may be found.

The density $\mathbf{B}$, being the number of lines of force per unit of area, i. e., per square inch, or per square centimeter, it is

evident that the product $L\ M$ must be expressed in the same units in order that the equation $N = \mathbf{B}\ L\ M$ should hold true.

EXAMPLE.—Suppose the conductor $a\ b$ in Fig. 1123 to be 1 foot 8 inches long, and that it is moved in a magnetic field whose density is 50,000 lines of force per square inch at such a (uniform) velocity that at the end of 1 minute it would have moved 2,250 feet. What is the E. M. F. generated in the conductor?

SOLUTION.—As the density is expressed in lines of force per square inch, the other dimensions must be reduced to the same unit, i. e., inches.

The length of the conductor $L$ is then 20 inches, and the velocity, or distance through which it would move in 1 second, $= M = \frac{2,250}{60} =$ 37.5 ft., or $37.5 \times 12 = 450.0$ in.

Hence, from formula **473**, $E = \frac{\mathbf{B}\ L\ M}{10^8}$, where $\mathbf{B} = 50,000$, $L = 20$, and $M = 450$, $E = \frac{50,000 \times 20 \times 450}{10^8} = \frac{450,000,000}{10^8} = 4.5$ volts. Ans.

**3019.** The formula given in Art. **3018** does not hold good as it stands if the conditions governing the direction of the motion of the conductor are not as before stated, which are, that the conductor must lie in a plane at right angles to the lines of force and move in a direction at right angles to its own length and to the direction of the lines of force. It is evident that a conductor might readily be moved in a direction which would not conform to all or any of the above conditions; the formula, to be generally applicable, must then be modified to suit such cases.

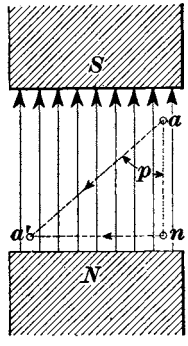

FIG. 1124.

**3020.** Fig. 1124 represents a case where a conductor $a$ lies in a plane at right angles to the lines of force (so that we are looking along its length, and consequently see only the round section, as shown), and is moved in a direction at right angles to its own length, but at the angle $p$, which is not a right angle, to the direction of the lines of force flowing between the poles $N$ and $S$ of a magnet. If the conductor move from $a$

to $a'$ in unit time (say one second), the area swept over by the conductor in unit time is a rectangle, and the area is measured by the product $L\ M$ of the length of the conductor $L$ and the length of its path in unit time, or its velocity, $M$; but the total number of lines cut by the conductor is *not* the product of the density **B** and the area $L\ M$, since the density is measured on a plane at right angles to the lines of force, and the area $L\ M$ is at an angle to this plane.

From an inspection of Fig. 1124, it will be seen that the conductor will cut exactly the same number of lines of force if moved from *any* point on the line $a\ n$ (which is parallel to the lines of force) to the point $a'$; in other words, whatever the value of the angle $p$, the number of lines of force cut by the conductor in moving from $a$ to $a'$ will be the same.

By making this angle a right angle, as at $n$, the path of the conductor along the line $n\ a'$ will be at right angles to the lines of force, and all the conditions prescribed in Art. **3018** will be fulfilled.

The length of the line $n\ a'$ is, however, not equal to the length of the line $a\ a'$; but as the former length must be used in calculating the total number of lines cut, and the latter is the length which is known, an expression for the length $n\ a'$ in terms of the length $a\ a'$ must be found. From the construction of the figure, the triangle $a\ n\ a'$ is a right-angled triangle, with the length of the hypotenuse $a\ a'$ and the adjacent angle $p$ given; the length of the side $n\ a'$ opposite the angle $p$ is found by trigonometry to be $a\ a' \sin p°$, which is the desired value.

**3021.** Calling the length of the conductor $L$ and the length of its path $M$, as before, it follows from the above that the total number of lines of force cut by the conductor is given by the formula

$$N = \mathbf{B}\ L\ M \sin p°. \qquad (474.)$$

With given values of **B**, $L$, and $M$, it is evident that $N$ is a maximum when $p° = 90°$, as then $\sin p° = 1$, and $\mathbf{B}\ L\ M \sin p° = \mathbf{B}\ L\ M$, corresponding to the case given in Art. **3018,**

while if $p^\circ = 0^\circ$, then $\sin p^\circ = 0$ and $\mathbf{B}\ L\ M \sin p^\circ = 0$, which means that if the conductor be moved in a direction at an angle of 0°, i. e., parallel to the lines of force, no lines will be cut by it and no E. M. F. generated.

A method of considering the relation between the length $n\ a'$ and the length $a\ a'$, which is very useful in some cases, is to regard the length $n\ a'$ as the *projection* of the length $a\ a'$ on a plane at right angles to the lines of force. The application of this method will appear in other parts of this section.

**3022.** In a similar manner other variations from the conditions given may be considered. Fig. 1125 represents the case where the conductor $a\ b$ lies in a plane at right angles to the lines of force, and is moved in the same plane, but in a direction $b\ b'$ at an angle $s$, which is not a right angle, to its length $a\ b$. The shape of the area swept over in moving from $a\ b$ to $a'\ b'$ is evidently a rhomboid, of which the area is equal to the product of the base $b\ b'$ and the altitude $a\ n$. This altitude being perpendicular to the base $b\ b'$, the triangle $a\ b\ n$ is a right triangle, and, by trigonometry, side $a\ n = a\ b \sin s$. Consequently, the total number of lines of force cut by the conductor $a\ b$ of length $L$ in moving over a distance $b\ b' = M$ through a field whose density $= \mathbf{B}$, is

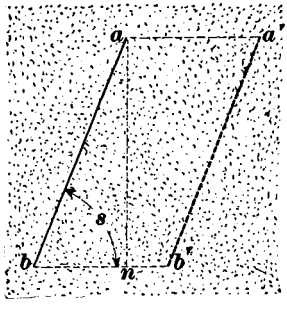

FIG. 1125.

$$N = \mathbf{B}\ M\ L \sin s. \qquad (\mathbf{475.})$$

Again, with given values of $\mathbf{B}$, $L$, and $M$, the value of $N$ is a maximum when $s = 90^\circ$, for $\sin 90^\circ = 1$ and $\mathbf{B}\ M\ L \sin s = \mathbf{B}\ M\ L$; and where $s = 0^\circ$, $\sin s = 0$ and $\mathbf{B}\ M\ L \sin s = 0$, which means that if the conductor is moved at an angle of 0°, i. e., parallel to its own length, no lines of force are cut by it, and no E. M. F. is generated in the conductor.

In this case, again, the length $a\ n$ is the *projection* of the

actual length of the conductor $a\ b$ on a plane at right angles to the direction of its path.

**3023.** Fig. 1126 represents the plan and elevation of the case where a conductor $a\ b$ is situated in a magnetic field at an angle $r$ to the lines of force, as represented in the elevation, and is moved through the field in the direction $a\ a'$ or $b\ b'$ at right angles to the lines of force and to its own length, as represented in the plan.

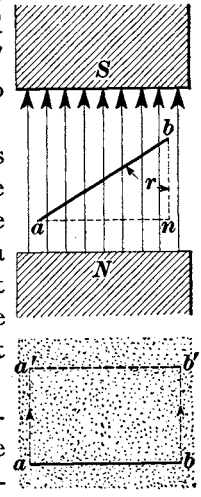

FIG. 1126.

The area swept over by the conductor is equal to the product of its length $a\ b$ (see elevation) and the length of its path $a\ a'$ (see plan), but, as before, the product of this area and the density of the lines of force is not equal to the total number of lines of force cut, as the area is not measured at right angles to the lines of force.

The number of lines of force cut, however, is measured by the product of the density, the length of the path of the conductor, and the *projection* of its length on a plane at right angles to the lines of force. This projection is represented by $a\ n$, Fig. 1126, and the triangle $a\ b\ n$ being a right triangle, side $a\ n = a\ b \sin r$, as before, and the total number of lines cut is

$$N = \mathbf{B}\ M\ L \sin r. \qquad (476.)$$

With given values of $\mathbf{B}$, $L$, and $M$, $N$ will again have a maximum value when $r = 90°$, as $\sin 90° = 1$ and $\mathbf{B}\ M\ L \sin r = \mathbf{B}\ L\ M$; and when $r = 0°$, and $\sin r = 0$, $\mathbf{B}\ M\ L \sin r = 0$, which means that if the conductor is located in a plane at an angle of 0°, i. e., parallel to the lines of force, no lines of force will be cut; hence, no E. M. F. will be generated by a movement of the conductor.

**3024.** For any case where the conditions governing the motions of the conductor differ in more than one respect from those given in Art. **3018,** a formula may be

constructed by combining formulas **474, 475,** and **476.** Thus, the total lines of force cut by any conductor of length $L$ situated in a uniform magnetic field of density **B**, lying in a plane at an angle of $r°$ with the lines of force, and moved with a velocity $M$ through the field in a direction at an angle of $s°$ with its length, and at an angle of $p°$ with the lines of force, will be given by the formula $N = \mathbf{B}\ L \sin r° \sin s° M \sin p°$, and the E. M. F. resulting from this motion will be given by the formula

$$E = \frac{\mathbf{B}\ L \sin r° \sin s° M \sin p°}{10^8}. \qquad \textbf{(477.)}$$

It is evident that with given values of **B**, $L$, and $M$, the value of $N$, hence of $E$, will be a maximum when the angles $r$, $s$, and $p$ are each equal to 90°, while if any of these angles is equal to 0°, the value of $N$ and $E$ will be 0.

It follows, then, that to get the maximum E. M. F. with a given length of conductor, these angles should all be as near 90° as possible, which is the case in almost all dynamos, as will be pointed out.

**3025.** Thus far a field of uniform density has been assumed; but from the statements which have been made the effect of variations in the density of the field may be readily found.

It should be remembered that as the E. M. F. generated in a moving conductor is proportional to the *rate* of cutting lines, it is not necessary that the conductor should actually move over any particular area in order that an E. M. F. be generated in it; it is only required that the conductor move at such a velocity that *if* that velocity were maintained for one second, the conductor would cut a certain number of lines of force, as measured by the area which would be swept over. This area is obviously the same whether it encloses lines of force or not; so if at any one point in a conductor's path the density is known, the number of lines of force which *would be cut* by the conductor in moving over that area *if* the density were uniform at its known value would evi-

dently be the product of the known density and the area, and the E. M. F. generated *at the instant* when the conductor is passing through the part of the field where the density is of the given value may be found from the formula.

**3026.** The considerations just mentioned apply if the velocity is not constant, for if the velocity at any instant is known, the area which *would be* moved over by the conductor in one second *if* the velocity were constant at the known value, measures the number of lines which would be cut in one second, and hence the *rate* of cutting or the E. M. F. generated.

In actual practice the velocity of conductors in any particular case is almost invariably constant, while the density of the field is seldom uniform.

EXAMPLE.—A conductor 3 feet 3 inches long is dropped vertically through a magnetic field whose lines of force are horizontal, but of varying density. At a certain point *a* the velocity is known to be 40 feet per second, and at the same point the density of the magnetic field is known to be 28,000 lines of force per square inch. What E. M. F. is generated in the conductor when at the point *a*?

SOLUTION.—The velocity of the conductor at this point is $40 \times 12 = 480$ in. per sec. The conductor being 3 ft. 3 in. $= 39$ in. long, if moved at this velocity for one second would sweep over an area of $480 \times 39 = 18{,}720$ sq. in., which area would enclose $18{,}720 \times 28{,}000 = 524{,}160{,}000$ lines of force, if the density were uniform at the known value throughout the area. From the formula $E = \frac{N}{10^8}$,

$$E = \frac{524{,}160{,}000}{10^8} = 5.2416 \text{ volts.} \quad \text{Ans.}$$

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### THE EFFECT OF CURRENT IN THE CONDUCTORS.

**3027.** Thus far, only the production of the E. M. F. has been considered. If this E. M. F. is allowed to act on a closed circuit, so that a current will flow, certain effects will be produced, which must be taken into account. First, the passage of the current through the conductor implies a loss or drop of potential equal in value to the product of

the current and the resistance of the conductor. (Art. **2315.**) The difference of potential between the terminals of the conductor in which the E. M. F. is generated is then less than that E. M. F., by an amount equal to the drop. Calling $e$ the E. M. F. generated, or the internal E. M. F., $E$ the difference of potential between the terminals, $R_i$ the internal resistance of the source of $e$, and $C$ the current flowing, then, $E = e - C R_i$. The total amount of energy expended in the circuit $w$ is evidently the product of $C$ and $e$; i. e., $w = C e$. Of this, $C \times C R_i = C^2 R_i$ is expended within the source of the E. M. F. itself, leaving $C e - C^2 R_i = C E = W$, the energy expended in the external circuit, or the *output*. It is evident that as $C^2 R_i$ is entirely expended in heating the conductors in which the E. M. F. is generated, it is wasted as far as any practical application is concerned, and should, therefore, be made as small as possible, in order that $C E$ can be as large a proportion as may be of the total energy developed, $C e$.

On this account, the internal circuits of dynamo machines are made of copper, that being the metal which has the greatest conductivity for a given cost and bulk.

**3028.** In addition to this drop of potential, the presence of the current introduces reactions between the magnetic field in which the conductors are moved and the field due to the current itself. (Arts. **2438** and **2439.**)

These reactions result in a tendency for the conductor to move, relative to the lines of force of the field, in a direction at right angles to its own length and to the direction of the lines of force.

The amount of the force is proportional to the amount of current and also to the density of the magnetic field, measured in a plane at right angles to the direction of the lines of force. If the length of the conductor lies in this plane, the force acting *on each centimeter of its length*, when the field is of unit density (one line of force per square centimeter) and a current of one absolute (C. G. S.) unit is flowing through it, is one *dyne*. From this it follows that, calling

$A$ the current in absolute units, **B** the density of the field in lines of force per square centimeter, and $L$ the length of the conductor that is within the limits of the field in centimeters, the force on the whole conductor in dynes,

$$f = A\,\mathbf{B}\,L. \qquad \textbf{(478.)}$$

**3029.** This force acts in a direction at right angles to the length of the conductor and to the direction of the lines of force; it is evident, however, that $f$ may be resolved into components in any other direction, by a method similar to that used in finding the E. M. F. generated in a moving conductor. If this is done, it will be found that similar results are obtained; namely, that the component of the force $f$ in any direction is equal to the value of $f$ given by the above formula multiplied by the sines of the angles which the direction of the component makes both with the length of the conductor and with the direction of the lines of force, and of the angle which the length of the conductor makes with the lines of force. From this it follows that if any one of these angles is equal to 0°, the component to that direction is also 0; that is, there is no tendency for the conductor to move in a direction parallel to its own length or parallel to the lines of force, nor in any direction if the length of the conductor is parallel to the lines of force.

It will be seen that the maximum component of the direction of the force is in the same direction as the motion required to produce the maximum E. M. F. in the conductor; and, further, in any other direction the force is reduced in the same proportion as the E. M. F. would be reduced from the maximum by movement in the same direction.

**3030.** If, then, the E. M. F. generated in a moving conductor is allowed to cause a current to flow, the reaction of the current in the magnetic field will cause the conductor to tend to move in a direction opposite to its motion in generating the E. M. F. (See Arts. **2439** and **2440.**) In order to move the conductor, it is necessary, then, to apply to it a force (neglecting inertia, friction, etc.) equal to

the component of the reaction between the current and the field that is in the direction in which the conductor is moved.

The product of this force and the distance through which the conductor is moved is evidently the mechanical work done upon the conductor; hence, the product of the force and the distance through which the conductor is moved in unit time is equal to the rate at which energy is expended in moving the conductor. In C. G. S. units, then, $w = A\,\mathbf{B}\,L\,M$, where $w$ is the rate of doing work in *ergs* per second; $A$, $\mathbf{B}$, and $L$ have the same values as before, and $M$ is the distance through which the conductor is moved in one second, in centimeters.

As $10^7$ ergs per second equal 1 watt, dividing both sides of the equation by $10^7$ gives the power directly in watts, or $W = \frac{A\,\mathbf{B}\,L\,M}{10^7}$. By dividing the upper term of the fraction by 10, $C$, the current in amperes, may be substituted for $A$, and the formula will then read $W = \frac{C\,\mathbf{B}\,L\,M}{10^8}$.

Formula **477**, which gives the E. M. F. generated in the moving conductor, may, on the assumption here made that the angles between the path of the conductor and its length, and the direction of the lines of force, are all 90°, be written $E = \frac{\mathbf{B}\,L\,M}{10^8}$, in which $\mathbf{B}$, $L$, and $M$ have each the same value as in the above formula; which, therefore, may be written $W = C\,E$.

This means *that the work done in moving a conductor through a magnetic field (neglecting friction and inertia) is equal to the work done by the resulting E. M. F. and current;* which also follows from the law of conservation of energy.

**3031.** From this it will be seen that it is necessary to supply mechanical power to the armature of a dynamo in order that it may supply a current, and the manner in which this power is expended should also be clear.

In commercial apparatus, it is evident that aside from the power required to move the conductors, an additional

amount of power must be supplied for overcoming the friction and all other sources of loss that may exist in the mechanism which is used for moving the conductors; further, the amount of electrical energy that appears in the external circuit is less than the total energy generated, by the amount expended in heating the conductors in which the E. M. F. is generated, as has already been pointed out. The ratio of the energy appearing in the external circuit, or the output of the dynamo, to the total amount generated, is called the **electrical efficiency** of the dynamo; the ratio of the output to the input, the input being the total amount of energy mechanically applied to the conductors to move them, including all losses in the mechanism used, is called the **commercial efficiency** of the machine. Both values are usually given in per cent. of the input; it is evident that this percentage must be less than 100, and in commercial machines it ranges from 75% to 95%, or higher, depending upon the size and design.

In finding the efficiency, both output and input must be reduced to the same units.

**3032.** If, instead of mechanically moving the conductors through the magnetic field, they be located therein with their lengths at an angle to the lines of force, and an E. M. F. from some external source be applied to the terminals of the conductors, a current will flow through them, and the reaction between the field produced by the current and the field in which it is located will produce a tendency of the conductors to move relatively to the magnetic field, just as when the current is produced by the E. M. F. generated in the conductors themselves. This tendency is exerted in a direction at right angles to the lines of force and to the length of the conductor, producing a force acting in that direction, which may be resolved into components acting in any other direction.

If the conductor be free to move in any direction, then this force will cause it to move, provided its component in that direction is greater than 0, and the rate at which work

will be done by the conductor in moving will be equal to the product of the value of the force in the direction of motion and the distance moved in unit time, i. e., the velocity. This apparatus is then an **electric motor,** capable of doing external mechanical work.

**3033.** The motion of the conductors through the field under these conditions will set up in them an E. M. F. which is opposite in direction to the E. M. F. which is sending the current through the conductors. (See Arts. **2439** and **2440.**)

It is evident, then, that in order to keep up the strength of the current in the moving conductors, the E. M. F. applied to their terminals must be equal to the E. M. F. generated, plus the drop or fall of potential in the conductors.

**3034.** It has already been shown that the energy represented by the product of the force on the conductor and the velocity of the conductor is equal to the energy represented by the product of the current flowing and the E. M. F. generated by the motion of the conductor. Calling $e$ the E. M. F. generated in the winding and $C$ the current flowing, as before, the mechanical work done by the moving conductor is $e\ C$. The energy represented by $C^2\ R_i$ ($R_i$ being the internal resistance of the conductors), as in the case previously considered, appears only as heat. The sum of these two, then, equals the total amount of energy which must be put into the apparatus to move the conductors; that is, $e\ C + C^2\ R_i = E\ C$, $E$ being the E. M. F. applied to the terminals of the winding. (Compare this with Art. **3030.**)

**3035.** It appears, then, given a conductor, or several conductors, situated in a magnetic field, with their lengths at an angle to the lines of force, that the conductors may be moved by the application of a mechanical force so that an E. M. F. will be generated in them, and this E. M. F. may be utilized in sending a current through an external circuit; this is the dynamo, in which the mechanical energy supplied

is converted into electrical energy. Or, an E. M. F. may be applied to the terminals of the conductors, causing a current to flow through them, which will cause them to move through the field; this is the motor, in which the electrical energy supplied is converted into mechanical energy. It will be seen that precisely the same features are required for both kinds of apparatus, and the same actions go on in both, the distinction being that what is the *output* of one is the *input* of the other. If the conductors had no resistance, and there was no friction or any other loss in the mechanism used to transmit the mechanical energy to or from the conductors, then the input would equal the output, and the efficiency would be 100%. This is manifestly impossible, so that the input must exceed the output by the amount of energy lost in heating the conductors and in the mechanism used to move the conductors, or that is moved by the conductors; that is, the efficiency is *always* less than 100%, in either dynamos or motors, and the various losses are of the same kind in both cases. This subject will be taken up more in detail later.

The development of the various systems of armature winding from the principles that have been given will now be taken up.

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## GRAPHICAL REPRESENTATION OF E. M. F. OR CURRENT.

**3036.** The value of the E. M. F. generated in a moving conductor during successive instants may be graphically represented by a "curve" on cross-section paper, the method usually adopted being to make the ordinates represent the E. M. F. and the abscissas either intervals of time or, what usually amounts to the same thing, distances passed over by the conductor. In the case of a conductor moving in a straight line at a constant velocity through a uniform magnetic field of unlimited extent, the E. M F. generated at any instant is constant, and would, therefore, be represented by a straight line parallel to the axis of abscissas, and at a

certain distance from that axis, depending upon the value of the E. M. F. generated and the scale selected to represent it. Thus, the graphical representation of the E. M. F. generated in the conductor, as given in the example in Art. **3018,** would be a straight line parallel to the axis of ab-

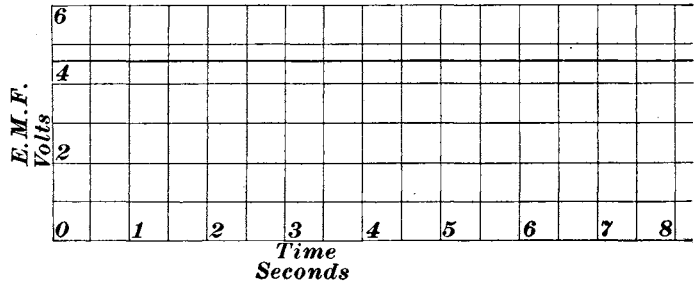


FIG. 1127.

scissas and at a distance from it equal to 4.5 volts on the scale of the ordinates, as shown in Fig. 1127.

The direction of the E. M. F. may be found from the rule given in Art. **2442,** the E. M. F. being considered as having the direction in which the current which it would produce is considered to flow.

By applying this rule, it will be seen that if *either* the direction of the lines of force or the direction of motion of the conductor be reversed, the direction of the E. M. F. is also reversed, but if *both* be reversed, the direction of the E. M. F. is unchanged.

**3037.** If the *direction* of the motion of a moving conductor is instantly reversed, but the *velocity* maintained constant, the E. M. F. generated in that conductor will be reversed in direction, but unchanged in value. In order to represent this condition graphically, it is necessary to make some distinction whereby the change in the direction of the E. M. F. will be indicated. This is done by plotting the E. M. F. curve on both sides of the axis of the abscissas, assigning to one side the values of the E. M. F. when in one direction, and to the other its values when in the opposite

direction, both to the same scale. It is customary to plot the curve of the E. M. F. or current when in a *positive* direction with respect to some given part of the circuit *above* the axis of the abscissas, so that this part of the curve is considered as + in direction.

Thus, if the conductor giving the curve represented in Fig. 1127 had been moved in one direction for 2 seconds, then instantly reversed and moved in the opposite direction

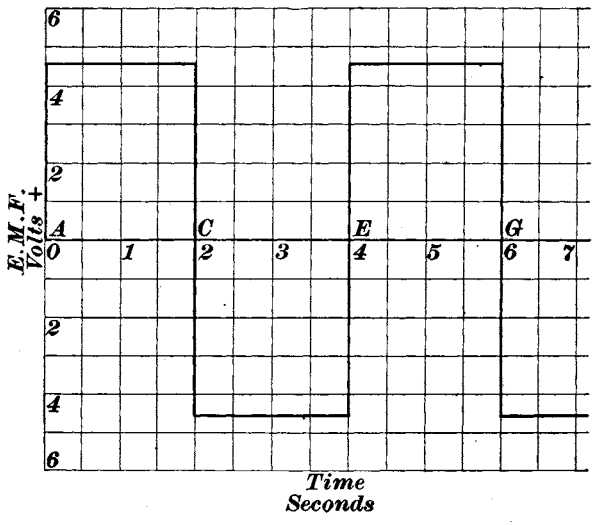


FIG. 1128.

at the same velocity for 2 seconds, then reversed again and so on, the curve of the E. M. F. would be as represented in Fig. 1128.

Here from *A* to *C* the curve is the same as Fig. 1127, 4.5 volts in one (the +) direction; at *C* (the end of the 2d second) the direction of the motion, also the E. M. F., is reversed, and is represented by the line drawn on the other side of the axis of the abscissas from *C* to *E*, where the E. M. F. is again reversed, and so on.

As at the instant the E. M. F. is reversed it passes through all the intermediate values between 4.5 volts in one direction and 4.5 volts in the other, a line must be drawn to

indicate all these values, as shown; the reversal being assumed to be instantaneous, this line coincides with the ordinate which passes through the abscissa which represents the time at which the reversal took place, as at 2 seconds, 4 seconds, 6 seconds, etc.

**3038.** If the change from the maximum E. M. F. in one direction to the maximum in the other were not instantaneous, this line would not coincide with one of the ordinates; for example, assume that this same conductor was not moved at a constant velocity, but with a uniform *acceleration* of such an amount that, starting from zero, the velocity at the end of the 1st second was the same as the constant value assumed in the previous case; then the E. M. F. generated at successive instants during this 1st second would be represented, as in Fig. 1129, by a straight line

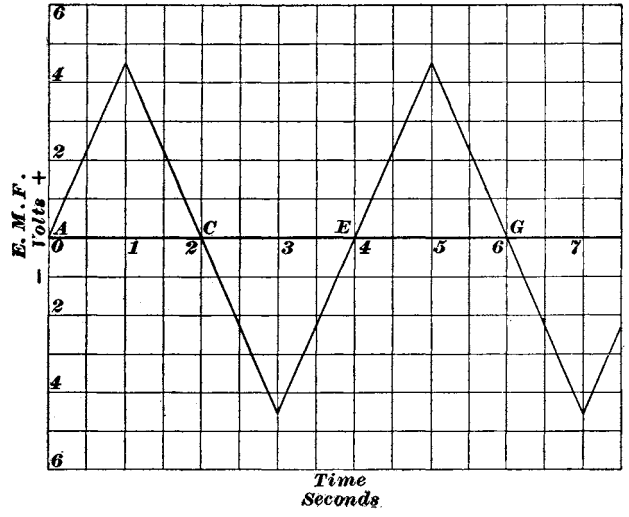


FIG. 1129.

commencing at 0 volts at 0 time and rising to 4.5 volts at the end of the 1st second.

If from this point the velocity of the conductor is retarded at the same rate as it was previously accelerated, its velocity at the end of the 2d second would be 0 and the curve of the

E. M. F. generated during the 2d second would again be a straight line, commencing at 4.5 volts at the end of the 1st second and falling to 0 volts at the end of the 2d second.

If the conductor is now moved in the opposite direction and the same cycle of acceleration and retardation gone through with, the curve of the E. M. F. generated during this cycle of motions will be of exactly the same shape as that for the previous cycle, but will lie on the opposite side of the line, as is represented by the part $C\,E$ of the curve shown in Fig. 1129. Continuation of this cycle of motion gives a series of repetitions of this curve, as represented in Fig. 1129.

**3039.** A similar curve would result if the velocity of the conductor had been kept constant, as in the case in Art. **3037,** but the density of the field had been uniformly varied along the path of the conductor from 0 to a maximum, and then to 0 again.

Both of these cases assume that the change from accelerating to diminishing velocity, or from increasing to decreasing density, is instantaneous, as indicated by the sharp peaks of the E. M. F. curve. In any apparatus as actually constructed these changes would be more gradual, which would result in more or less rounding the peaks of the curve.

**3040.** If a conductor is moved in a straight line through a succession of magnetic fields of alternate polarity, as represented in Fig. 1130, the curve of the E. M. F. generated

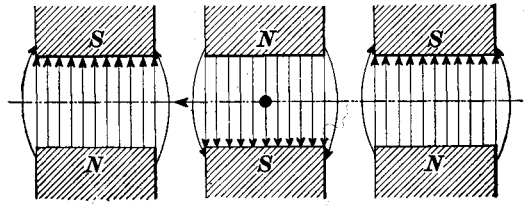


FIG. 1130.

will be of similar character to those shown in Figs. 1128 and 1129; that is, the E. M. F. will be maintained in one direction as long as the conductor is moving through a field of

one polarity, but as soon as the direction of the lines of force is reversed, the E. M. F. is also reversed. (Art. **3036.**) The actual shape of the waves of the curve will depend, as in the previous cases, upon the variation in the uniformity of the density of the field or of the velocity.

The manner of finding the E. M. F. generated in any conductor moved in any *straight* line through a magnetic field of any condition of density should now be clear.

It is evident, however, that motion in a straight line or in any irregular line is not in general desirable for dynamos; motion in a straight line can not be indefinitely continued, for that would require a field of unlimited extent, and sudden changes in the direction of motion of the conductor do not usually permit of good mechanical construction. To avoid both the infinite field and the sudden changes in the direction of motion, the conductor may be moved in a circular path, which is mechanically convenient and allows of the use of a field of limited extent; the effect of such motion will now be considered.

**3041.** In the case of a conductor moving in a circular path through a field of uniform density, if the lines of force are at every point radial to the path of the conductor, as represented in Fig. 1131, the angle which the direction of motion of the conductor makes with the lines of force at every instant is constant; the E. M. F. generated in the conductor is, therefore, constant as long as a constant velocity is maintained.

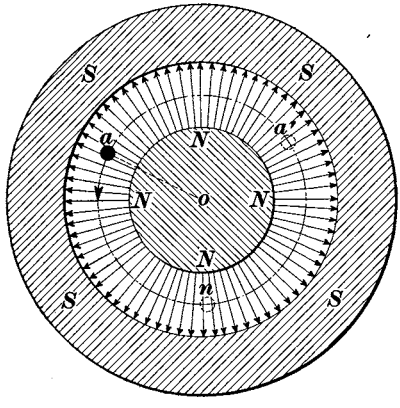


FIG. 1131.

In order to obtain the distribution of the lines of force required in the above case, one pole of the magnet (*S S S S*) must be made in the form

of a hollow cylinder, concentric with and enclosing the path of the conductor ($a\ n\ a'$) and the other pole ($N\ N\ N\ N$). In the space between these two poles the lines of force will be radial in direction and uniform in density if the rest of the magnetic circuit is properly designed.

**3042.** If the direction of the length of the conductor is radial, instead of parallel to the axis, as in the above case, by making the lines of force parallel to the axis and uniform in density all along the path of the conductor, the angle between the lines of force and the direction of motion of the conductor will at all instants be the same; hence, the E. M. F. will be of the same character as before. This arrangement of the lines of force may be obtained by making the pole faces circular in shape and placing them in two parallel planes with the center of the pole-pieces coinciding with the axis of rotation of the conductor, as represented in Fig. 1132.

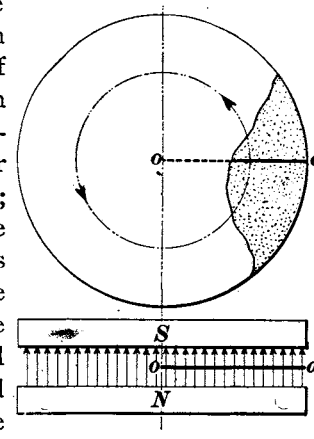

FIG. 1132.

The arrangement of the balance of the magnetic circuit is not indicated in this figure. A part of the north pole-piece is broken away in the elevation to show the conductor *a o*.

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### THE SINE CURVE.

**3043.** Fig. 1133 illustrates a case of circular motion which differs in many features from the first two considered. Here the lines of force are parallel to each other and at right angles to the axis of rotation; consequently, the angle between the direction of motion and the direction of the lines of force changes at every instant. From this it follows that the E. M. F. also varies during successive instants. Although the direction of motion of the conductor changes, at any one point it may be considered to be along

a straight line tangent to the circle at that point, and a certain length may be assigned to this line which will represent the velocity of the moving conductor. Thus, at the instant when the conductor is at the point *a* (Fig. 1133) of its path, the line representing its direction of motion at that point makes an angle of 0° (is parallel) with the lines of force; hence, no E. M. F. is generated at this point. As the conductor moves along its path, this angle becomes greater until at a point 90° from *a* the angle is also 90°, and the E. M. F. generated is a maximum. Further continuation of the motion for another 90° decreases the angle until it is again 0°, and the E. M. F. is again zero.

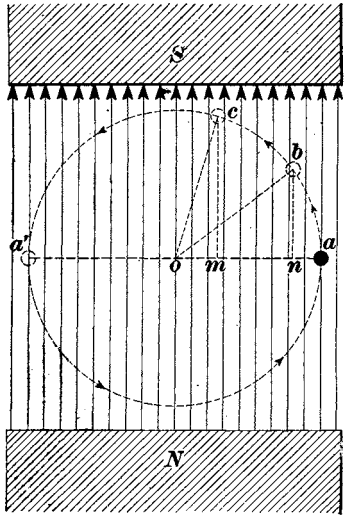

FIG. 1133.

The remainder of the revolution repeats this cycle of changes of the angle, but, as the conductor is moving in the opposite direction relative to the lines of force, the E. M. F. is reversed in direction. From this it follows that the curve of this E. M. F. would form a series of waves on each side of the axis of the abscissas, as in the cases described in Arts. **3037** and **3038.**

**3044.** The shape of the waves of this curve may be found by calculating the E. M. F. generated at successive intervals of time; this E. M. F. will evidently be proportional to the sine of the angle which the direction of motion makes with the lines of force (see Art. **3020**), so that by constructing at any point on the circle a right-angled triangle which includes the above angle, the side opposite this angle may be used as the length of the ordinate representing the E. M. F. generated at that point.

This process is represented in Fig. 1134, where *b* represents a certain point in the path of the conductor *a* at which it is desired to know the E. M. F. generated. The line *b r*, tangent to the circle at the point *b*, represents the direction of the motion of the conductor at this point, and makes the angle *p* with the direction of the lines of force, represented by the line *r t*. The line *t b*, at right angles to *r t*, is, then, the sine of the angle *p*; hence, it is a measure of the E. M. F. generated in the conductor at the point *b*, and by repeating this process for successive points around the circle a series of values will be obtained which may be used as ordinates of the E. M. F. curve, as stated.

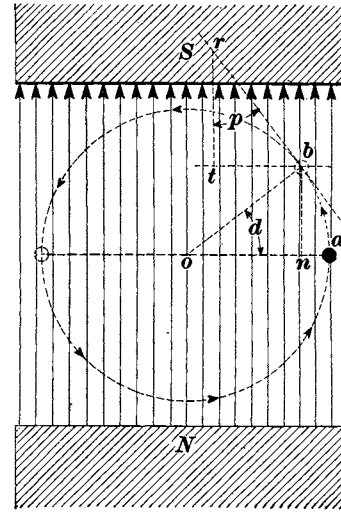

FIG. 1134.

From the construction of the figure, the line *o b* is perpendicular to the line *b r*, and the line *o a* is perpendicular to the line *r t*; hence, the angle *d* included between the lines *o a* and *o b* is equal to the angle *p* included between the lines *b r* and *r t*, and the E. M. F. is, therefore, proportional to the sine of the angle *d*, or to the length of the line *b n*. This length (*b n*) may or may not *equal* the E. M. F. when laid out on any scale, but will always be *proportional* to it.

Hence, the E. M. F. generated at any instant in a conductor moving in a circular path through a magnetic field of uniform density whose lines of force are at right angles to the axis of rotation and parallel to each other is *proportional to the sine of the angle through which the conductor has been rotated from a point where its direction of motion is parallel to the lines of force.*

**3045.** If the velocity of the conductor is uniform (as is assumed above), the conductor will move through equal angles in equal intervals of time; hence, the abscissas of the E. M. F. curve may represent either the intervals of time required for the conductor to move through the various angles or the angles themselves. The ordinates may represent the sines of the same angles, the E. M. F. being proportional to them. This curve may be conveniently drawn by laying off on a circle a series of points representing successive positions of the conductor after equal intervals of time, as represented at $a$, $b$, $c$, . . . . $a'$ in Fig. 1135 ($a$),

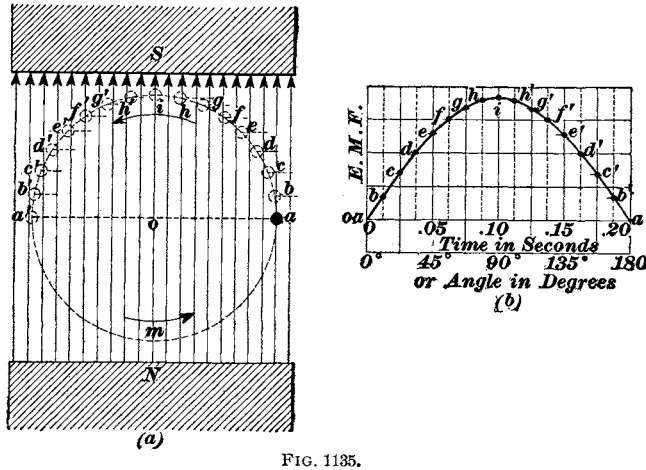


FIG. 1135.

$a$ $a'$ being a diameter at right angles to the lines of force. The vertical height of any of these points above the diameter $a$ $a'$ is, then, the sine of the angle through which the conductor has been moved, and these heights may be projected on the ordinates of properly arranged cross-section paper, as represented in Fig. 1135 ($b$), giving the curve $a$, $b$, $c$, . . . . $a'$, as shown. The curve for the remainder of the revolution, $a'$ $m$ $a$, may be laid out in the same way, and would evidently be of the same shape, but would be on the opposite side of the axis of the abscissas. This form of curve is called a **sine curve,** or **sinusoid,** from its method of con-

struction, and possesses several peculiar features, as will be pointed out.

**3046. Value of E. M. F.**—From the explanation given in Art. **3024,** it will be seen that the E. M. F. generated in the conductor in the above case at any instant may be found from formula **477;** $r°$ and $s°$ being in this case each equal to 90°, sin $r°$ and sin $s°$ are each equal to 1, and may be omitted, making the formula read

$$E = \frac{\mathbf{B}\, L\, M \sin p°}{10^8}.$$

It is evident that during one complete revolution the conductor passes over a distance equal to $2\pi r$, $r$ being the radius of its circular path, or $o\,a$ (Fig. 1135).

Then, if the speed of the conductor is $S$ revolutions per minute, its velocity is equal to $2\pi r \frac{S}{60}$ ($\frac{S}{60}$ being the revolutions per second), and this value may be substituted for $M$ in the above formula, which would then read

$$E = \frac{\mathbf{B}\, L\, 2\pi r \frac{S}{60} \sin p°}{10^8}.$$

All the lines of force cut by the conductor in each revolution are included in the area obtained by multiplying together $L$ and $2r$. This being the case, the total number of lines cut by the conductor, which is represented by $N$, is equal to $\mathbf{B}\, L\, 2r$.

From this, $\frac{N}{2r} = \mathbf{B}\, L$, which value may be substituted for $\mathbf{B}\, L$ in the previous formula, which then reads as follows:

$$E = \frac{\frac{N}{2r} 2\pi r \frac{S}{60} \sin p°}{10^8}.$$

Simplifying this, it becomes

$$E = \frac{N \pi S \sin p°}{10^8 \times 60}.$$

When $E$ is at its maximum value, $E_m$, $p^\circ = 90^\circ$ and $\sin p^\circ = 1$; hence,

$$E_m = \frac{N \pi S}{10^8 \times 60}. \qquad \textbf{(479.)}$$

## THE AIR-GAP.

**3047.** If the field through which the conductor moves in its circular path, having a radius $o\ a$, exists between two parallel pole faces, as represented in Fig. 1135, it is evident that the distance between the pole faces must be a little greater than $2\ o\ a$, in order that the conductor may not touch the pole faces in its rotation.

This distance between the pole faces introduces an air-gap of great length compared to its area, thus requiring a considerable expenditure of M. M. F. (magnetomotive force) in forcing the field across the gap.

The average length of this air-gap may be reduced by making the pole faces concentric with the path of the conductor, but as in this case the length of the air-gap is no longer uniform, the density of the field in the gap will not be uniform; and, further, the increased density is situated at a point where it has the least effect; i. e., at the point where the conductor is moving in a direction nearly or quite parallel to the lines of force, as represented in Fig. 1136.

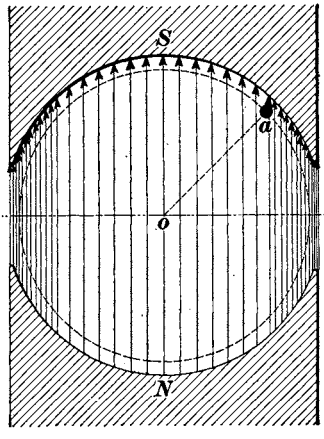


FIG. 1136.

**3048.** As there is actually required for the movement of the conductor only a thin cylindrical space near the pole faces, the length of the air-gap may be reduced very largely by filling in the space not required for the movement of the conductor with a cylindrical core of iron. The distribution of the lines of force will now be

materially different from that shown in Fig. 1136; the length of the air-gap being practically uniform and much shorter, the direction of the lines of force will be in nearly the shortest distance across the gap, i.e., will be nearly radial, and the density will be practically uniform and, with the same M. M. F., much higher.

The actual distribution of the lines of force will be about as represented in Fig. 1137. It will be noted that some of the lines of force do not pass into the core at all, and are even entirely outside the path of the conductor. These *leakage lines* (see Art. **2415**) are always present in any magnetic circuit which includes an air-gap, although they have not thus far been represented. Their influence on the design of the magnetic circuit may be neglected for the present, but will be fully discussed later.

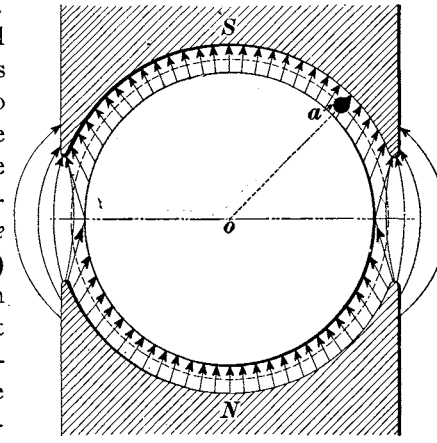

FIG. 1137.

**3049.** If the lines of force in the air-gap were absolutely radial and of uniform density throughout, the direction of the motion of a conductor moving through this air-gap would at any instant be at right angles to the lines of force, and (assuming a constant velocity) the E. M. F. would be constant in value, but, of course, reversed at the end of each half revolution. The E. M. F. curve would, therefore, be similar to that shown in Fig. 1128, Art. **3037.**

This differs from the case described in Art. **3041,** in that the direction of the motion of the conductor with respect to the direction of the lines of force is not constant, but is reversed at the end of each half of a revolution, which causes the E. M. F. to be reversed, as stated.

The actual distribution of the lines being different from this just described, the curve is actually more like the sine curve (Fig. 1135), but with a more flattened top, consequently a more rapid increase from zero to values near the maximum.

## ARMATURE CORE LOSSES.

**3050.** A very convenient method of moving the conductor through the magnetic field is to mechanically attach it to the surface of the cylindrical core, which may then be rotated around its axis by any convenient means. The motion of the core does not of itself affect the distribution or the density of the lines of force ; but in order to maintain the motion of the core, certain losses, due to *hysteresis* and to *eddy currents* circulating in the core, must be overcome.

**3051.** The hysteresis is due to the continual change in the direction of the lines of force through the core, as it rotates, amounting to one complete reversal in each half revolution ; the amount of the hysteresis loss depends upon the quality of the iron of which the core is made, the density of the lines of force in the core, the number of reversals of magnetism per unit of time, and the amount of iron affected. (Art. **2413.**)

**3052.** The eddy-current loss is due to the fact that, the iron of the core being a conductor, the E. M. F. generated in it by its rotation in the magnetic field causes currents to circulate through the mass of metal in the core ; these currents do not differ from the currents flowing in the conductors attached to the surface of the core, but as they do not appear in the external circuit, they represent so much wasted energy.

**3053.** The E. M. F. of these eddy currents is necessarily low ; but if the core is a solid mass of metal, the resistance offered to these currents is extremely small, so that the small E. M. F. may cause enormous currents to flow, which would thereby be the source of a great loss of energy.

The direction of these currents may be found by applying the rule given in Art. **2442,** when it will be seen that if the direction of the current in a section of the core under one pole is from front to back, under the other pole it will be from back to front, so that these currents will circulate around the core, as represented in Fig. 1138, in which only the lower half of the core is represented, the paths of the eddy currents being indicated by the lines with the arrow-heads.

In order to reduce the value of the eddy currents as much as possible, it is evidently necessary to reduce their E. M. F. and to increase the resistance of their path. This is usually accomplished by building up the core of a number of thin iron disks, as represented in Fig. 1139, arranged parallel to the lines of force and at right angles to the axis of rotation, and insulated from one another.

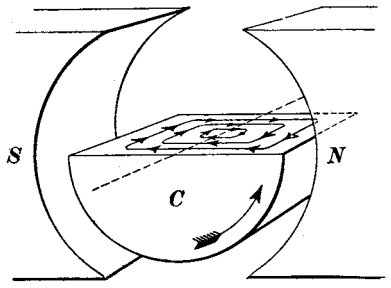

FIG. 1138.

Instead of being one single conductor of large section, the core is now made up of a number of conductors of less section and shorter length ; the E. M. F. generated in each conductor is, therefore, much less, and the current produced thereby is relatively much smaller than in the case of the solid core, so that the loss of energy is reduced.

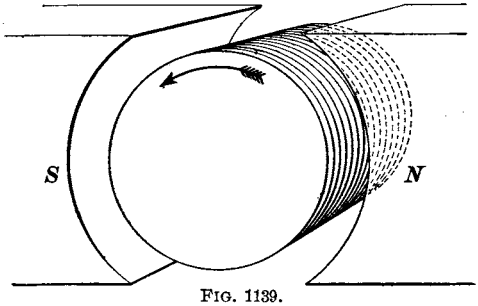

FIG. 1139.

**3054.** This process of dividing the core into thin plane sections is called **lamination,** the separate sections forming

the **laminae.** Lamination does not affect the magnetic qualities of the core, since all the sections are continuous in the direction of the lines of force.

Building up the core of lightly insulated iron wire will also prevent eddy currents, but as in this case the iron of the core is not magnetically continuous, the reluctance of the core as a whole is much greater than that of the iron of which it is composed. The laminated structure is, therefore, most extensively used.

**3055.** As in the case mentioned in Art. **3042,** the direction of the length of the conductor may be radial instead of parallel to the axis of rotation. In that case the cylindrical core would take the form of a disk, and the lines of force would enter and leave the core at the end faces instead of the cylindrical face, as represented in Fig. 1140, *a b* being the conductor supported on the core *C*, which rotates about the axis *o o'*.

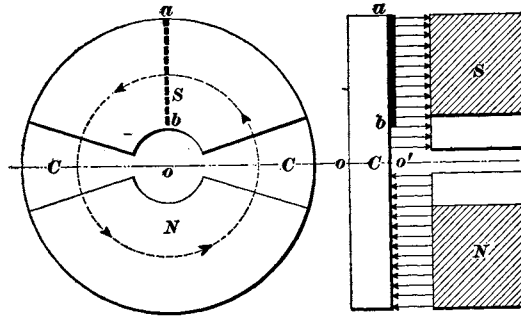


FIG. 1140.

The curve of the E. M. F. generated under these circumstances would be similar to that mentioned in Art. **3049,** i. e., similar to a sine curve, but with flatter peaks to the waves.

From an inspection of the figure, it will be seen that if the core were made up of disks arranged at right angles to the axis of rotation as in the previous case, the laminæ would not act to reduce the E. M. F. available for the production of

eddy currents; so this type of core is usually constructed of a long strip of thin iron, wound in a helical form, with strips of insulating material between the layers. This makes a core of the requisite form that is magnetically continuous in the direction of the lines of force, and is free from excessive eddy currents.

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## CHARACTER OF COMMERCIAL CURRENTS.

**3056.** Any electric current in commercial use may be classified either as a **direct current** or an **alternating current.** The abbreviations for these are D. C., direct current, and A. C., alternating current.

A *direct current* may be defined as *a current which always flows in the same direction through the conductor or circuit.*

A direct current may be **continuous,** so-called, or **pulsating.** A strictly continuous current is one in which the E. M. F. has an absolutely constant value during succeeding intervals of time, which would, therefore, cause a perfectly steady current to flow through a circuit of constant resistance.

The curve of a continuous current would then be a straight line parallel to the axis of the abscissas, as represented in Fig. 1127. Incandescent dynamos or constant potential dynamos are familiar examples of machines that furnish continuous currents.

**3057.** The pulsating current is practically unknown in the commercial world, and although the current from a Thomson-Houston arc machine may be called a pulsating current, yet it is never mentioned as such. As will be explained farther on, a pulsating current is one which always flows in the same direction, but the electromotive force constantly varies, so that the current consists of distinct impulses or rushes of current.

In Fig. 1141, (*a*), (*b*), and (*c*) represent three possible curves of pulsating currents; in (*a*) the fluctuations of the E. M. F. or current occur between a maximum and zero, while in (*b*)

the minimum is about .7 of the maximum; (*c*) represents a slightly different type of curve, in which the minimum is about .85 of the maximum. It will be seen that either of the last two quite closely approaches a strictly continuous current.

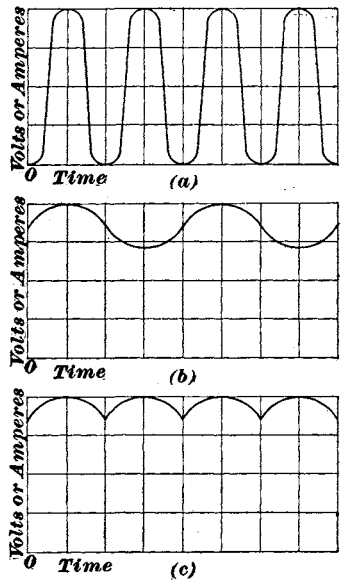

FIG. 1141.

**3058.** An *alternating current* may be defined as *a current which is continually reversed in direction;* consequently, its E. M. F. and current *alternate* between two opposite maximum values; the curve of the E. M. F. or current would, therefore, lie on both sides of the axis of the abscissas. A dynamo which generates an alternating E. M. F. is called an **alternator.** The E. M. F. generated in a conductor whose direction of motion with respect to the direction of the lines of force is periodically reversed would, therefore, be an alternating E. M. F., as shown by the curves in Figs. 1128, 1129, and 1135.

If the conductor so moved cuts the lines of force in each direction in the same time and at the same rate, the curves of the E. M. F. generated by the motion in each direction will both be of the same shape, and will lie equally on both sides of the axis of the abscissas, and a continuation of the

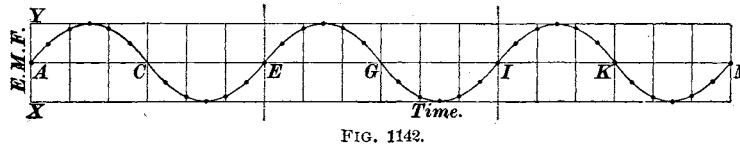

FIG. 1142.

cycle of motions, under the same conditions, will give an E. M. F. curve that is merely a series of repetitions of the

curve representing the E. M. F. generated during the first cycle of motions. Such an E. M. F. (or its resulting current) is called a **cyclic, periodic,** or **harmonic** alternating E. M. F. (or current). A curve showing a form of such an E. M. F. is given in Fig. 1142, the axis being *A M*; the positive impulses are above, at *Y*, and the negative impulses at *X*. The curve crosses the axis at the points *C*, *E*, *G*, etc.

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## GENERAL PRINCIPLES OF ARMATURE WINDINGS.

**3059.** It should be clear that rotary motion of a conductor in a magnetic field may be divided into two general classes: (1) where the arrangement of the field with regard to the path of the conductor is such that the direction of the motion is always the same, relative to the direction of the lines of force, and (2) where the arrangement is such that the direction of motion is periodically reversed, relative to the direction of the lines of force.

A further distinction between these two classes is that in the first class each line of force is cut *only once in each revolution*, while in the second class each line of force is cut *twice in each revolution.* This has given rise to the names **unipolar** and **bipolar** (or **multipolar**) induction for the two classes; i. e., the E. M. F. generated in a conductor so arranged as to come under the first class would be said to be due to *unipolar induction*, etc. These terms have been extended to the machines themselves, so a machine in which the E. M. F. is generated by unipolar induction is called an *unipolar dynamo;* if the E. M. F. is generated by bipolar induction, it is called a *bipolar dynamo*, and so on. This application of the term *unipolar* is hardly correct, since an "unipolar dynamo" must necessarily have two poles. Its application to induction, however, is more accurate, because, aside from its influence on the design of the magnetic circuit, the presence of more than one pole is not necessary in considering this class of induction; that is, as

each line of force is cut only at one point, it does not matter what course it takes after being cut. With bipolar or multipolar induction, it is necessary that the lines from each magnet be grouped together in the same manner at the two separate points of their own path at which they are cut by the conductor, which is most conveniently done by making these points the surfaces of the poles of the magnet. Still, the distinction is usually applied to the machines themselves.

**3060.** It has been shown that with either unipolar or bipolar induction the conductor may occupy one of two radically different positions; namely, the direction of its length may be *parallel* or *radial* to the axis of rotation. In either case, with unipolar induction, as illustrated in Arts. **3041** and **3042,** Figs. 1131 and 1132, it is evident that the E. M. F. generated in the conductor is a *direct* E. M. F. in the sense of being continuous in direction, while with bipolar induction, as illustrated in the cases given in Art. **3043** and those following, the E. M. F. generated in the conductor is an *alternating* E. M. F.

**3061.** In order to electrically connect a stationary external circuit with the moving conductor, some form of sliding or rubbing contact is necessary, which usually takes the form of stationary strips of copper, carbon, or other conducting material called **brushes,** which form the terminals of the external circuit, and which rest upon bare metallic surfaces which are electrically connected to the conductors and mechanically attached to but insulated from the shaft by which the armature core, conductors, and collecting devices are driven. In case it is desired to make continuous connection throughout the revolution with the conductor, these bare metallic surfaces are made continuous, i. e., in the form of rings, and the device is then called a **collector,** while if it is desired to make the connection between the conductors and the external circuit during a part of a revolution only, the bare metallic surfaces are made segmental. It is never the case that the external circuit is entirely dis-

connected from all the conductors of the armature at the same time, so that if any particular conductor is disconnected from one of the terminals of the external circuit at any time during the revolution, another must be substituted. This results in a collecting apparatus consisting of a series of separate metallic segments arranged in cylindrical form, each connected to some part of the winding, forming a device called a **commutator.**

From the nature of the device, the character of the difference of potential which appears between the terminals of the external circuit (the brushes), if a *collector* is used, is the same as the character of the E. M. F. generated in the conductors; i. e., it is subject to the same fluctuations in value or reversals of direction.

If a *commutator* is used, this is not necessarily the case; in fact, is not likely to be, since the connection with any particular conductor is not maintained throughout that conductor's cycle of motion, so that the character of the E. M. F. generated is not reproduced in the difference of potential existing between the brushes. This is an important distinction, since it is the character of this difference of potential which *directly* determines that of the current in the external circuit, and not the character of the E. M. F. generated.

**3062.** It has been pointed out that, in order to generate a sufficiently high E. M. F. for commercial applications, a number of conductors must be used, so connected together that their E. M. F.'s will add together to the desired amount. These conductors may obviously be located in the same magnetic field, and rotated under the same conditions; then, the E. M. F. of each will pass through exactly the same cycle, with a phase difference depending upon their relative positions in the field at any instant. From a study of these features, the proper methods of connecting the conductors to each other and to the external circuit to attain any desired result may be deduced.

Fig. 1143 represents 16 conductors, *a*, *b*, *c*, . . . . *p*,

equally spaced around the periphery of the core $C$. The direction of the lines of force being from $N$ to $S$, and the direction of motion being as indicated by the arrows, the direction of the E. M. F. in the conductors under the $N$ pole face is from back to front, while in those under the $S$ pole face it is from front to back, as will be seen if the hand rule (Art. **2442**) is applied. This is indicated by marking the conductor with a + or a solid black dot, as shown. Conductors in the positions $a$ and $i$, being in such a position that no lines of force are cut by them, have no E. M. F., and are not marked.

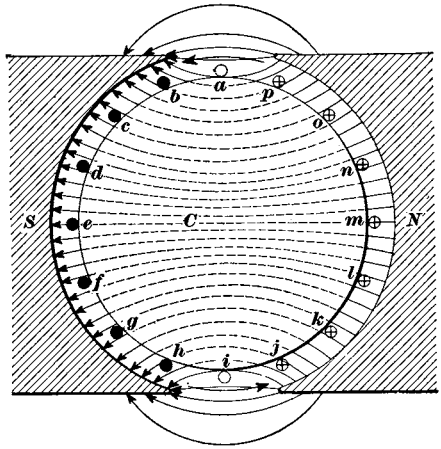

FIG. 1143.

**3063.** In connecting two or more conductors in series, it is evident that the maximum E. M. F. will result when the E. M. F.'s of the two conductors coincide in phase, for, otherwise, at a part of their cycle the E. M. F.'s in the two conductors would oppose each other; the same result may be obtained if the phases are displaced 180°, for then the two conductors will each have a maximum E. M. F. generated in them at the same instant, and although these two E. M. F.'s would be represented in a clock diagram as acting in opposite directions, the conductors may be so connected that the E. M. F.'s will add together. This is represented by the diagram, Fig. 1144, where $a\ b$ and $c\ d$ represent two conductors, in which the E. M. F.'s generated are in opposite directions, as indicated by the arrow-heads, but by

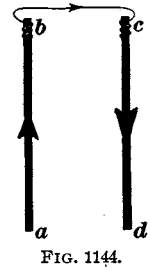

FIG. 1144.

connecting the ends *b* and *c* together the difference of potential between *a* and *d* is equal to the sum of the two E. M. F.'s.

Applying these principles to the case illustrated in Fig. 1144, it is evident that the proper conductor with which any one of the conductors—for example, conductor *e*—should be connected in series is either the conductor diametrically opposite it, in this case conductor *m*, or either of the conductors immediately adjacent to it, in this case either conductor *f* or *d*.

NOTE.—The figure being very much out of proportion, the angular distance between these adjacent conductors would seem to be sufficient to cause a considerable difference in their phase; in practice, however, the angular distance between adjacent conductors would be very small, and the difference in phase of the E. M. F.'s generated in them almost inappreciable.

**3064.** Applying the principle illustrated in Fig. 1144, opposite conductors would be connected by conductors extending across one of the end faces of the core. But in connecting adjacent conductors in series a different method must be followed, since the ends which are similarly situated on the core must be connected together, as illustrated in Fig. 1145, where *a b* and *c d* represent two conductors, in each of which the E. M. F. generated is in the same direction, as indicated by the arrow-heads. In order to connect these two conductors in series, so that the E. M. F.'s will add, the ends *b* and *d* (or *a* and *c*) must be connected together, as represented, in which case the difference of potential between *a* and *c* (or *b* and *d*, if *a* and *c* are connected) would be equal to the sum of the two E. M. F.'s generated.

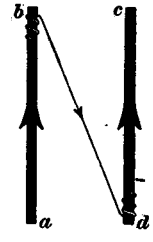

FIG. 1145.

**3065.** Now, in the armature, the above connection manifestly can not be made across the end faces of the drum; neither can it be made directly across the cylindrical face, for in the latter case an E. M. F. would be set up in the connecting wire, opposite in direction to the E. M. F. of the

conductors. The only reasonable way in which this style of connection can be made is to make the armature core in the form of a *cylindrical ring*, and pass the connecting wires through the hole in the center of the ring, as illustrated in Fig. 1146. Here the conductor *e* is connected to the conductor *d* by a wire passing down the back face of the ring, through the hole in the center at *x* and up the front face to *d*.

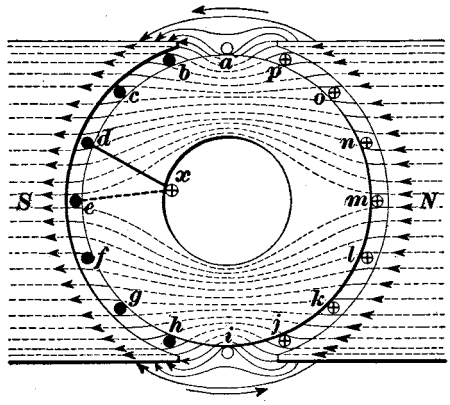


FIG. 1146.

The lines of force pass from pole to pole through the iron of the core, as represented in Fig. 1146, and hence are not cut by this connecting wire *x*, which, therefore, has no E. M. F. generated in it.

**3066.** These two general methods of connecting conductors in series are called **drum winding** and **ring winding,** respectively, from the shape of the cores used. The first practical use of the ring winding was due to Gramme, hence it is often called the **Gramme winding.** It was invented by Paccinotti. The drum winding was originated by Siemens.

**3067.** In building up a drum armature core, the disks of which it is composed may be slipped directly on the driving shaft, forming a solid mass of metal; but in the ring core it is necessary to provide a support for the ring-shaped disks, which shall have sufficient strength to drive the armature core and at the same time provide a sufficient opening between the shaft and the inside of the core to admit the connecting wires of the winding. Such a support is called a **spider,** and usually consists of two castings, made

with a central hub bored out for the shaft, from which hub a number of thin arms radiate and support the armature core, the connecting wires being wound in between these arms.

**3068.** It will be seen that if the conductors are arranged *radially* on the end faces of the core, with the pole-pieces facing these surfaces (see Art. **3055**), the same two systems of winding may be followed when connecting the conductors in series. In this case the connecting wires are arranged on the cylindrical surface (or surfaces in a ring winding) instead of the radial surfaces. To get the best results, these armatures are made in the form of a disk; the distinctive features of the ring or drum winding are not altered by this change in the form of the core, but the mechanical construction is materially different.

In order to distinguish between the two forms of cores, those in which the lines of force enter and leave the cores at the cylindrical surface are called **cylinder** armatures, whether the winding be ring or drum, and those in which the lines of force enter and leave at the end face (or faces) are called **disk** armatures. (See Arts. **3041** and **3042.**)

**3069.** Fig. 1147 illustrates these two methods of connecting conductors in series for cylinder amatures, (*A*) being the ring and (*B*) the drum winding. In each the upper half of the core is removed, showing the loop formed by the conductors and the connections between them. In order to connect the free ends of the loop to the collecting device, or to other conductors, other connecting wires are added, as represented at *1*, *2*. It will be seen that in either form of winding the active conductors and the connecting wires form a coil of one or more turns. In practice these coils are usually formed from a single piece of insulated wire, of suitable length, wrapped around the core a sufficient number of times to make the coil of the requisite number of turns. Each coil so wound covers a certain fraction of the surface of the armature core; in the case of the drum winding, this

fraction of the surface is divided into two parts that are on opposite sides of the core, while in the ring winding it is

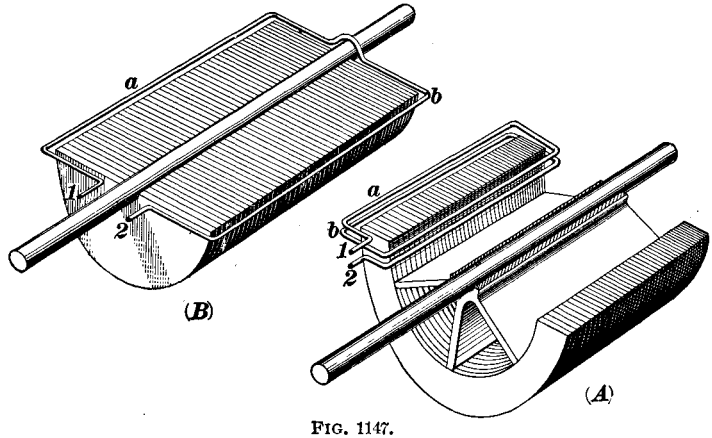


FIG. 1147.

altogether on one side. The amount of surface of the core covered by the coil may be called the *width* of the coil.

## DIRECT-CURRENT ARMATURE WINDINGS.

### UNIPOLAR ARMATURES.

**3070.** In order that an E. M. F. which acts continually in one direction may be generated in a moving conductor, it is necessary that the direction of motion of the conductor be always the same with reference to the direction of the lines of force of the magnetic field in which the motion takes place. Motion in a straight line is here obviously impossible, since it could not be continued for any length of time; motion in a circular path is, therefore, the only kind that answers the requirements.

In Arts. **3041** and **3042** two methods of moving a conductor in a circular path in a constant direction relative to the lines of force are described and illustrated. These are examples of *unipolar induction.* (See Art. **3059.**) In either of the above methods, it is evident that a number of

conductors may be used, distributed along their circular path, and in each the same E. M. F. will be generated. In order to obtain a high E. M. F., it would then be desirable to connect these various conductors in series, in such a way that all their E. M. F.'s would be added together.

If this is attempted, it will be found that, owing to the fact that the lines of force form closed loops, it is impossible to *permanently* connect the active conductors in series in any manner so that the connecting wires will not cut the lines of force in such a way as to set up in them an opposing E. M. F. of exactly the same value as that generated in the armature conductors proper. The final effect of connecting any number of armature conductors in series is, therefore, at most only the E. M. F. of a single conductor.

The only way, then, in which the conductors may be connected is by means of sliding contacts, whereby the connecting wires may be stationary with respect to the moving armature conductors.

It is evident that this method is of limited application, since the connections for a large number of conductors would become too complicated.

**3071.** With unipolar induction, then, the maximum E. M. F. possible is that of a single conductor; it is evident, however, that if a number of separate conductors are used, they may all be connected in *parallel*, which, while it does not increase the E. M. F., does increase the possible current output, since it decreases the internal resistance of the armature winding.

A number of such conductors connected in parallel are equivalent to a single wide conductor; in the case illustrated in Fig. 1131, this would be equivalent to a tube, of a thickness sufficient to allow it to rotate freely between the poles $N$ and $S$, while in the case illustrated in Fig. 1132 it would be equivalent to a disk rotating between the poles $N$ and $S$.

It is in one or the other of these forms that the armatures of unipolar dynamos, which have a limited application in cases where a large current at a low potential is required, are constructed.

## OPEN-COIL BIPOLAR ARMATURES.

**3072.** The E. M. F. generated in the separate coils of an armature winding which is revolved between the opposite poles of a bipolar magnet is naturally alternating in character, since its direction when passing through one field is opposite to that which it has when passing through the other.

When connected to the external circuit by means of collector rings, this alternating E. M. F. is impressed directly on the external circuit; but by using a suitably arranged commutator, the connections between the coils of the armature winding and the external circuit may be reversed at proper intervals, so that the current in the external circuit will be uniform in direction.

A simple way of accomplishing this result with a single coil is shown in Fig. 1148, in which a coil of three con-

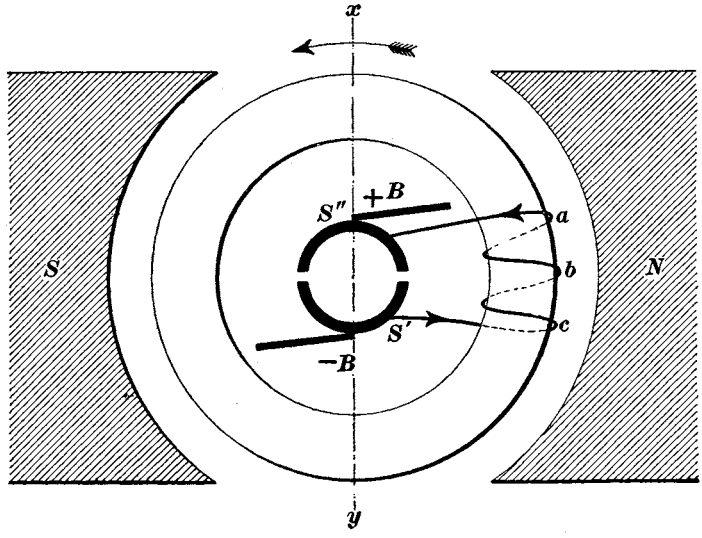


FIG. 1148.

ductors, *a b c*, is wound on a ring core and connected to the two commutator segments *S'* and *S''*, each of which covers nearly one-half the circumference of the commutator. On

these two segments rest the two brushes $+B$ and $-B$, they being placed opposite each other and making contact with the segments $S'$ and $S''$ on the neutral line $x\ y$.

**3073.** When the coil is in the position shown, it being rotated in the direction indicated by the arrow, the E. M. F. generated in the coil will be acting in the direction indicated by the arrow-heads, thus making the top brush positive. When the coil reaches the neutral space, the brushes will each momentarily make contact with both commutator segments, by bridging the space which separates them; but as in this position there is no E. M. F. generated in the coil, this has no effect. On further motion of the coil under the opposite pole-piece, by which its E. M. F. is reversed in direction, the top brush comes in contact with segment $S'$ and the bottom brush with segment $S''$. Since the direction of the E. M. F. in the coil has been reversed, this reversal of the connection between the brushes and segments results in keeping the difference of potential between the brushes in the same direction as before.

It is evident that this difference of potential is not at all constant, but varies from a maximum to zero and then to maximum again; the curve of its various instantaneous values would be a series of waves, all on one side of the base line. In other words, such an arrangement as has been described would cause a *pulsating* current to flow in the external circuit. (See Art. **3056.**)

**3074.** Another coil can be wound on the core directly opposite the first, and connected in series or in parallel with it. The width of the coils can not be greater than the width of the neutral spaces, without causing opposing E. M. F.'s during parts of a revolution; consequently, only a part of the surface of the armature can be utilized, and at best there is a part of the time that the E. M. F. of the winding is zero.

However, other pairs of coils may be wound on the surface of the core, in positions intermediate between those of

the original pair; these pairs may then each have its own commutator and brushes, and as the maximum and zero of values of the E. M. F.'s of the new windings occur at different periods of time from those of the first pair, the E. M. F.'s may be combined so as to prevent the E. M. F. acting in the external circuit from falling to zero.

**3075.** Fig. 1149 shows the arrangement, for both ring and drum winding, of two sets of coils *A A'* and *B B'*, each

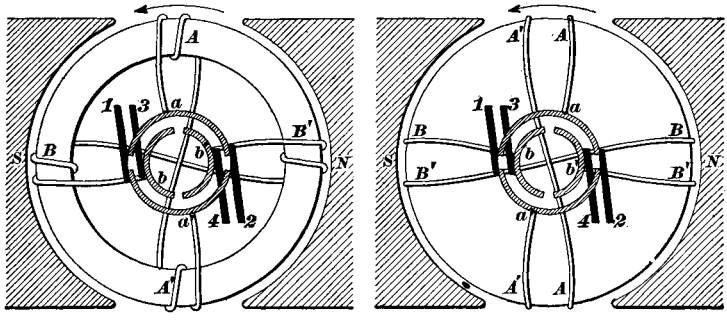


FIG. 1149.

set containing four active conductors, those of one set occupying a position on the core 90° from those of the other. Both sets are supplied with their two-segment commutators, which for convenience are represented as being concentric, *A A'* being connected to *a* and *a'*, and *B B'* to *b* and *b'*. Brushes *1* and *2* rest on segments *a* and *a'*, and brushes *3* and *4* rest on segments *b* and *b'*.

**3076.** The maximum E. M. F. of each of these sets is the same, but that of the one occurs $\frac{1}{4}$ revolution ahead of the other, so that the curves representing the instantaneous values of the E. M. F.'s of these two sets of coils for one revolution would be about as represented in Fig. 1150, where curve *1* is the E. M. F of coils *A* and *A'*, and curve *2* is the E. M. F. of coils *B* and *B'*, for a complete revolution, starting from the position of the coils represented in Fig. 1149.

If the two sets of coils are connected together in series by

means of an external connection between, say, brushes *2* and *3*, then the difference of potential between brushes *1* and *4* at any instant is equal to the sum of the E. M. F.'s of the

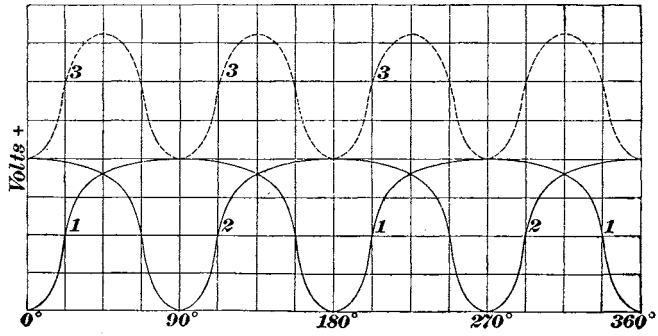


FIG. 1150.

two sets of coils at that instant. The result of the addition for the entire revolution is represented by the dotted curve *3*, Fig. 1150.

It is readily seen that for about one-fourth of each wave the E. M. F. of one set of coils is nearly at its zero value, and, therefore, contributes but little to the total E. M. F. of the armature; the resistance of this set of coils must, nevertheless, be overcome, since it forms a part of the circuit.

**3077.** Instead of connecting the sets of coils in series, they may be connected in parallel; but with the coils connected as shown in Fig. 1149, this would result in having the more active set of coils short-circuited by the set that is less active, which would very materially reduce the difference of potential between the brushes. There is, however, a part of the revolution when the E. M. F.'s of the two sets of coils are nearly enough the same to allow of their being connected together in parallel, and by widening the gap between the ends of the segments of the commutator, each set of coils may be entirely disconnected from its brushes during the part of its revolution when its E. M. F. is much lower than that of the other set.

This arrangement of the commutator segments for the windings shown in Fig. 1149 is represented in Fig. 1151, in which $a$ and $a'$ are the segments connected to coils $A$ and $A'$, and $b$ and $b'$ are the segments connected to coils $B$ and $B'$, as before.

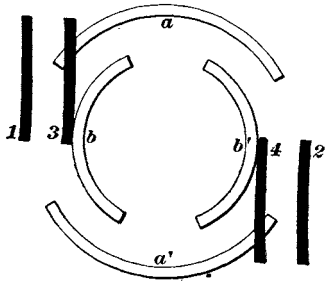

FIG. 1151.

**3078.** It is evident that curves showing the difference of potential between either pair of brushes would comprise that part of curves *1* or *2* (Fig. 1150) that represents the E. M. F. of the winding during the time that the brushes are in contact with the commutator segments. The curves in Fig. 1152 represent the difference of potential which would exist between the brushes if the arrangement shown in Fig. 1151 were used with the windings shown in Fig. 1149, curves *1*, *1*, etc., showing the difference of potential between brushes *3* and *4*, and curves *2*, *2*, etc., showing the difference of potential between brushes *1* and *2*, starting from the position of the commutator represented in Fig. 1151. It is apparent that with this arrangement the windings might be connected in parallel by connecting together brushes *1* and *3* and *2* and *4* (Fig. 1151). In that case, the difference of

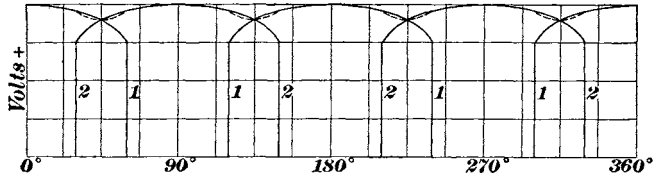

FIG. 1152.

potential between the brushes would be the E. M. F. of one winding until the other is connected in parallel with it, which connection would cause the difference of potential to drop a little, since the winding which is newly connected has a slightly lower E. M. F. than the other. The result of

this is that the curve is depressed a little during the time that the coils are in parallel, as represented by the dotted lines in Fig. 1152.

**3079.** From this curve (Fig. 1152) it will be seen that at the moment when the two sets of coils are thrown in parallel by the brushes, the E. M. F. in the two sets is not the same, that of the set which had just before alone been connected to the brushes being higher than that of the other. A little later, at the moment when one of the sets is disconnected from the circuit by one set of brushes leaving its segments, the coil which is disconnected has a less E. M. F. than the other.

If the coils had little inductance, this would result in the greater E. M. F. of the one set of coils sending a current around through the other set against the E. M. F. generated in it, which current would not appear in the external circuit, and would, therefore, represent so much wasted energy.

**3080.** This *local current* would evidently be greatest when the difference between the E. M. F.'s of the two sets of coils is greatest; that is, at the moment when the two sets of coils are connected in parallel, and at the moment one of the sets is disconnected from the brushes.

Then, when the one set of coils is disconnected from the other, this local current would be suddenly broken, which would result in sparking.

In an armature as actually constructed, however, the inductance of the coils is sufficient to prevent these local currents; when a coil is first connected in parallel with another, its inductance prevents a sudden rush of current through it, and allows it to take up its share of the current output gradually. As the coil approaches the point where it is to be disconnected from the circuit, and the E. M. F. generated in it becomes less than that of the coil with which it is connected, its inductance serves to keep up its E. M. F., so that its current gradually grows less, until at the time when it is disconnected from the circuit, if that time is

properly chosen, its current output is practically zero, and little or no spark results from breaking its connection with the circuit.

**3081.** In Fig. 1151 the two sets of segments have, for convenience, been represented as concentric; in practice, however, the two sets would be made of the same diameter and placed side by side. If made in this way, the separate brushes *1* and *3* and *2* and *4*, Fig. 1151, may be replaced by two wider brushes, wide enough to bear on either or both sets of segments. This is represented in Fig. 1153, in which *a* and *a'* and *b* and *b'* are the two pairs of commutator segments, and *1* and *2* are the brushes, which are wide enough to bear on either or both pairs of segments, according to the position of the commutator.

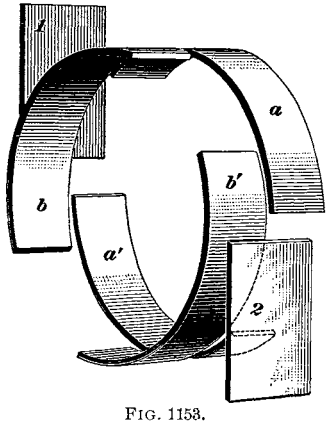

FIG. 1153.

**3082.** It will be seen that this arrangement of coils and commutator gives a direct but pulsating current, in which the pulsations are not excessive. As has been pointed out, however, the width of the coils should not be greater than the width of the neutral spaces, so that even with two sets of coils the entire armature surface can hardly be utilized.

More than one complete winding, however, can be placed upon the same core, and if each is provided with its own commutator, they may be coupled up in series or in parallel, as desired.

Such a winding as has been described, in which separate sets of coils are used, and which are connected together in various combinations and connected to or disconnected from the circuit during the rotation of the armature, is called an **open-coil winding.**

**3083.** Only two or three forms of open-coil windings are in commercial use at the present time. That which has

been described is used in the **Brush** dynamos, the ordinary sizes of machine using two separate windings, each with its commutator, as represented in Fig. 1154.

In this machine the pole-pieces face the sides of the armature, as represented by the heavy dotted lines. The segments of the two separate commutators are for convenience represented as concentric, with the brushes resting on their edges; whereas, actually, they lie side by side,

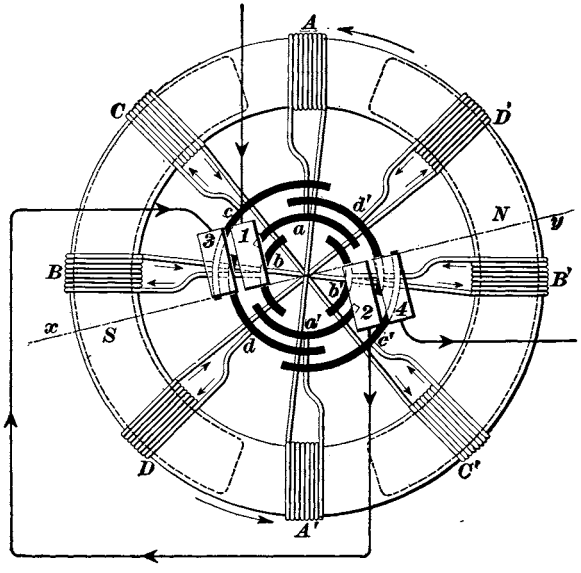


FIG. 1154.

forming two separate commutators of the same diameter, each having four segments, and the brushes rest on their circumference.

One winding consists of two pairs of coils $A$ and $A'$ connected in series, and $B$ and $B'$ also connected in series, the two pairs being located at right angles to each other, as represented.

This winding is connected to its commutator, coil $A$ to segment $a$, coil $A'$ to segment $a'$, coil $B$ to segment $b$, and coil $B'$ to segment $b'$, as represented. Brushes *1* and *2* rest

on this commutator, making contact on the line $x\ y$ of maximum action of the coils.

The second winding consists of two pairs of coils $C$ and $C'$ and $D$ and $D'$, located at right angles to each other and half way between the coils of the first winding. These coils are connected in series and to the segments of the second commutator, coil $C$ to segment $c$, coil $C'$ to segment $c'$, coil $D$ to segment $d$, and coil $D'$ to segment $d'$, as represented. Brushes *3* and *4* rest upon the segments of this commutator on the same line of maximum action of the coils.

**3084.** Taking each winding separately, it will be seen that its two sets of coils pass through the following combinations: One set of coils only connected to the brushes; then the two sets, connected in parallel, both connected to the brushes; then one set only; then both sets in parallel, and so on.

The maximum E. M. F. occurs when the single set of coils is connected, and is directly in the line of maximum action; the minimum occurs $\frac{1}{8}$ of a revolution ahead of this point, when both sets of coils are in parallel, and are equally distant from the line of maximum action. (See Fig. 1152.)

This being the case, it is evident that as the coils of one winding are half way between the coils of the other, the maximum E. M. F. of one winding occurs at the same instant as does the minimum E. M. F. of the other. On account of this, when the two windings are connected in series, the fluctuations of the current are much reduced.

This connection of the two windings is obtained by connecting the positive brush (*2*, Fig. 1154) of one winding with the negative (*3*, Fig. 1154) of the other, the external circuit being connected between the two remaining brushes (*1* and *4*, Fig. 1154).

In the larger sizes of these machines, three and even four separate windings are used, each with its commutator and all connected in series.

**3085.** Instead of using overlapping segments, the same results may be obtained with segments which are placed

end to end, by making the brushes have a large arc of contact, or, what amounts to the same thing, using two brushes on each side, spaced a distance equal to the desired arc of contact and connected permanently together. This is represented in Fig. 1155, $a$ and $a'$ being the segments connected to winding $A$ $A'$ (Fig. 1149), and $b$ and $b'$ being the segments connected to winding $B$ $B'$ (Fig. 1149). It will be seen that the pairs of brushes *1* and *3* and *4* and *2*, being permanently connected together, act as one wide brush. In the position shown, both sets of coils are in parallel; if the commutator is rotated in the direction of the arrow, segments $a$ and $a'$ will pass out from under brushes *3* and *4*, leaving only segments $b$ and $b'$ connected to the winding, and, therefore, only coils $B$ and $B'$ in circuit. Further rotation will bring segments $a$ and $a'$ under brushes *1* and *2*, respectively, throwing coils $A$ and $A'$ and $B$ and $B'$ in parallel again, and so on. It will be seen that this arrangement gives the same results as that previously considered.

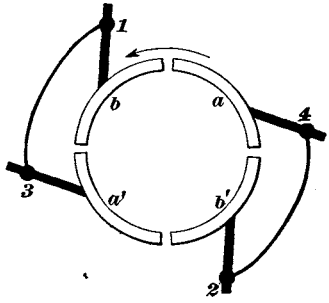

FIG. 1155.

**3086.** Instead of two sets of coils, three may be used, situated 120° apart on the armature.

In this arrangement, which is used in the Thomson-Houston open-coil dynamos, only one end of each set of coils is carried to a commutator segment, there being, therefore, but three segments; the other end is connected to a common junction of the three ends.

The commutator segments are each a little less than 120° in span, being placed end to end and separated by a small air-gap.

The brushes used are divided into pairs, as described in Art. **3085**; that is, the equivalent of two wide brushes is used, the arc of contact being about 60°, or about half the span of one segment.

Both ring and drum windings are used for the armatures; Fig. 1156 gives a diagram of the connections, etc., of the drum-wound armature. *A A'*, *B B'*, and *C C'* are the three coils, wound on the core in planes making angles of 120° with each other. One end of each of the coils is joined to a metal ring (not represented in the figure) on the back of

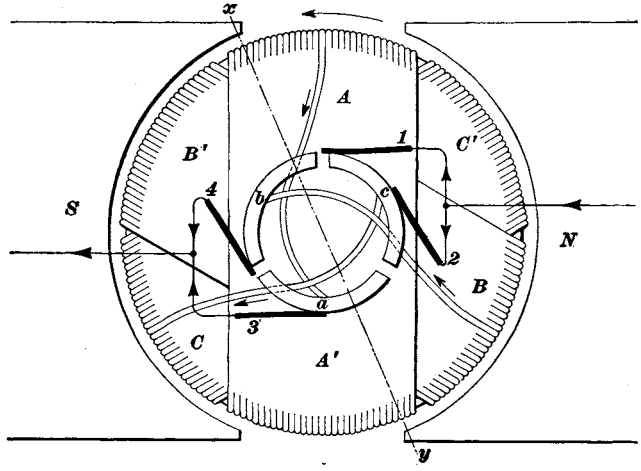


FIG. 1156.

the armature, which forms a common connection for the three. The other ends are joined to the commutator segments, that of *A A'* to segment *a*, that of *B B'* to segment *b*, and that of *C C'* to segment *c*, as represented. *1*, *2*, *3*, and *4* are the brushes, as before. Those numbered *2* and *4* are usually called the *primary* brushes, and *1* and *3* the *secondary* brushes, to distinguish them.

**3087.** From the diagram (Fig. 1156) it will be seen that coil *A A'*, though half way between the pole-pieces, is partly active, since the neutral line is shifted forwards in a manner which will be taken up later, into the position indicated by the line *x y*. This coil *A A'* is connected in parallel with the coil *B B'* by the two positive brushes, and the two are in series with coil *C C'*. If the armature be considered as moving in the direction indicated by the arrow, it will be seen that as coil *A A'* gets to the position of least

action, it is disconnected from the circuit by segment *a* passing out from under brush *3*, leaving coil *B B'* and coil *C C'* in series. However, as the distance between brush *3* and brush *2* is only slightly greater than the span of one segment, coil *A A'* is almost immediately connected in parallel with coil *C C'*, as segment *a* passes under brush *2*, making the following combination: coil *B B'* in series with coils *A A'* and *C C'* in parallel.

As the rotation of the armature continues, coil *C C'* is disconnected from the negative brush *1* and connected to the positive brush *4*, being thus thrown in parallel with coil *B B'*, the two being then in series with coil *A A'*.

Completing the half revolution, coil *B B'* is disconnected from the positive brush *3* and is joined in parallel with coil *A A'* by the two negative brushes *1* and *2*, leaving coil *C C'* connected to the positive brushes.

Further rotation of the armature repeats this series of connections; that is, during every half revolution, one of the coils (*A A'* in the preceding paragraphs) is first in parallel with the coil *behind* it, then momentarily disconnected from the circuit, then connected in parallel with the coil *ahead* of it, then connected in series with the other two, which are then in parallel.

**3088.** From the diagram (Fig. 1156) it will be seen that when a coil is disconnected from one set of brushes it is very nearly in the position of least action, and the coil with which it was just before connected in parallel has the higher E. M. F. of the two. As explained in Art. **3080,** the self-induction of the coil prevents the higher E. M. F. of the other sending a current through it in opposition to its own E. M. F. at the time when they are connected in parallel; in fact, when a coil is disconnected from its mate it is still supplying some of the current, so that there is a spark at the brushes.

There being but three sets of coils in this machine, a great number of turns must be used in each coil to give the required E. M. F., which gives each set of coils a high inductance. This lessens to a great extent the fluctuations

in the E. M. F. acting on the external circuit, which would otherwise, owing to the small number of coils used and the changes in the manner in which they are interconnected, be very considerable.

**3089.** Since only a very small fraction of a revolution carries a segment from contact with one set of brushes to contact with the other, a slight increase in the arc of contact of the sets of brushes would allow each segment of the commutator to momentarily be in contact with *both* sets of brushes at the same time; the effect of this is evidently to short-circuit the armature, thus reducing the difference of potential between the brushes (momentarily) to zero.

There being two places where the short circuit occurs, i. e., between brushes *1* and *4* and *2* and *3*, and there being three commutator segments, six short circuits occur during every revolution, and if the armature is revolving at 850 revolutions per minute, there are $6 \times 850 = 5{,}100$ short circuits every minute; each can, therefore, last only an extremely short time, and the high inductance of the armature coils prevents any excessive flow of current from one to the other through the short circuit. It will be seen that this short-circuiting of the armature does not reduce the maximum value of the E. M. F., but as it introduces periods in each revolution where the difference of potential between the brushes is zero, it does reduce the *effective* E. M. F. acting on the circuit. By varying the arc of contact of the brushes, and thus varying the length of time in each revolution that the armature is short-circuited, the effective E. M. F. of the machine may be varied within comparatively wide limits.

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## OPEN-COIL MULTIPOLAR ARMATURES.

**3090.** Thus far the open-coil winding has only been considered with reference to bipolar fields. It is evident, however, that introducing multipolar fields will only result in a duplication of the parts used with a bipolar field for each pair of poles of the multipolar field. Thus, for a wind-

ing for a four-pole field equivalent to that shown in Fig. 1149, four coils would be required in each set.

Since each set would have to go through its various combinations of connections during each half revolution, instead of each revolution, it is evident that twice as many commutator segments, of one-half the span, would be required, or, rather, each segment would be divided into two. These two parts of the segment would be situated directly opposite each other, and either four brushes would be used on each commutator, of which the opposite brushes would have to be connected together, or the opposite commutator segments would be permanently connected together, and only two brushes would be used. This latter plan is best, as permanent connections are less difficult to maintain than sliding connections.

**3091.** A form of multipolar open-coil armature which differs slightly from the above description is used in the Westinghouse open-coil dynamo. A diagram of the connections of this armature is given in Fig. 1157.

The two commutators are represented as concentric, though they are actually side by side on the shaft, and, as in the Brush machine, Fig. 1154, are situated on the end of the shaft outside one of the bearings, the leads to the commutator being brought out through a hole in the shaft, instead of being connected directly, as represented in the diagram.

This type of machine employs a field-magnet with six poles; the armature is drum-wound, but instead of the coils being laid flat on the surface of the core, they are wound around eight projecting teeth on the armature core, there being, therefore, eight armature coils. This armature winding, as in the Brush machine, is divided into two separate windings, each consisting of two pairs of opposite coils, and each connected to a separate commutator. The combination of connections of the various sets of coils is similar to that of the Brush machine; that is, the set of coils in the position of least action is disconnected entirely from the

circuit; those near the position of maximum action are connected in parallel, and in series (by external connection of the brushes) with that set which is actually in the position of maximum action.

In this style of winding, any coil, such as $A$, is in the position of least action when the projection on which it is wound

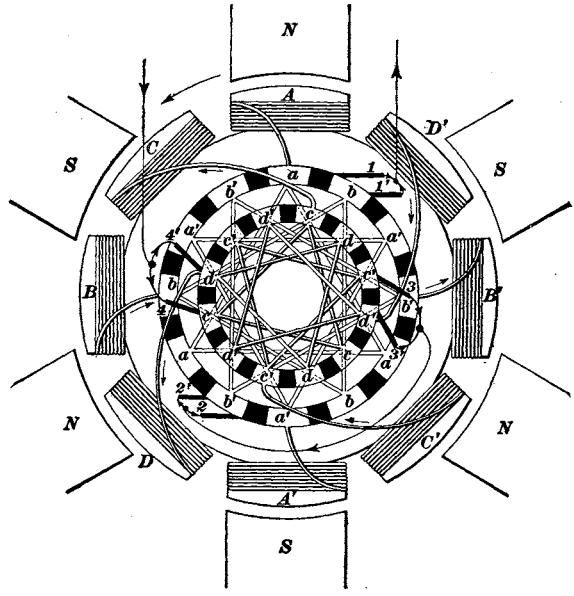


FIG. 1157.

is directly under a pole-piece, as at $N$; for when in this position all the lines of force from the pole-piece $N$ pass directly through the center of the coil, which, therefore, cuts none of the lines of force. As soon as the coil moves from this position, one side begins to cut the lines of force of the pole-piece $N$ as it passes from in front of it, and as it moves still farther, the *other* side of the coil begins to cut the lines of force of the pole-piece $S$, *towards* which it is moving, so that when half way between the two poles $N$ and $S$, both sides of the coil are cutting lines of force equally and at the maximum rate, and this is, therefore, the position of *maximum* action. With eight coils and six pole-pieces, only two

(opposite) coils can each be directly under a pole-piece at the same instant.

**3092.** Referring to Fig. 1157, the two pairs of coils $A$ and $A'$ and $B$ and $B'$ make up one winding, and are connected to one commutator, as shown. The two opposite coils $A$ and $A'$, and also $B$ and $B'$, are connected in series by connections across the back of the armature core (not shown in the diagram).

The other winding is made up of the two pairs of coils $C$ and $C'$ and $D$ and $D'$, the coils of each pair being connected in series, and to the other commutator, as before.

It will be seen that each commutator is made up of twelve segments separated by a considerable width of insulating material (indicated by the solid black parts). These twelve segments are connected together by cross-connecting wires in four sets (one for each coil of the windings), of three segments each (one for each pair of poles).

Two sets of brushes are used on each commutator, each set consisting of two brushes, permanently connected together, which rest on the commutator a distance apart equal to the span of one segment, as shown at *1*, *1'* or *2*, *2'*.

It will be seen that the positions of the commutator segments and brushes are so arranged that when the brushes of one commutator bear on the ends of single segments, the brushes of the other commutator bear on the middle points of the adjacent segments, and *vice versa*.

**3093.** When the armature is in the position represented in Fig. 1157, coils $A$ and $A'$ are in the position of least action, and are disconnected from the external circuit. The other set of coils $B$ and $B'$ of this winding is, however, in the position of maximum action, and is connected to the circuit through brushes *1* and *1'* and *2* and *2'*, which rest on segments $b$ and $b'$, respectively. Of the second winding, each set of coils $C$ and $C'$ and $D$ and $D'$ is equally distant from the position of maximum action, and these two sets are, therefore, connected in parallel with each other

through brushes *4* and *4'*, which rest on segments *c* and *d*, and brushes *3* and *3'*, which rest on segments *c'* and *d'*, and are connected in series with the set of coils *B* and *B'* by the external connection between the two sets of brushes *2* and *2'* and *3* and *3'*.

To follow out the changes in the connections of the coils, consider that the armature is moving in the direction indicated by the arrow.

As coils *B* and *B'* move away from their position of maximum action, brushes *1'* and *2'* are disconnected from segments *b* and *b'*, and as the armature moves, finally come into contact with segments *a* and *a'*, thus throwing the two sets of coils *A* and *A'* and *B* and *B'* in parallel. At the same time, brushes *4* and *3* being disconnected by the insulating segments from segments *c* and *d*, only coils *D* and *D'* of the second winding are connected to the circuit through brush *4'* and in series with the coils of the other winding (now connected in parallel) through brush *3'* and its connection with brushes *2* and *2'*, coils *C* and *C'* being entirely disconnected.

It will be seen that these successive combinations of coils are precisely the same as take place in the Brush machine, except that each combination takes place six times in each revolution instead of twice, due to the multipolar field.

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## CLOSED-COIL BIPOLAR ARMATURES.

**3094.** The greater part of the applications of the electric current demands that the current shall not only be *direct*, i. e., unchanging in direction, but *continuous*, i. e., maintaining a constant voltage. (See Art. **3056.**)

Of the two types of direct-current armatures considered, the unipolar is limited in its application by reason of the impossibility of coiling its conductors; in the open-coil type this difficulty does not exist, but in order to avoid serious pulsations in the current output, it is necessary to use a large number of armature windings, each with its com-

mutator and brushes, which soon leads to undesirable complication in the construction.

**3095.** It is easily seen that with bipolar or multipolar induction, it is necessary to employ some form of commutator in order to obtain a direct current in the external circuit, since the E. M. F. induced in the coils of the winding is alternating; further, to obtain a practically *continuous* current, it is evident that a considerable number of coils must be used, and the number of active coils that are connected between the brushes must be as nearly as possible the same, and connected in the same manner, in all parts of a revolution, and not alternately connected in parallel and in series with other coils, or disconnected entirely from the circuit, as in the open-coil windings. In order to maintain this equality in the number and connections of the coils, they must be connected in series with one another, otherwise their unequal E. M. F.'s would give rise to wasteful local currents. This being the case, and in order that the connection between any particular coil and the external circuit be reversed as the E. M. F. of the coil is reversed, i. e., as the coil passes through the neutral space, without disconnecting the coil altogether from the circuit, it is necessary that both of the commutator segments to which it is attached should come in contact with the same brush at the time the coil is in the neutral space; that is, the coil must be short-circuited by the brush.

**3096.** In the windings illustrated in Fig. 1149, two separate coils are connected between each pair of commutator segments, the coils being connected in series. It is evident, however, that each separate coil may be supplied with a two-segment commutator, as represented in Fig. 1158.

Here, as in Fig. 1149, the four coils are represented at $A$, $A'$, $B$, and $B'$, and each coil is connected to a commutator of two segments, coil $A$ to segments $a$ and $a$, etc.

This results in four commutators (which are, for convenience, represented as being concentric, as before), upon

each of which rests a pair of brushes, *1*, *2*, *3*, and *4*, representing the — brushes and *1'*, *2'*, *3'*, and *4'* the + brushes. Since in the ring winding coils *A* and *B* are, respectively, diametrically opposite coils *A'* and *B'*, and in the drum winding the same coils practically coincide in position, it is evident that the E. M. F.'s of each of these *pairs* (*A* and *B* and *A'* and *B'*) will be the same, although the E. M. F.'s of the individual coils may differ in different parts of the revolution. Consequently, the winding may now be connected up (by suitable external connections between the

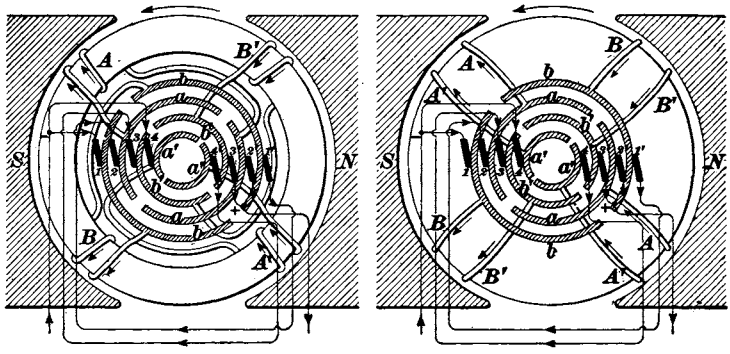


FIG. 1158.

brushes) so that coils *A* and *B* and *A'* and *B'* will be in series, while the two *pairs* of coils are in parallel. This condition is represented in Fig. 1158, coils *A* and *B* being connected in series by the connection between brushes *1'* and *2*, and coils *A'* and *B'* being similarly connected in series by the connection between brushes *3* and *4'*. The two pairs of coils are connected in parallel by connecting together brushes *1* and *4* and brushes *2'* and *3'*, these pairs of brushes then serving as the terminals + and — of the external circuit.

**3097.** From the above it follows that there are two paths for the current in passing through the armature; in the position shown in the figure, one of these is from brush *1*, through coil *B* to brush *1'*, thence through the external

connection to brush *2*, thence through coil *A* and out through brush *2'*. The other is from brush *4*, through coil *A'* to brush *4'*, thence through the external connection to brush *3*, thence through coil *B'* and out through brush *3'*.

As the armature revolves (in the direction indicated by the arrows), coils *B* and *B'* approach the neutral position, and when their E. M. F.'s are reduced to zero, they are momentarily short-circuited as brushes *1* and *1'* and *3* and *3'* bridge over the gaps between the ends of segments *b* and *b* and *b'* and *b'*. Immediately after they are again connected in circuit, but in the opposite direction, so that the E. M. F. generated in them as they pass under the *S* pole still adds to the E. M. F. acting on the external circuit.

**3098.** It will be seen that this winding fulfils some of the conditions laid down in Art. **3095,** namely, that the connections between the coils are not disturbed throughout a revolution, and that the connections between a coil and the external circuit are reversed as there described.

There is not a sufficiently large number of armature coils to give anything but a pulsating current, and any increase in the number of armature coils, and, consequently, commutators, would lead to a very complicated and undesirable construction, if arranged in the same manner as those already used.

However, as the external connections between the various brushes (in Fig. 1158) serve to connect certain commutator segments together, these segments might be permanently connected without affecting the action of the armature *when in the position shown* in Fig. 1158, and only two brushes would then be required, as *1* and *2'*. Under these conditions the commutator would have but four pairs of segments, the segments of each pair again forming practically one segment. Thus, these four segments could be made in the form of a single four-segment commutator, as represented in Fig. 1159.

**3099.** In this new arrangement each segment of the commutator is made up of two of the segments shown in the

original scheme. These parts have been lettered to correspond with the segments shown in Fig. 1158.

Further, as will be seen by comparing the two figures, these parts of the original segments are so located that the brushes (*1* and *2*, Fig. 1159) bridge over the gap between

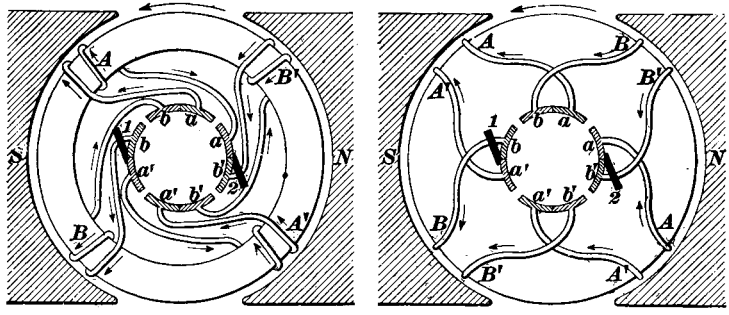


FIG. 1159.

them at exactly the same part of the revolution as the *terminal* brushes (the brushes connected directly to the external circuit, *1* and *4* and *2'* and *3'*, Fig. 1158) in the original scheme shown in Fig. 1158, and the connections made by the intermediate brushes (*2* and *3* and *1'* and *4'*, Fig. 1158) are replaced by the permanent connections between the two parts of a segment.

The action of this new arrangement is then identical with that shown in Fig. 1158, since the coils are connected directly to the brushes, short-circuited when in the neutral space, etc., at exactly the same part of the revolution and in the same manner.

**3100.** In order to more clearly show the similarity of the two methods, the brushes have been shown in the same position relative to the pole-pieces in each figure, the only requirement in this respect being that the coils shall be short-circuited by the brushes when in the neutral space. The connections between a coil and its commutator segments can be so carried out that the brushes may have any position with respect to the pole-pieces.

Thus, in the ring winding shown in Fig. 1159, the commutator and the brushes may be moved bodily around to the left until each of the gaps between the commutator segments stands opposite the coil which is connected across the gap, which would materially lessen the length of the connections between the coils and the commutator, and the brushes would then rest at the ends of the vertical diameter instead of the horizontal, as at present. In the case of the drum winding, the connections between the ends of a coil and the commutator segments are now of equal length, so that any change in the position of the commutator would only result in shortening one connection and lengthening the other.

**3101.** This new arrangement is still open to the objection of having too few coils, but it will be evident from an inspection of Fig. 1159 that to increase the number of coils it is only necessary to divide each segment in the middle and connect a new coil across the gap so formed. The effect of this is shown in Fig. 1160, which represents the

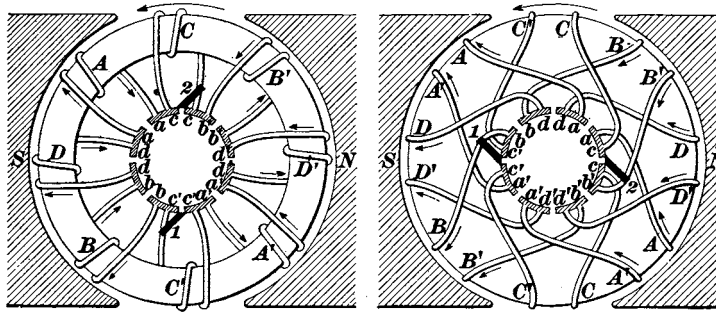


FIG. 1160.

same windings as Fig. 1159, with four new coils $C$, $C'$, $D$, and $D'$ inserted in each. In the case of the ring winding the commutator and brushes have been turned to the left to bring the segments to which a coil is connected directly opposite the coil. In the drum winding the position of the commutator and brushes remains unchanged.

**3102.** From an examination of Fig. 1160, it will be seen that there are two **leads** (pronounced *leeds*) connected to each commutator segment; that is, the segment *a c* has the two leads *c C* and *a A*.

It is evident, however, that instead of connecting a lead from each coil directly to the commutator, the coils may be connected directly together, and a single wire run from this connection down to the corresponding commutator segment. In this case the current would traverse the commutator segment only during the time that the segment is in contact with a brush.

The result of this arrangement is that the winding itself forms a continuous spiral around the armature core, with the end joined to the beginning; that is, the winding is *reentrant*, or *closed upon itself*. From this feature, this form of winding, whether applied to a ring or a drum core, is called a **closed-coil winding.** Having the closed coil wound upon the core, the connections or leads to the commutator segments may be tapped in at convenient points; the number of turns of the winding which exist between two adjacent points where the leads to the commutator segments are attached constitute an armature coil.

By winding the turns close together on the core so as to utilize the whole of its surface, and bringing out a sufficient number of leads to the commutator, a winding consisting of a large number of coils may be obtained.

**3103.** From the nature of the winding, these coils will be *equally* divided into two parallel circuits around the armature. Beginning at one brush, the current generated passes from one commutator bar through one lead, and splits (or, if there be two leads to each bar, splits at the commutator bar), passing on around and around the armature till it finds an outlet through the lead (or leads) to the commutator bar at the opposite side, and arrives at the other brush. If there is an even number of bars, the brushes will cover opposite bars at the same instant, which means that there is an even total number of coils, and that each branch of the

circuit contains the same number of coils. If there is an odd number of commutator bars, and, consequently, an odd number of coils, the instant when one brush makes contact with one bar the opposite brush makes contact with two bars, thus cutting one coil out of action for the time being, which leaves as before an equal number of coils in each circuit of the armature. As the brushes pass on from bar to bar, in either case, it is seen that the brush must touch two bars, and thus short-circuit a coil, or cut it out of action. For this reason the number of coils employed in generating the current will not be constant, and, consequently, the voltage will vary. This variation is very slight, however, when the number of coils is high, and is of no material importance.

The E. M. F. of each half of the armature winding is made up of the sum of all the E. M. F.'s generated in the separate conductors that are connected in series between the brushes, and as the various commutator segments are connected to the winding at successive intervals, the difference of potential between the brushes rises in a series of steps from the negative to the positive brush, the difference of potential between adjacent segments being equal to the E. M. F. generated in the coil which is connected between them. The greatest difference of potential between adjacent segments is, therefore, in the forms of winding so far considered, only equal to the maximum E. M. F. that is generated in a single coil.

### CALCULATION OF E. M. F.

**3104.** Although at any instant the E. M. F.'s of all the separate conductors may be quite different, owing to variations in the density of the field, the sum of all the separate E. M. F.'s is practically constant. It is only necessary, then, to calculate the *average* E. M. F. in each conductor, and to multiply this average E. M. F. by the number of conductors connected in series to obtain the E. M. F. of the armature.

Let $N$ = the total number of lines of force that emanate from one pole-piece and are cut by the conductors; then,

each conductor cuts $2N$ lines of force per revolution, since it cuts each line twice. Let $S =$ the number of revolutions per minute of the armature; then, the *average rate* at which each conductor cuts the lines of force is $\frac{2NS}{60}$ lines of force per second. The *average* E. M. F., $e$, generated in each conductor is, then, $e = \frac{2NS}{60 \times 10^8}$. Let $c =$ the total number of conductors on the surface of the armature; then, in each an E. M. F. $= e$ is generated, but in only $\frac{c}{2}$ conductors are these E. M. F.'s added, since the conductors are arranged in two parallel circuits. The total E. M. F. generated in the armature $E$ is, then,

$$E = \frac{c}{2} \times \frac{2NS}{60 \times 10^8}.$$

It will be seen from the above that the fact that each conductor cuts the lines of force twice is balanced by the fact that only half the conductors are in series, so, by canceling the 2's, the formula becomes

$$E = \frac{cNS}{60 \times 10^8}. \qquad \textbf{(480.)}$$

From this formula, having given any three of the four quantities, $E$, $c$, $N$, and $S$, the fourth may be readily found.

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### COMMUTATION OF CURRENT.

**3105.** From Fig. 1160 it will be seen that although a coil when approaching the middle of the neutral space may have little or no E. M. F. generated in it, it must carry the entire current which is flowing in the part of the armature in which it is included, until the *following* segment of the pair to which it is connected comes into contact with a brush, which allows the current from that part of the armature to flow through the brush without passing through the coil under consideration. When the *leading* segment of the

pair to which the coil is connected passes out from under the brush, the coil is again inserted in the armature circuit, but in the other side, so that the current flowing through it is in the opposite direction. From this it follows that the current in the coil must be reversed in direction during the time that a brush is resting on *both* of the segments to which the coil is connected. Since the coil, whether of the ring or the drum winding, consists of one or more turns of wire wrapped around an iron core, its inductance is an appreciable quantity; hence, when the coil is short-circuited by the brush, the current does not immediately drop to zero, but continues to circulate through the local circuit formed by the coil, the two commutator segments, and the brush, it being maintained by the self-induced E. M. F. of the coil.

**3106.** Further, when the leading segment of the coil passes out from under the brush and introduces the coil into the armature circuit again, the inductance of the coil will tend to prevent the current in it from suddenly attaining the same value as that flowing in the part of the armature circuit into which the coil is introduced. The result of this action is that the apparent resistance of the coil is very largely increased at that time, so that only a part of the current passes through the coil to the brush when the leading segment of the coil first passes out from under it, but, instead, continues to flow directly between the leading segment and the brush through the narrow air-space that separates them, thus causing a spark. As this distance gets greater, more and more of the current flows around through the coil which has been short-circuited, and the spark becomes less and less intense, and finally disappears. All these operations take only a very short time, usually about as long as is required for the armature to rotate through the angle embraced by one or two commutator segments, so that the spark lasts only a small fraction of a second; but as it is repeated at every brush for every coil that is short-circuited, the aggregate result is that the sparking eats away both brushes and commutator segments, thus causing a consider-

able deterioration of the machine, besides wasting a certain amount of energy.

**3107.** If an E. M. F. is introduced into the local circuit (formed by the coil, its commutator segments, and the brush), which is opposite in direction to the E. M. F. of self-induction, not only may the current in the coil be brought more quickly to zero, but it may even be reversed and caused to flow in the opposite direction, while the coil is still short-circuited by the brush. Evidently, then, if this reverse current is brought up to the same value as that flowing in the part of the armature into which the coil is inserted at the moment the brush leaves the leading segment, there is no change in the amount or direction of the current flowing in the coil, consequently no sparking as commutation is effected.

If the value of the reverse current in the short-circuited coil at the moment the brush leaves the leading segment is less than the current it will have to carry, the spark will occur as before, but to a much less degree, since the amount of change in the current of the coil is much less, consequently its E. M. F. of self-induction and its apparent resistance are much reduced; if the current in the coil is greater than that which it is to carry, the excess of current can not immediately disappear as the brush leaves the leading segment, owing, as before, to the inductance of the coil, but continues to flow, the local circuit now including the small air-space between the leading segment and the top of the brush. In other words, sparks appear at the brushes, as before.

**3108.** Fig. 1161 illustrates both these conditions, representing a section of a ring armature with the coils *a*, *b*, *c*, *d*, and *e* and the corresponding commutator segments. In each figure (*A* and *B*) each half of the armature winding is supposed to have flowing in it 10 amperes, as indicated by the numbers near the arrows that show the direction of the current. In each figure, coil *c* is represented as just passing out of the condition of short circuit, i. e., the brush *C* is just

leaving the leading segment of coil *c*. In *A*, coil *c* is supposed to have an E. M. F. acting in it which is sufficient to reverse the current and bring it up to a value of 5 amperes at the instant its short circuit is broken, so that at that instant, owing to the inductance of the coil, only 5 amperes of the main current can flow through the coil, the balance passing through the tiny air-space *from* the leading segment *to* the tip of the brush *C*, as represented. In *B*, the E. M. F.

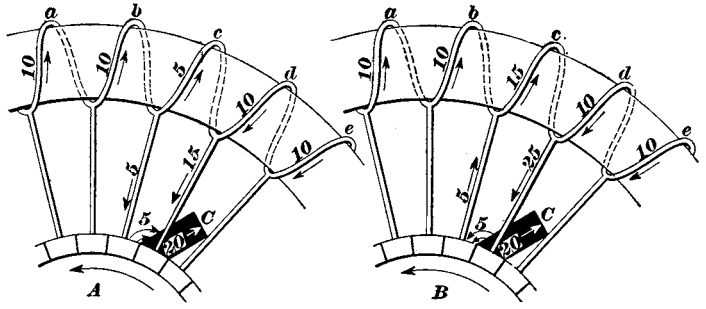


FIG. 1161.

acting in coil *c* is supposed to be great enough to bring the current in the coil up to 15 amperes, so that when the brush leaves the leading segment the 15 amperes continue to flow for an instant, 10 being supplied by the half of the armature into which the coil is connected, and the other 5 passing across the tiny air-space *from* the tip of the brush *C to* the leading segment of the coil, as represented.

Of course, this condition of affairs lasts for only a moment, the current in coil *c* quickly adjusting itself to the armature current (10 amperes in this case).

**3109.** The E. M. F. necessary to reverse the current in the coil may be supplied in a variety of ways. It will be seen that the *direction* of this E. M. F. must be the same as that generated in the coils of the part of the armature circuit into which the coil is to be introduced. Consequently, by moving the brush *ahead*, i. e., in the direction of rotation of the armature, until the coil, when short-circuited, is in the magnetic field, the necessary E. M. F. will be generated in the coil. When the armature is furnishing

a very small current, the E. M. F. required to reverse the current in the short-circuited coil will be comparatively small, and as the current output of the armature increases, this E. M. F. will have to be similarly increased. There is no abrupt change from the neutral space to the magnetic field; that is, at the edge of the field the density of the lines of force gradually shades off to zero in the neutral space. Consequently, when only a small current is flowing in the armature, it is not necessary to push the brushes ahead very far to move the short-circuited coil into a field of sufficient strength to supply the necessary E. M. F. during the period of short circuit; as the current in the armature increases, however, it is necessary to move the brushes ahead still farther, in order that the field in which the coil moves while short-circuited may be of sufficient density to supply the necessary E. M. F. for reversing the current.

This movement of the brushes is usually obtained by mounting the holders for the several brushes on a common support that can be made to turn around the axis of the armature and be clamped in any desired position. By rotating this support, the brushes are simultaneously moved to the desired position, as evinced by the cessation of the sparking whenever a change in the current calls for such an adjustment.

**3110.** Another method of introducing an E. M. F. into the short-circuited coil results from the fact that the local circuit through which the current in the short-circuited coil flows is in part through the brush. In addition, the current from both parts of the armature winding also flows through the same two commutator segments into the brush. It is evident, then, that as the leading segment passes out from under the brush, the area of brush surface that is in contact with this segment grows rapidly less, thus increasing the resistance in the path of the current that is flowing from the part of the armature circuit into which the short-circuited coil is about to be inserted. If the brush is made of a material of high conductivity, this increase in the resist-

ance will be slight, and will produce little or no effect until the leading segment is actually leaving the brush; but if of comparatively low conductivity, the increase in the resistance will be more pronounced, and will cause a drop, or difference of potential, between the commutator segment and the brush. The other segment, however, is all the time moving more and more under the brush, thus reducing the resistance at that point, so that the difference of potential between the *leading* segment and the brush tends to send the current around through the short-circuited coil and into the brush through the *other* segment.

**3111.** In other words, this difference of potential acts as an E. M. F. to reverse the current in the short-circuited coil; consequently, it will prevent sparking just as setting up an E. M. F. in the coil itself will, if of the right amount. It will be seen that as the current in the armature increases, thus requiring a greater E. M. F. to reverse the current in the short-circuited coil, the difference of potential between the leading segment and the brush also increases at the same rate, so that this method of preventing sparking is, to some extent, self-regulating. However, this method by itself can not well be used, as it is impracticable to so adjust the nature and extent of the contact surface of the brush as to obtain the right E. M. F. for reversing the current; and even if this adjustment were once made, it could not be permanent, owing to changes in the extent and nature of the contact surface of the brush and its variations in pressure incident to the continual operation of the machine, the amount of the contact resistance depending upon all of these factors.

**3112.** In practice, commutation is effected by a combination of these two methods; that is, the brushes are shifted until the E. M. F. induced in the short-circuited coil, aided by the difference of potential between brush and segment, is sufficient to ensure sparkless commutation. With metallic brushes, the contact resistance is usually so low as to render the difference of potential between the brush and

segment of very little value in commuting the current. In other words, the E. M. F. induced in the coil itself must do the reversing; hence, the brushes must be newly shifted for each small change in the current output to proportionately change the E. M. F. acting in the short-circuited coil. With brushes of higher resistance, however, the difference of potential developed at the contact surface furnishes such a large proportion of the total E. M. F. required that the brushes may remain in one position during considerable changes in the current output. High-resistance brushes, therefore, require less shifting to obtain sparkless commutation than do those of low resistance.

**3113.** It will be seen that to commute a given current in a given length of time, the E. M. F. required will be proportional to the inductance of the armature coil. Consequently, it is desirable that the armature coils have as little inductance as possible, since there will then be less E. M. F. required to commute the current; or, in other words, there will be less shifting of the brushes necessary for sparkless commutation.

From the very nature of the factor, it is evident that as the armature coils are wound on an iron magnetic circuit, they must be of few turns in order that their inductance may be low; consequently, the winding should be divided into as many coils as convenient, thus making the number of commutator segments comparatively large.

**3114.** There are other considerations which influence the number of commutator segments to be used in any particular case; for example, if the maximum difference of potential between adjacent commutator segments is 20 volts or greater, any sparking at the tip of the brush is liable to continue between the commutator segments as the armature turns; as each segment passes out from under the brush a similar arc may be maintained, until they all extend from brush to brush, short-circuiting the whole armature. To prevent this, the *average* difference of potential between the segments should not be greater than about 15 volts, if

the machine is to give a current of more than about 20 amperes. With less current output, a greater average difference of potential may be used if necessary.

### ARMATURE REACTION.

**3115.** It has been discussed and shown previously that when a current is flowing in a conductor located in a magnetic field a reaction exists between the current and the field, so that a force must be applied to the conductor in order to move it through the field. This motion being opposed by the lines of force of the field, the force applied to the conductor ultimately acts on the lines of force of the field, tending to crowd them ahead in the direction that the conductor is moved. Consequently, when a current is flowing in the conductors of a dynamo armature (either ring or drum wound), the lines of force are crowded around in the direction of rotation, thus causing the field to be less dense under the *leading* pole tips, i. e., the pole tips *towards* which coils that are in neutral spaces are moving, and to be more dense under the *following* pole tips, than would be the case were the field symmetrically distributed. This is indicated in Fig. 1162, in which an armature core situated in a bipolar field is represented, with the conductors equally spaced around its periphery; these conductors are supposed to be connected up as a closed-coil winding, either ring or drum, and a current is supposed to be flowing in the winding. By applying the thumb-and-fingers rule to this figure, it will be seen that the direction of the current in the conductors under the *N* pole is up, through the paper, while under the

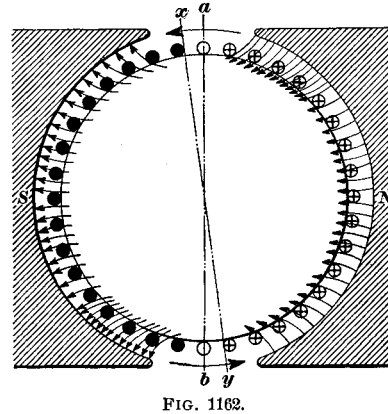

FIG. 1162.

*S* pole the current is in the opposite direction. This is indicated by marking the conductors with a + and a solid black dot, respectively.

The relative distribution of the lines of force is indicated by the lines from the pole-pieces to the core; their distribution within the armature core is immaterial at present. It will be noticed that the effect of the distortion of the field is to alter the relative density of the lines of force under the pole tips, and to shift the true neutral line (*x y*) from its theoretical position half way between the pole tips (line *a b*) in the direction of rotation.

**3116.** It does not matter how the conductors are joined together, so long as the current in each conductor is as represented. Consequently, supposing the armature to be stationary, the same shifting of the field would result if the conductors were so connected as to form a spiral coil wrapped around the core, with its axis along the line *a b*, as represented in Fig. 1163, the brushes being on the theoretical neutral line *a b*.

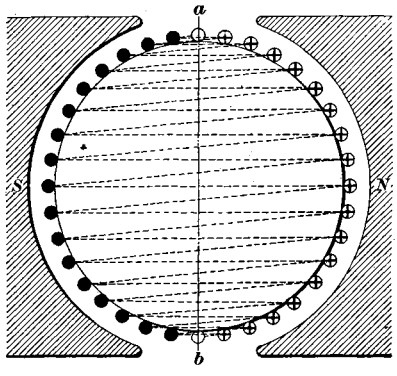

FIG. 1163.

The magnetizing force of this coil acts along the line *a b*, that being the axis of the coil. It will be seen that this introduces no magnetomotive force that is *opposed* to the lines of force passing through the armature, since on each side of a line connecting the centers of the pole faces there are the same number of conductors carrying the current in each direction. The only effect of this armature magnetomotive force is, then, to distort the field.

**3117.** As soon, however, as the brushes are shifted ahead to effect sparkless commutation, this condition does not hold; the shifting of the brushes introduces into that

part of the armature that lies on each side of the center line of the pole faces an excess of conductors carrying a current in one direction, as is shown in Fig. 1164, which represents an armature coil in a bipolar field, with 36 conductors, as before. It is supposed in this case that the brushes are shifted until they bring the short-circuited coils on the line *x y*, which is ahead of the theoretical neutral line *a b* by the angle *r*. From an inspection of this figure, it will be seen that on each side of the center line of the pole-pieces the number of conductors carrying the current in one direction exceeds that of the conductors carrying the current in the opposite by the number of conductors included between the lines *x y* and *s t*, which make equal angles with the line *a b*. Further, it will be seen that the current flowing in these conductors sets up a magnetomotive force which is *directly opposed* to the magnetic field in which the armature revolves. Hence, these conductors may be considered as forming a spiral coil around the armature, whose axis coincides with the center line of the pole-pieces, as represented in the illustration, Fig. 1164.

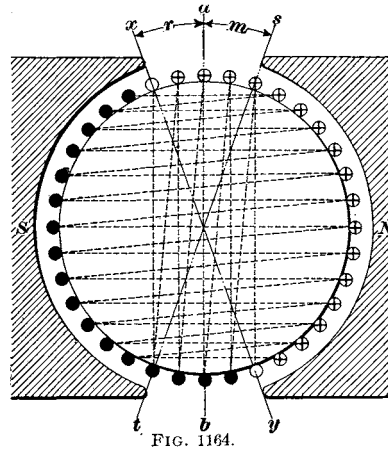

FIG. 1164.

**3118.** It will be seen, then, that when the brushes of an armature are shifted ahead from the position where the short-circuited coils are in the theoretical neutral line, in order to effect sparkless commutation, the magnetizing effect of the armature current may be divided into two components; one of these acts in a direction at right angles to the field in which the armature revolves, and so distorts it, while the other acts in a direction opposite to the field, hence, reduces its strength. The angle *r*, Fig. 1164, is

evidently the angle through which the brushes are shifted; hence, it is called the *angle of lead* of the brushes. It has been shown that the current in all the conductors included in *twice* the angle of lead makes up the magnetomotive force that directly opposes the field, and this is called the **counter magnetomotive force** of the winding. It is measured (in ampere-turns) by the product of the number of conductors included in twice the angle of lead and the current in each. The current flowing in the rest of the conductors makes up the **cross magnetomotive force** of the winding, its value in ampere-turns, as before, being the product of the number of conductors and the current in each.

**3119.** It has been shown that the brushes must be shifted ahead of the neutral line in order to bring the short-circuited coil into a field of sufficient density to set up the proper E. M. F. in it; it will be seen that as the armature current increases, the density of the field under the leading pole tip is decreased more and more, so that the brushes must be shifted farther to bring the short-circuited coil into a field of the proper density. This introduces a greater and greater counter magnetomotive force, which reduces the strength of the field still more, and makes the effect of the counter magnetomotive force greater; and it will be readily seen that the armature current might rise to such a value that any amount of shifting of the brushes would not be sufficient to bring the short-circuited coil into a field of sufficient density for sparkless commutation.

Thus, the armature reaction introduces a factor which tends to limit the amount of current which the armature can supply, by making an excessive shifting of the brushes necessary to effect sparkless commutation, this limit of load being known as the *sparking limit.*

**3120.** It has already been pointed out that force is required to move a conductor through a magnetic field when a current is allowed to flow through the conductor.

Applying this principle to the armature winding of a dynamo, it will be seen that the current in each conductor

gives rise to a force acting approximately tangent to the surface of the armature; the amount of the force on each conductor depends upon the strength of the current in each conductor and the strength (density) of the field in which it lies, and the sum of all these forces (in pounds) multiplied by the velocity of the conductors (in feet per minute) is the power (in foot-pounds per minute) necessary to apply to the conductors to move them through the field against the force set up by the current.

It will be seen that the calculation of the force acting on each conductor at any instant would be difficult, requiring a knowledge of the density of the field in which each conductor is moving. But this is not necessary, for, as has already been pointed out (Art. **3030**), the power required to move the conductor is equal (when reduced to the same units) to the product of the E. M. F. generated in the conductors and the current flowing, which are quantities readily measured.

**3121.** The total power required to drive the armature, or the **input,** is equal to the power required to drive the conductors, which may be found as pointed out above, plus whatever power is necessary to overcome the friction of the journals and the hysteresis and eddy-current losses (see Arts. **3050** to **3052**) that take place in the armature core. These quantities may be found or calculated separately by methods which will be taken up later. It has already been shown that the **output** of a dynamo is the product of the difference of potential between its terminals and the current flowing in the external circuit; the **efficiency** of the dynamo is, of course, the ratio between the output and the input.

## CLOSED-COIL ARMATURE WINDINGS.

**3122.** Thus far only the simplest forms of ring and drum windings for bipolar field-magnets have been considered. These are susceptible of many modifications, however, especially when used with multipolar fields, some of which are essential for certain applications.

In the following discussion of the most generally used windings, for the sake of simplicity, only a few conductors will be represented in each winding, showing the *principle* of the winding and arrangement of the connections. The conditions which govern the design of a winding for a commercial machine and the actual construction of the winding will be taken up later.

## RING WINDINGS.

**3123.** The simplest form of ring winding is that already described, in which the conductor forms a continuous closed spiral, with leads brought out at a series of equidistant points to the commutator segments, and with bipolar fields, and this form of winding is not susceptible of much modification.

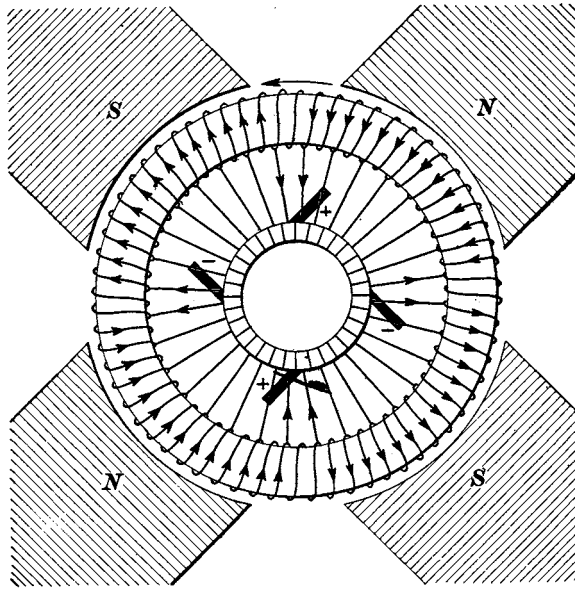


FIG. 1165.

If a simple ring-wound armature is placed in a multipolar field, each adjacent pair of poles will act on the winding in

the same manner as a bipolar field, so that *that section* of the armature will be divided into two parallel circuits. The whole winding will, therefore, be divided into as many circuits as there are poles, consequently requiring as many brushes. This is represented in Fig. 1165, which shows a four-pole field, with a ring-wound armature of 32 coils, each of two turns. With the larger number of coils the device used as the commutator heretofore, namely, metallic segments placed side by side and separated by air-spaces, can not be used to advantage; instead, a large number of segments of approximately rectangular section are placed side by side, separated by thin strips of insulating material. This is indicated in Fig. 1165.

**3124.** It will be seen that in this arrangement the armature is divided up into four circuits, and four brushes are required, which must be placed so as to short-circuit a coil when in the neutral space, as represented in the figure.

There is no difference of potential between the *opposite* brushes, + and +, or − and −, so that each of these pairs may be connected together in parallel, to supply a single external circuit. Similarly, with 6, 8, 10, or more poles, a corresponding number of brushes must be used, of which all those of like sign are connected together in parallel. In this form of four-pole armature (Fig. 1165), opposite commutator bars are always at the same potential; consequently, there is no difference of potential between them, and they may, therefore, be permanently connected together. This is accomplished by means of cross-connecting wires, and does away with the necessity of more than two brushes. This can be done only when the winding is made up of an even number of coils, for with an odd number there will always be one segment "left over."

**3125.** In general, with *any* number of poles this form of winding has the segments that are always at the same potential situated $\frac{360^\circ}{p}$ apart, $p$ being the number of *pairs* of poles in

the field; and these segments may be connected together by cross-connecting wires; only two brushes are used, provided the number of segments is a multiple of $p$.

**3126.** The E. M. F. generated in a simple ring armature rotated in a multipolar field may be found from formula **480,** given in Art. **3104.** The total number of cuttings of lines of force by each conductor in one revolution is $2pN$, $p$ being the number of *pairs* of poles and $N$ the number of lines of force that emanate from *one* pole face; but since only $\frac{c}{2p}$ conductors are connected in series, the term $2p$ cancels out, and $E = \frac{cNS}{60 \times 10^8}$, as before.

**3127.** Thus the *total* number of lines of force in the armature of a multipolar machine is equal to $pN$, $p$ and $N$ having the values given above. Each line of force is cut twice by each conductor in each revolution, however, from which results the value $2pN$, given above.

The same E. M. F. will be generated in each of the four circuits of the winding, provided that the number of lines of force through each gap space under the poles is the same, which is usually the case, although, as will be pointed out later, it is quite possible for it to vary.

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### TWO-CIRCUIT WINDINGS.

**3128.** If the number of lines of force through each gap space is not the same, then the E. M. F. generated in each circuit will not be the same; consequently, the higher E. M. F. of one circuit will tend to make it furnish more than an equal share of the current output when connected to the external circuit.

To obviate the possibility of such an event occurring, several systems of multipolar ring windings are in use, all of which are based on the general principle of connecting each coil of the armature in series with one which is in another field, of either the same or opposite polarity. This divides the armature winding into two parallel circuits, a

part of each circuit being in two different fields, so that even if the fields are individually not of the same strength, the E. M. F. of each armature circuit is the same.

A winding which is divided into only two circuits in parallel, whatever the number of pairs of poles in the field, is known as a **two-circuit** winding, to distinguish it from the form in which the winding has as many circuits in parallel as there are poles, which is called a **multiple-circuit** winding.

**3129.** One form of two-circuit winding, in which coils situated in fields of *like* polarity are connected in series, is

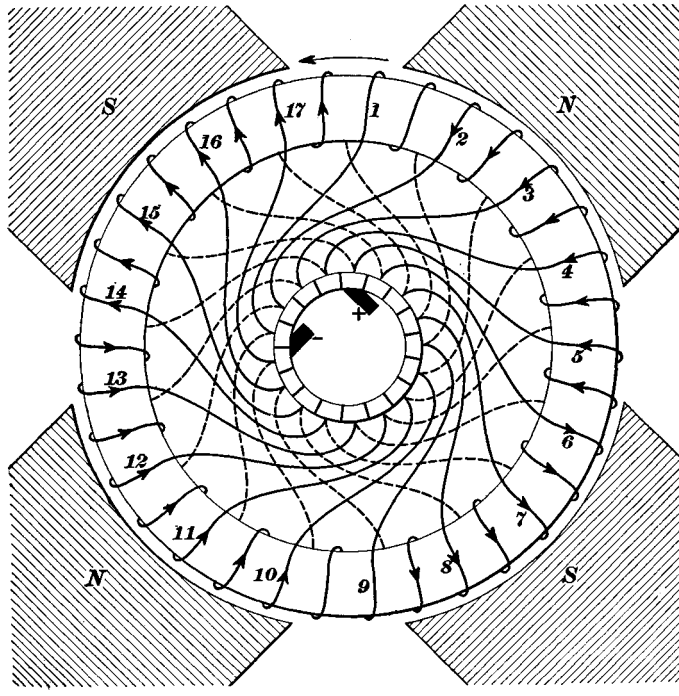


FIG. 1166.

illustrated in Fig. 1166. A four-pole field is shown with an armature having 17 coils numbered from 1 to 17. Each

coil is connected to two commutator segments, and each *segment* being connected to two *coils*, there are, therefore, as many segments as coils, i. e., 17.

It will be seen that the *end* of any one coil is connected to the *beginning* of a coil which is a certain number of coils away from it; for example, the end of coil *1* is connected to the beginning of coil *9*, which is $9 - 1 = 8$ coils to the right of coil *1*. This spacing is called the **pitch** of the winding; that is, in the above case, the pitch is 8, and the end of each coil throughout the winding is connected to the beginning of the 8th coil to the right, as shown in the figure.

**3130.** Whether the pitch in this form of winding be odd or even, in order that all the coils may be included in the winding before it closes upon itself, the number of coils must be one more or one less than the product of the pitch and the number of *pairs* of poles. Then, if $p =$ the number of pairs of poles, $y =$ the pitch, and $s =$ the total number of coils, in general,

$$s = py \pm 1. \qquad \textbf{(481.)}$$

Thus, in the case illustrated in Fig. 1166, where $p = 2$ and $y = 8$,

$$s = (2 \times 8) \pm 1 = 15 \text{ or } 17.$$

In this case 17 was the number used, as shown. It will be seen from this formula that when $p$ is an *even* number, $s$ must be an odd number; while, if $p$ is *odd*, $s$ may be odd or even, depending on whether $y$ is even or odd.

There being but two circuits through the armature, two brushes only need be used, as represented.

NOTE.—To prevent confusion, the brushes have been represented as *inside* the commutator in this and other figures.

In the position represented in the figure, coils *1* and *9* (in series) are short-circuited by the −brush; as the armature continues to rotate, coils *14* and *6* (in series) would next be short-circuited by the +brush, and so on.

**3131.** In general, the brushes for this style of winding may be located as follows: If one is to the *left* of a pole-

piece, the other must be to the *right* of a pole-piece of *like* polarity. In a four-pole machine, this allows of an angle of only 90° between the brushes; but in a six-pole machine, it allows of an angle of either 60° or 180°, and in an eight-pole machine an angle of either 45° or 135°. With a greater number of poles, a greater number of different angles between brushes may be used.

**3132.** Another form of two-circuit ring winding is represented in Fig. 1167. Here the number of coils is the

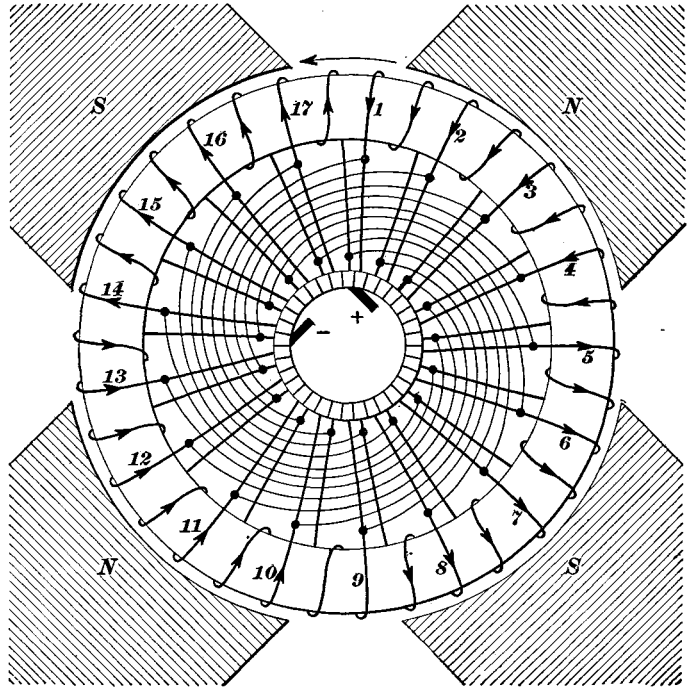


FIG. 1167.

same as before, but twice the number of commutator segments are employed. In this case each end of each coil is carried straight down to a separate commutator segment, and, in addition, a cross-connection is made between each

commutator segment to the one directly opposite it. In practice, it is customary to place the cross-connections inside the end of the commutator, instead of between the leads to the commutator, which is the method represented in the diagram.

Two brushes are used, located (with the four-pole field) 90° apart on the commutator. In the position of the armature represented in the diagram, coil *9* is short-circuited by the +brush; a moment later the −brush will short-circuit coil *5*, then the +brush will short-circuit coil *1*, then the −brush will short-circuit *14*, and so on, from which it will be seen that the coils in the successive neutral spaces are short-circuited one at a time.

**3133.** The formula for the total number of coils in the winding given in Art. **3130** (formula **481**) also applies to this winding; but if the direction of the winding in the coils is always assumed to advance in the same direction as the numbering of the coils, so that the *end* of coil *1* adjoins the *beginning* of coil *2*, and so on (which is the logical way of considering it), then the number of coils which can be used is only that given by the formula $s = p\,y - 1$.

Thus, in Fig. 1167, $p = 2$ and $y = 9$, and $s = (2 \times 9) - 1 = 17$ coils. If +1 had been used instead of −1, the number of coils would have been 19, and a closed-coil winding would have resulted, but the distribution of potentials between commutator segments would have been very irregular, since several coils would be included between adjacent bars in some instances.

**3134.** Since the object of the cross-connections is to connect together in series coils which lie in fields of like polarity, it is evident that opposite segments are connected together only in the case of a four-pole field, for which this form of winding is generally used.

In general, for any number of poles, the segments connected together are $\frac{360°}{p}$ apart, $p$ being the number of pairs of poles, as before. Two segments for each coil may be

used, but if this scheme of winding is laid out for a field with 6 poles, it will be seen that the distribution of potentials around the commutator is irregular. By introducing a third commutator segment for each coil at a point $\frac{360^\circ}{p} = 120^\circ$ removed from each of the other two, the distribution of potentials will become uniform. In general, then, the number of segments in the commutator for this form of winding will be equal to $p$ times the number of coils.

**3135.** There are several forms of two-circuit ring windings besides the two given, but as they introduce new complications in the way of cross-connections, they are of limited practical application. Of the two given, the latter is very generally used, since it is very simple and the cross-connections are very regular. By making the cross-connections a part of the commutator construction, as is generally the practice, the winding itself is as simple as a plain ring winding.

The fact that there are twice as many commutator segments as coils is also advantageous in reducing the difference of potential between segments. (See Art. **3114.**)

**3136.** In a two-circuit ring winding, a greater E. M. F. will be generated than in a multiple-circuit winding with the same number of conductors, since in the two-circuit winding the number of conductors connected in series is always $\frac{c}{2}$, while in the multiple-circuit winding it is always $\frac{c}{2p}$. The E. M. F. of the two-circuit winding is then $p$ times as great as that of the multiple-circuit winding with the same number of conductors, and by introducing this term in formula **480,** given in Art. **3104,** it becomes

$$E = \frac{cpNS}{60 \times 10^8}, \qquad \textbf{(482.)}$$

which is the formula for determining the E. M. F. of any *two-circuit* winding.

## BIPOLAR DRUM WINDINGS.

**3137.** From the nature of the drum winding, each coil must have at least two active conductors, in order to bring both ends of the coil to the front of the armature core; further, these two conductors must lie in fields of opposite polarity, and the E. M. F.'s generated in the two conductors must be as nearly as possible in phase, in order that they may add together without opposition. From an examination of the drum winding shown in Fig. 1160, it will be seen that the winding is constructed as follows: The surface of the armature core being divided into a number of *winding spaces* equal to *twice* the number of coils the winding is to have, then, starting at, for example, segment *d a*, coil *A A* is formed by carrying the conductor along one of the winding spaces to the back of the core, across the back to the winding space alongside the one diametrically opposite the one in which the coil was begun, then along this winding space to the front and up to commutator segment *a c*, the one next on the right of segment *d a*. From this point the next coil (*C C*) is started, the conductor being carried along the core from front to back, not in the winding space *next* to that occupied by the conductor first considered, but in the *second* winding space to the right of that one; the one skipped over will be filled by another coil. The coil is completed in the same manner as the first, the end being carried to the next segment to the right of *a c*. By proceeding with the remainder of the coils in the same manner, it will be seen that when half the coils (*A A*, *C C*, *B' B'*, and *D' D'*) are wound on the core, there is an even spacing of conductors all around, but only half the commutator segments are utilized, and only alternate winding spaces occupied. To proceed with the winding, coil *A' A'* is wound, starting at segment *a' d'* and carrying the conductor along the core from front to back in the winding space between spaces occupied by the parts of coils *A A* and *C C* that return from back to front, then across the back and along the core from back to front in the winding space left between the first parts of coils *A A* and *D D* that

were wound, and then to segment $a'$ $c'$. The remainder of the coils, $C'$ $C'$, $B$ $B$, and $D$ $D$, are wound on in a similar manner, and the end of coil $D$ $D$ connects with segment $d$ $a$ from which the winding started, thus forming a closed-coil winding.

**3138.** If it were desirable to make each coil of more than two turns, the extra turns would be wound around the core in the same winding spaces occupied by the first two before carrying the lead to the commutator segment and proceeding with the next coil. In practice, this is generally done, the size of the coils being so calculated that the whole of the armature surface is covered. In the diagrams used to represent the various drum windings, to prevent confusion, only a few coils, with two conductors per coil, will be represented.

**3139.** In drum windings there are two different factors which correspond to the *pitch* as used in two-circuit ring windings, namely, the number of winding spaces skipped over in connecting together the oppositely situated conductors of the *same* coil, across the back (and also across the front, if each coil has more than two conductors), which is called the **back pitch,** and the number of winding spaces skipped over in connecting together *succeeding* coils, across the front of the core, which is called the **front pitch.** In the diagram given in Fig. 1160, the back pitch is 7 and the front pitch 5. In the case of the two-circuit ring windings the pitch was always taken in the same direction, i. e., if a coil was connected to a coil situated $y$ coils to the *right*, this latter was in turn connected to a coil $y$ coils to the right again. In the drum winding given in Fig. 1160, however, the front pitch is in the opposite direction to the back pitch, and this is indicated by giving the front pitch a $-$ sign. Thus, the back pitch being 7, the front pitch is $-5$.

**3140.** The method of representing drum windings used in Fig. 1160 is not convenient, since it is difficult to represent the connections across the back of the core without a confusion of lines. Fig. 1168 shows the method of

diagrammatically representing drum windings that will be used in this discussion. This winding is the same as that represented in Fig. 1160, it being imagined that the armature and winding is expanded from the back until it becomes a flat disk. The heavy radial lines represent the conductors on the face of the core, the lighter lines represent the connections between them; the ring represents the cylindri-

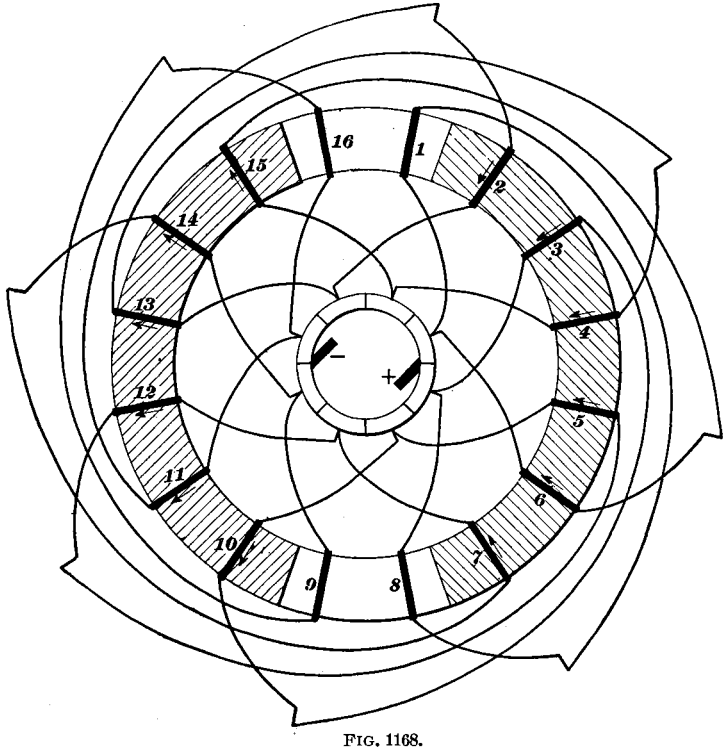


FIG. 1168.

cal surface of the core, and the shaded parts represent the portions of the core that are covered by the pole-pieces; that is, they represent the magnetic fields. The commutator and brushes are represented in a similar manner as for the ring windings.

**3141.** It will be seen from this diagram (in which the 16 conductors are evenly distributed on the surface of the

armature) that the conductors of each of the short-circuited coils *1–8* and *9–16* do not lie in the same part of each neutral space, because they are not diametrically opposite on the core.

With an even number of coils, and with the conductors placed in one layer on the surface of the core, opposite conductors can not be connected together and give a symmetri-

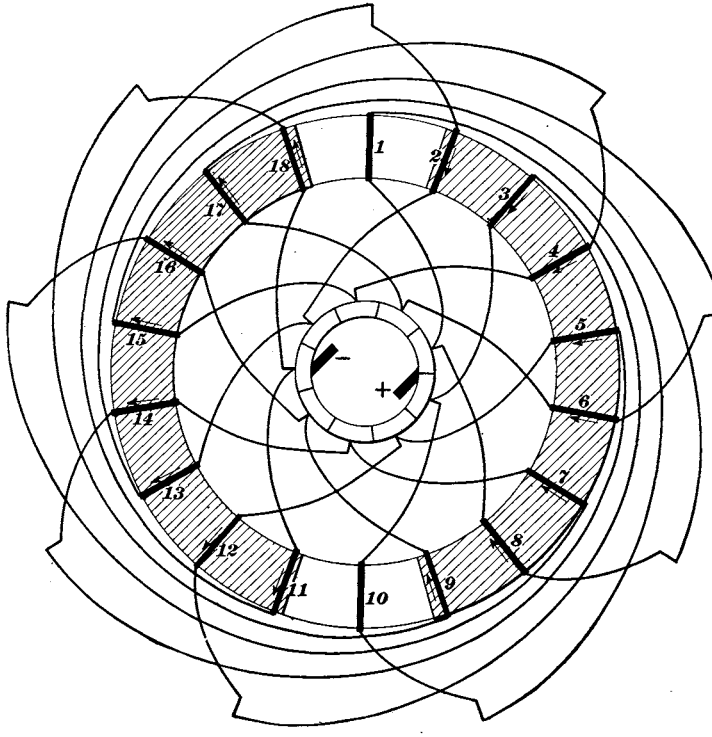


FIG. 1169.

cal winding. With an odd number of coils, however, opposite conductors may be connected together, as illustrated in Fig. 1169, which shows a winding with 9 coils, i. e., 18 conductors. In this winding the back pitch is 9 and the front −7. In the position shown, the coil formed of conductors *1* and *10*, which lie directly in the center of the neutral spaces, is short-circuited by the +brush. There being an

odd number of commutator segments, only one coil is short-circuited at a time.

**3142.** If, in the winding illustrated in Fig. 1168, alternate conductors, e. g., those with odd numbers, are moved around to the left until they coincide in position with the even numbered conductors, then the two conductors in each coil would be directly opposite each other, as in the case of the winding with the odd number of coils. With this form of winding, half of each coil is in the outside and half in the inside layer of windings, which introduces no difficulty in winding if each coil consists of but one turn; but if each coil consists of two or more turns, then the fact that the conductors of the coil that are in the inner layer must all be wound on before the outer layer can be wound causes serious difficulties in the winding. It is usually better to wind the coils side by side, as represented.

When the coils are wound in slots cut in the periphery of the armature core instead of being wound continuously over the surface, it becomes an easy matter to construct coils of many turns of wire. These coils are wound on a form and taped, after which they may be slipped into place and connected up.

**3143.** The possible variations in the method of winding bipolar drum armatures are many. In general, the number of conductors must always be even, although the number of coils may be either odd or even. The back pitch determines the relative position on the core of the members of a coil, from which it follows that in order to have both members in the neutral spaces at the same time the back pitch should be very nearly equal (in bipolar fields) to $\frac{w}{2}$, $w$ being the number of winding spaces.

The back pitch obviously can not be exactly equal to $\frac{w}{2}$, unless $s$ (the number of coils) is odd. With an even number of coils the nearest approach to this value is evidently $\frac{w}{2} \pm 1$; if $+1$ is used, the end connections are longer and

make more crossings, and the winding has no particular advantage over that resulting from the use of $-1$ in the above formula. It is better, then, to make the back pitch $= \frac{w}{2} - 1$.

**3144.** The front pitch determines the position of a coil relative to the coils with which it is immediately connected, and should, therefore, differ from the back pitch by 2. (See Art. **3137.**) If the front pitch is less than the back pitch, each of the coils, taken in the order in which they are connected, lies to one side of the coil preceding it in the *same direction* as the back pitch; for example, in Figs. 1168 and 1169 the direction of the back pitch is to the *right*, and the front pitch being in each case less than the back pitch the successive coils each lie to the *right* of that preceding it, e. g., coil *3–12* lies to the *right* of coil *1–10* (Fig. 1169). This is called the **advance** of the winding.

**3145.** If the front pitch is greater than the back pitch, the advance is opposite in direction to the back pitch. There is no particular advantage in this, however, and it has the disadvantage that the connections across the ends of the core are longer for the same winding than in the case where the back pitch and the advance are both in the same direction, thus requiring a greater length of wire for the winding and increasing the number of crossings of the end connections. It is better, then, to make the front pitch less than the back pitch, in which case its value would be $= \frac{w}{2} - 3$, when the back pitch $= \frac{w}{2} - 1$, as noted above.

**3146.** It is possible to use values for the back and the front pitch which are less than those given by the above formulas, as indicated in Fig. 1170, which gives a winding in which $s = 10$ and $w = 20$; the back pitch $= +7$ and the front pitch $= -5$.

In the position represented in this figure the coil formed

of conductors *1* and *8* is short-circuited by the +brush, and that formed of conductors *18* and *11* is short-circuited by the —brush. It will be seen that these coils do not lie alongside one another, as has been the case in all the previous windings where *s* is even, but instead are separated by

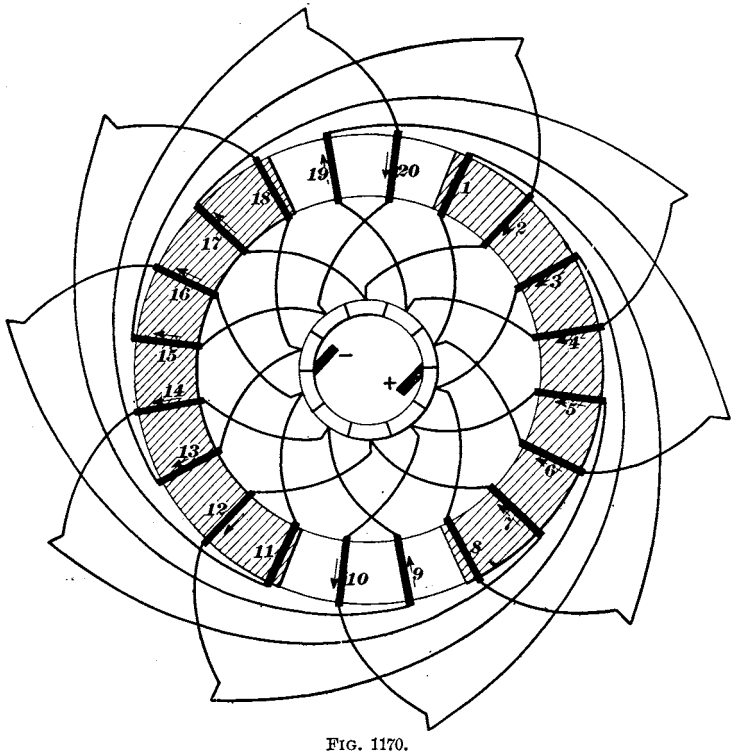


FIG. 1170.

conductors in which the armature current is flowing. This results in causing the short-circuited coils to lie on the edge of, or even in, the magnetic field, unless the width of the field is made smaller than has been represented.

**3147.** This form of winding, where the back pitch is *less* than $\frac{w}{2}-1$, is called a **chord winding,** and the disadvantage of having the short-circuited coils slightly out of the neutral space (which with a greater number of coils would be much

less than with the few coils represented in the diagram) is to some extent balanced by the shorter length of wire required for the end connections and the fewer crossings made by them, providing the space between the two winding spaces occupied by a coil is not less than the width of the field.

In addition, it will be seen that where the brushes are shifted the current in some of the armature conductors included in twice the angle of lead of the brushes is opposite in direction to that in the others, which reduces the counter magnetomotive force of the armature winding.

**3148.** Another modification of the drum winding consists in giving to both the front and the back pitches the *same*

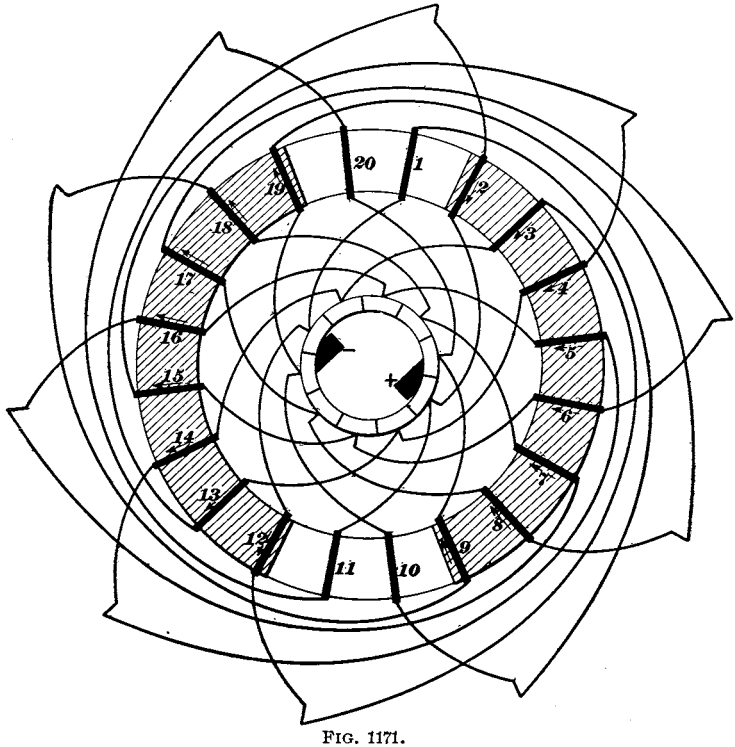


FIG. 1171.

direction. Fig. 1171 represents a winding in which $s = 10$, as in Fig. 1170, $w = 20$, and the front and the back pitches are

each equal to +9. It will be seen that one effect of giving both pitches the same direction is to make it possible to have both pitches equal, which is obviously not the case when they are given opposite directions. As in the windings previously considered, the winding space occupied by the *first* half of a coil must be the *second* winding space away from that occupied by the *first* half of the preceding coil. (See Art. **3137.**) Since both pitches are in the same direction, this condition makes it necessary that the total number of winding spaces be equal (in bipolar fields) to the sum of the front and back pitches, $\pm 2$. If $y =$ the *average* pitch, i. e., half the sum of the front and back pitches, then the number of winding spaces which must be used is given by the formula

$$w = 2y \pm 2. \qquad \textbf{(483.)}$$

In Fig. 1171, $y = 9$, and $w$ might then have been 16 or 20. If $-2$ is used, the advance of the winding is in the same direction as the pitch; but if $+2$ is used the advance is in the opposite direction.

This is more advantageous, since the end connections are a little shorter for the same number of conductors; hence, a less length of wire is required for the winding.

**3149.** In order that all of an even number of winding spaces may be passed over in connecting up this form of winding, both front and back pitch must be odd, so that if they are equal the average pitch will also be odd. If the front and the back pitches differ by 2, the average pitch may be even.

For example, with an average pitch of 8, the number of winding spaces might be $w = (2 \times 8) \pm 2 = 18$ or 14; since each pitch must be odd, the back pitch might be taken as +9 and the front pitch as +7, or *vice versa*.

In this style of winding, both pitches having the same direction, it will be seen that when the *average pitch* is *even* the number of *coils* is *odd*, but when the *average pitch* is *odd* the number of *coils* is *even*. Further, when the average pitch is odd, the end connections on both ends are of the same length, which is often an advantage in manufacture.

### END CONNECTIONS OF COILS.

**3150.** Though it has not thus far been represented, the end connections of the drum winding must be made to avoid the armature shaft in crossing the ends of the core. This is accomplished in a variety of ways. In the ordinary forms of drum winding with coils made up of several turns each, the end connections of each coil are simply carried across the end of the core and bent out to one side to avoid the shaft; as each coil is wound, its end connections are laid over the end connections of the coils previously wound, the whole being so disposed as to make as nearly as possible a symmetrical-looking winding when done. In this form of winding, the several coils may be of quite different lengths, those wound on last being longer than those first wound.

Further, the end connections lap over and cross each other in all directions, and special precautions must be taken to insulate carefully between coils, and in case of accident to one of the coils first wound, the rest of the coils must be removed before the injured coil can be repaired.

**3151.** It is apparent, then, that on account of these difficulties some other method of winding is desirable which shall not be open to some or all of the above mentioned objections. In case each coil consists of but one turn (two conductors), the end connections may be arranged as represented in Fig. 1172, in which $C$ is the drum armature core; $a$ and $b$ are the two conductors of an armature coil, and $c$ and $d$ the two conductors of the coil next succeeding coil $a\ b$ in the winding. Considering that the view represents the *back* end of the core and that $b$ is the conductor from which the winding starts, then the winding is proceeded with as follows: Conductor $b$ is bent down at right angles at the end of the core (see plan, Fig. 1172) and carried in a spiral curve along the end face of the core to a point $n$, which is on the diameter about at right angles to the plane of the coil, and at a sufficient radial distance from the axis of the core to clear the shaft. At this point the conductor is bent outward at right angles, carried along away from

the core parallel to the shaft for a short distance, as represented at *n* (in the plan), then bent at right angles again and carried in a spiral curve parallel to the end face of the drum and bent over to form conductor *a*. In forming the

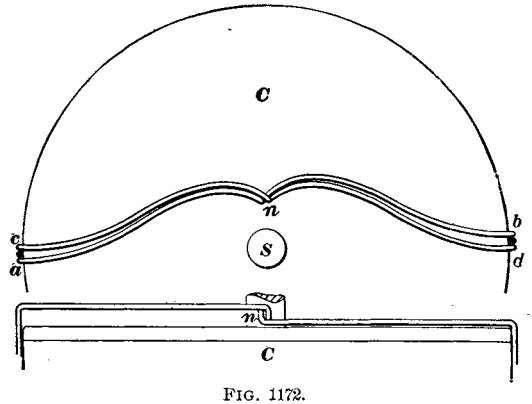


FIG. 1172.

next coil *c d*, which is located two winding spaces away from coil *a b* (see Art. **3137**), a similar process is gone through with, the two spiral connectors being carried along parallel with those of the first coil to be wound, as represented.

**3152.** It will be seen that by completing the whole winding in a similar manner, the end connections are situated in two parallel planes, those in the inner plane being the connections from the *first* conductors of the coils to the center, and those in the outer plane being the connections from the center to the *last* conductors of the coils. This forms a very symmetrical winding, and the end connections cross in such a manner that it is a very simple matter to insulate them thoroughly. It is evident that the number of short lengths of conductors at *n* (Fig. 1172) is equal to the number of coils; hence, the distance of *n* from the axis must be great enough to allow this number of conductors to lie side by side, with insulation between. If the conductors are of uniform section throughout, and are spaced closely on the surface of the core, this might require that the point *n* be

too far from the axis. To avoid this difficulty, the end connections may be made in the form of separate connectors, of thin sheet copper, wide enough to give the necessary cross-section, and bent to the proper shape; these are placed in position, with the width of the copper strip parallel to the shaft, and fastened to the conductors on the face of the armature core. In such a "built up" winding, the active conductors are often made of heavy copper bars of rectangular section, to which the end connectors are riveted or soldered. Fig. 1173 shows one form of end connector made

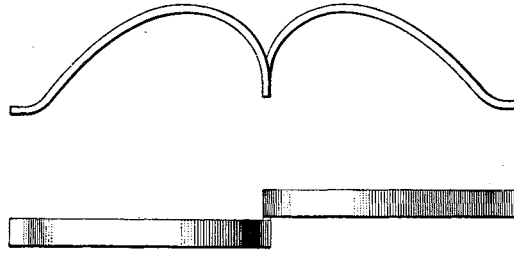

FIG. 1173.

from a rectangular piece of sheet copper, which is slotted for almost its entire length. The two tongues of metal thus formed are bent over, one to the right and one to the left, forming the end connector represented in the figure. The proper curves for the spiral parts of the end connector may best be determined by laying them out on the drawing-board, and by trials determining which curve will give the most uniform clearance between adjacent connectors. When using these end connectors, the shorter conductors of the winding may as well be *under* as *alongside* the longer conductors, if their number is properly chosen, thus forming a two-layer winding.

**3153.** In case it is desired to use more than one turn in each coil, a winding which is usually attributed to Eickemeyer may be used. In this winding each coil is wound on a wooden form to the proper shape, and the proper number are then placed in position on the armature core. The shape of the coil as completed is approximately rectangular, the

ends of the rectangle being bent in a manner similar to the end connections illustrated in Fig. 1172, so that when the coils are placed in position on the core, the end connections of each coil as a whole cross in the same manner as in the winding described in Art. **3151**, where each coil consists of a single turn. Of the two sides of the coil which form the active conductors, one is shorter than the other by reason of difference in the planes in which the two parts of the end connections lie. (See Fig. 1172.) This shorter side, in the completed winding, may lie beneath or alongside the longer side of the neighboring coil, thus forming a two-layer or a single-layer winding, as the designer may decide.

**3154.** By referring to the various diagrams for drum windings which have been given, it will be seen that in all the windings the adjacent conductors which lie in the neutral spaces have between them nearly or quite the full difference of potential that exists between the brushes. This is not quite so marked in the chord winding (Fig. 1170), which is one advantage of this form of winding.

In the two-layer winding it will be seen that as the two adjacent conductors are placed one over the other, the full difference of potential exists between the members of the two layers at such time as they are in the neutral spaces. This feature requires that the adjacent conductors in single-layer windings and the two layers in two-layer windings be carefully insulated one from the other.

---

## MULTIPOLAR DRUM WINDINGS.

**3155.** The use of the drum winding for large multipolar armatures has become very general, as it possesses many advantages. In these larger machines the number of conductors in the winding may usually be so chosen that only one turn is required for each coil, and each coil is made up of two active conductors made from copper bars and two separately formed end connectors.

For greater mechanical security, these bars are let into

grooves cut or punched in the periphery of the core, which grooves are necessarily (as will be pointed out later) narrow, close together, and comparatively deep. Such a winding as this is known as a **bar winding,** and if the grooves or slots in the armature core have overhanging tops, so that the conductors are thoroughly enclosed, the armature is said to be **iron-clad.**

**3156.** One of the principal features of a drum winding is that opposite sides of a coil must be in magnetic fields of opposite polarity. It follows that a drum winding that is designed for a two-pole field will not give any E. M. F. if rotated in a four-pole field, since opposite sides of a coil would then be in fields of like polarity.

In order to obtain a drum winding for a multipolar machine, it is necessary then that conductors which are similarly situated with respect to fields of opposite polarity should be connected together to form the armature coils. To accomplish this, the pitch of the winding must be something near the value given by $\frac{w}{2p}$, $w$ being the number of winding spaces and $p$ the number of pairs of poles, as before.

As in the bipolar windings, the front pitch should equal the back pitch $\pm$ 2 when the two pitches are in opposite directions, and as the total number of winding spaces must be even, both pitches must be odd in order that all the winding spaces may be passed through.

---

### LOOP WINDING.

**3157.** When the front and the back pitches are of opposite sign, *half* the conductors under any pair of adjacent poles are connected together in series, and, therefore, form one circuit of the armature. This results in there being as many armature circuits as poles, as in the simple multipolar ring, with the same necessity for either as many brushes as poles or a cross-connected commutator and a single pair of brushes.

This type of multipolar drum winding is called a **loop winding,** since, in following the course of the winding, a

series of loops is formed, caused by the opposite sign of the two pitches.

**3158.** Fig. 1174 is a diagram of a four-pole loop winding, in which 32 conductors are represented. The back pitch is taken as $+9$ and the front pitch as $-7$.

As in the previous diagrams, the conductors which make up the coils that are short-circuited by the brushes have no

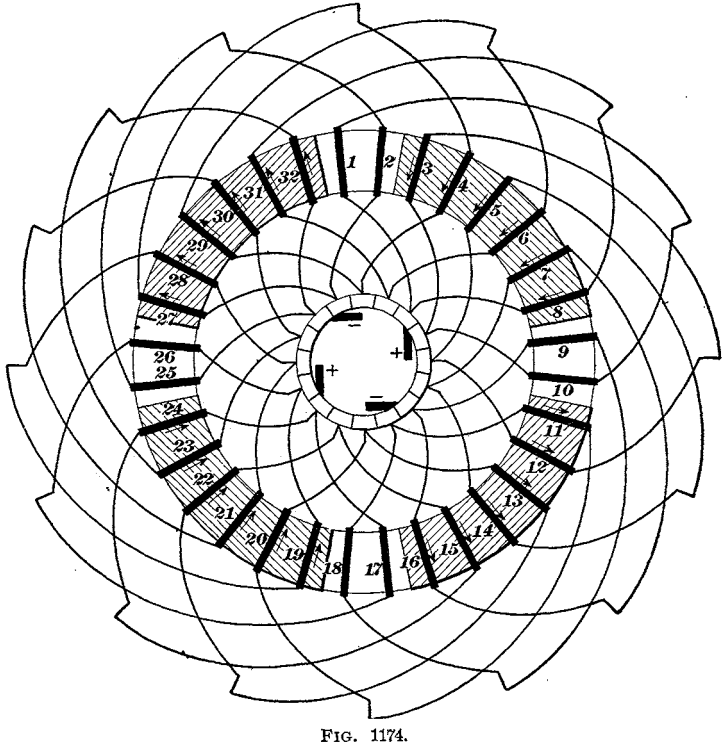


FIG. 1174.

arrows, the arrows near the other conductors indicating the direction of the E. M. F. induced in them.

This form of winding needs no further elaboration. It can be used for 6, 8, or a greater number of poles, and its E. M. F. may be calculated in the same manner as for the multipolar ring winding with as many armature circuits as poles. (Art. **3126.**)

When this form of winding is used in slotted armatures (see Art. **3155**), the only requirement that has not already been given is that the number of conductors per slot must be some even number, and the total number of conductors must be a multiple of the number of slots.

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### WAVE WINDING.

**3159.** In bipolar drum windings, giving both pitches the same direction has little effect on the resulting winding; in multipolar drum windings, the effect is marked. If both pitches have the same direction, the winding, passing from front to back under one pole-piece and returning to the front again under the next pole-piece, would continue by passing from front to back under the *next* pole-piece, progressing in the same direction as before, and thus forming a series of *waves*, instead of loops, as when the pitches have opposite directions. (Art. **3157.**) This style of winding is then called a **wave winding.**

As in the bipolar winding, the pitch may be the same, both front and back, in which case it must be odd, or the front and the back pitch may differ by 2, in which case they must both be odd, making the average pitch even.

**3160.** It has been pointed out that the wave winding advances in a series of waves or steps, and it is evident that, after making a number of steps equal to the number of poles, the winding must come to the *second* winding space from that containing the conductor with which the winding started. From this it follows that the total number of winding spaces possible with this form of winding is equal to the product of the number of poles and the average pitch, $\pm$ 2, or, as expressed in the symbols previously used,

$$w = 2\,p\,y \pm 2. \qquad \textbf{(484.)}$$

It will be noted that this is the same formula as that used for the bipolar drum winding, in which both pitches were given the same direction (formula **483**), with the addition of the term $p$. (See Art. **3148** and Fig. 1171.)

**3161.** Fig. 1175 is a diagram of a four-pole wave winding, in which $y = 9$. Therefore, $w = 2py \pm 2 = 34$ or 38. The former number (34) is used in this diagram.

It will be seen from this diagram that the wave winding results in a two-circuit winding, requiring only two brushes,

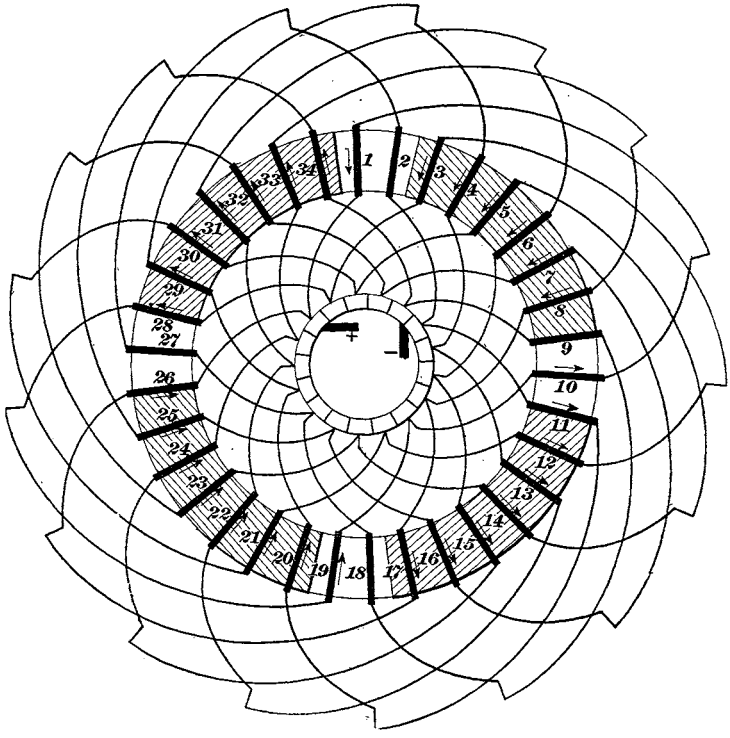


FIG. 1175.

just as the two-circuit multipolar rings. This holds true whatever the number of poles of the field.

The advance of this winding is in the same direction as the pitch. If +2 had been used in the formula, 38 conductors would have been required, and the advance would have been opposite in direction to the pitch.

If the average pitch had been taken as 8, using +9 for the back and +7 for the front pitch (or *vice versa*), the

same number of conductors might have been used; i. e., $w = 2 p y \pm 2 = (2 \times 2 \times 8) \pm 2 = 30$ or 34.

For bar-wound armatures, it is better to use $+2$ in the formula, and the same pitch on both ends, if the number of conductors required will allow, since that will give the most economical system of end connections.

From Fig. 1175 it will be seen that each brush alternately short-circuits two coils that are in series, and the point where these two coils are connected is the commutator segment that is as nearly as possible opposite the brush that is short-circuiting the coils.

**3162.** Sometimes it is desired to use a two-circuit armature, but the ordinary form would give too great a difference of potential between segments. Since in this form of winding there are $p$ coils included between every adjacent pair of commutator segments, an additional commutator segment may be inserted, in such a case, between each pair of segments of the winding as already given, each of these interpolated segments being connected with the segment of the original commutator that is directly opposite it. This is illustrated in Fig. 1176, which shows a four-pole wave winding with 30 conductors, in which the pitch (both front and back) is $+7$. A number of commutator segments equal to the number of conductors (30) is used; alternate segments are connected to the winding, and each of the rest is connected to the segment directly opposite, which is one of those connected directly to the winding. The result of this interpolated segment construction is that, unless the brushes are wider than one segment, only one coil, consisting of two conductors, is short-circuited at a time, and the difference of potential between adjacent segments is only that generated in one coil, instead of that generated in $p$ (2) coils, as would be the case if the interpolated segments were not used.

**3163.** When in the position shown in the figure, the coil formed of conductors *1* and *8* is short-circuited by the $-$brush. If the armature is rotated in the direction indicated

by the arrow, the next coil to be short-circuited is that formed of conductors *9* and *16*, by the +brush; the next is the coil formed by conductors *24* and *17*, by the −brush;

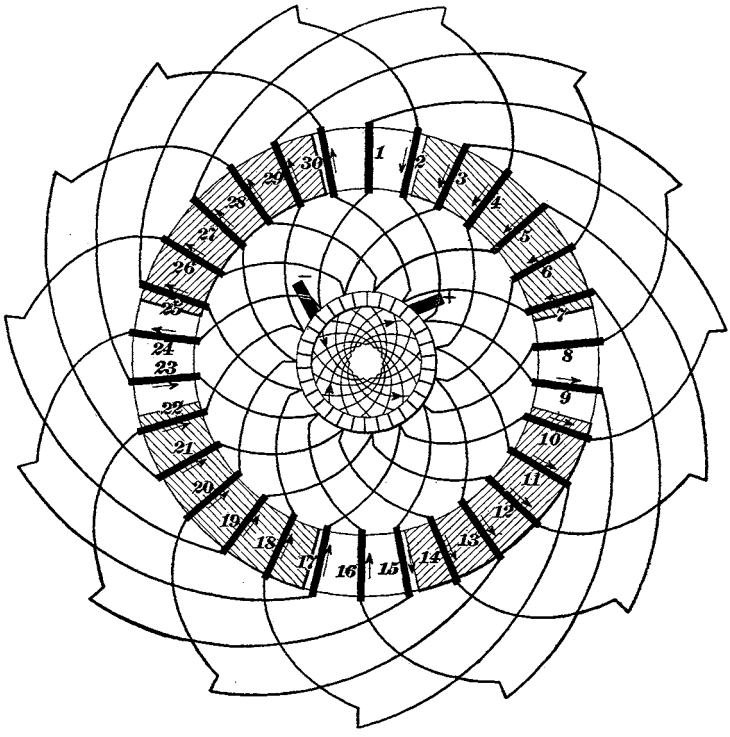


FIG. 1176.

and so on, as the armature rotates. (Compare this with Art. **3132.**)

Only two of the cross-connectors carry the current at any one time, as indicated by the arrow, Fig. 1176.

**3164.** With more than two pairs of poles, an additional set of interpolated segments must be used for each pair of poles increase over two, and these must be located $\frac{360^\circ}{p}$ apart on the commutator, and connected together. This makes such

a complicated system of connections that the interpolated segment construction is seldom used for fields with more than four poles, although, when the number of pairs of poles ($p$) is *even*, one set of interpolated segments connected to the segments directly opposite may be used, thus halving the difference of potential between segments and the number of conductors short-circuited at a time. Hence, with an eight-pole field, one set of interpolated segments would reduce the difference of potential between adjacent segments to the E. M. F. generated in two coils.

**3165.** From the formula for the number of winding spaces in the wave winding, $w = 2py \pm 2$, it will be seen that $w$ is always twice an odd number when $p$ is even, as in 4, 8, or 12 pole machines; while $w$ may be twice either an odd or an even number when $p$ is odd, as in 2, 6, or 10 pole machines. From this it follows that in machines with bar-wound iron-clad armatures and an even number of pairs of poles, not more than two conductors can be placed in each slot, in which case the number of slots must be odd; while in similar machines with an odd number of pairs of poles the number of winding spaces may be made such that either two or four conductors per slot may be used. It would seldom be the case that a greater number of conductors per slot than four would be desired, owing to mechanical difficulties in constructing the winding.

Unless an interpolated segment commutator is used, the number of commutator segments is equal to $\frac{w}{2}$, hence is odd when $p$ is even, and may be either even or odd when $p$ is odd.

**3166.** In multipolar drum armatures, end connections similar to those described in Art. **3152** are almost invariably used, especially as almost all the larger sizes of drum-wound armatures employ bars for the active conductors and flat strip end connectors, the armature coils then consisting of but two active conductors each.

In case it is desirable to use more than two active conductors per coil, the type of winding described in Art. **3153,** in which the coils are wound to shape on a separate form and afterwards placed in position on the core, may be very advantageously used, especially with slotted armatures.

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## MULTIPLE WINDINGS.

**3167.** Sometimes in large machines for large current output the size of the conductors required and the volume of current that must be commuted at the brushes are both inconveniently large with the ordinary forms of winding, as already described. To avoid these difficulties, two or more separate windings on the same armature may be employed, each of which will then furnish its share of the required current. A separate commutator may be employed for each winding, in which case the corresponding brushes of each commutator must be connected in parallel; but as this leads to undesirable complications, it is much better to combine the various commutators into one, by inserting the successive segments of one commutator between the similar segments of the other. The various windings are then connected in parallel by using a wide brush, which must evidently be of sufficient span to be always in contact with at least one segment that is connected to each winding, so that if there are $m$ separate windings, each brush must have a span not less than that of $m$ segments. Under these conditions, the coils of the successive windings will be short-circuited one at a time, and the volume of current commutated will be only $\frac{1}{m}$ of that which would be short-circuited if a similar form of single winding were employed for the same current output.

Such a winding as has been described is known as a **multiple winding,** to distinguish it from those forms in which the conductors are so connected as to form a *single* closed-coil winding.

Any specific winding is usually spoken of as a *double,*

*triple*, etc., winding, according to the number of separate windings employed.

**3168.** If a given number of conductors which, when connected up into any particular form of single closed-coil winding, will give an E. M. F. of $V$ volts, are so connected as to give $m$ separate windings of the same form, all connected in parallel, there will be but $\frac{1}{m}$ as many of the conductors connected in series as in the single winding, hence the E. M. F. will be only $\frac{V}{m}$ volts. To apply the formulas given for finding the E. M. F. developed in a winding consisting of a certain number of conductors (formulas **480** and **482**), it is only necessary then to introduce the term $m$ (the number of separate windings) into the denominator of the formula, so that for multiple-wound *multiple-circuit* windings the formula becomes

$$E = \frac{c N S}{60 \times 10^8 m}, \qquad \textbf{(485.)}$$

and for multiple-wound *two-circuit* windings it becomes

$$E = \frac{c p N S}{60 \times 10^8 m}. \qquad \textbf{(486.)}$$

**3169.** The principle of multiple winding may be applied to any form of closed-coil winding, if desired, and, further, by properly selecting the number of coils and their order of succession, the end of one winding may be joined to the beginning of the next, and so on, thus forming a single reentrant system of the whole series of conductors. This may also be modified, as will be pointed out, to make the windings form a number of separate reentrant systems which will be some whole factor of $m$. That is to say, the conductors of a multiple-wound armature having $m$ windings may be combined as $m$ separate reentrant systems, 1 reentrant system, or a number of separate reentrant systems equal to some whole factor of $m$. In practice, it is

seldom that $m$ exceeds 3 or 4, although it may be any whole number within reasonable limits.

The application of the principle of multiple windings to the various types of armature windings will now be taken up.

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### MULTIPLE-WOUND MULTIPLE-CIRCUIT RING WINDINGS.

**3170.** The multiple-circuit winding is the simplest form of ring winding, and, as has already been pointed out, it may be used in fields having any number of pairs of poles without changing the connections.

Since the adjacent coils of a single-wound ring are connected together, and for multiple windings the separate

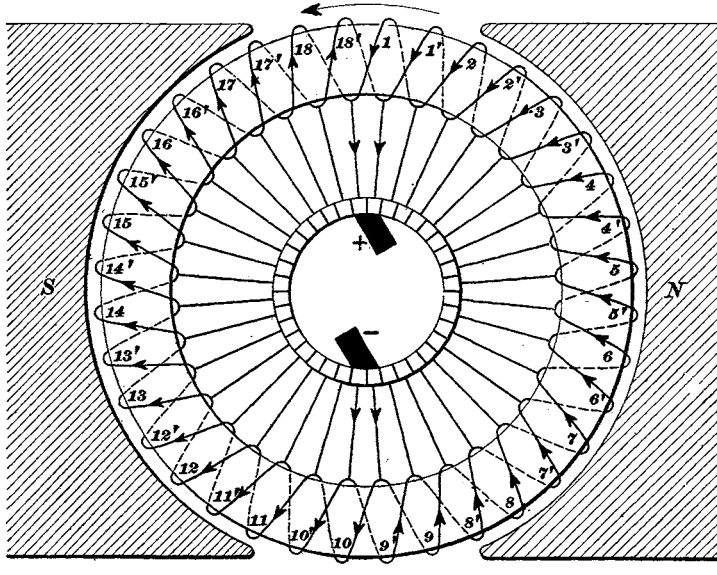


FIG. 1177.

coils of each winding are supposed to lie between successive coils of the others, it follows that, in connecting up the coils of a ring winding to form $m$ separate windings, each coil is connected to the $m$th coil on each side; that is, $m - 1$ coils are *skipped over* in connecting successive coils of the wind-

ing. This is shown in Fig. 1177, which represents a two-pole multiple-wound multiple-circuit ring armature of 36 coils, in which $m = 2$. Consequently, in connecting successive coils, $2 - 1 = 1$ coil is skipped once, and alternate coils are connected in each winding. Coils numbered *1*, *2*, *3*, etc., represent the one winding, and coils *1'*, *2'*, *3'*, etc., represent the other.

**3171.** It will be seen that, in connecting alternate coils of the even number (36) which is used in this case, the end of the 18th coil is connected to the first coil, thus forming one reentrant system, so that a fresh start must be made to form the second winding, which, therefore, forms a second reentrant system.

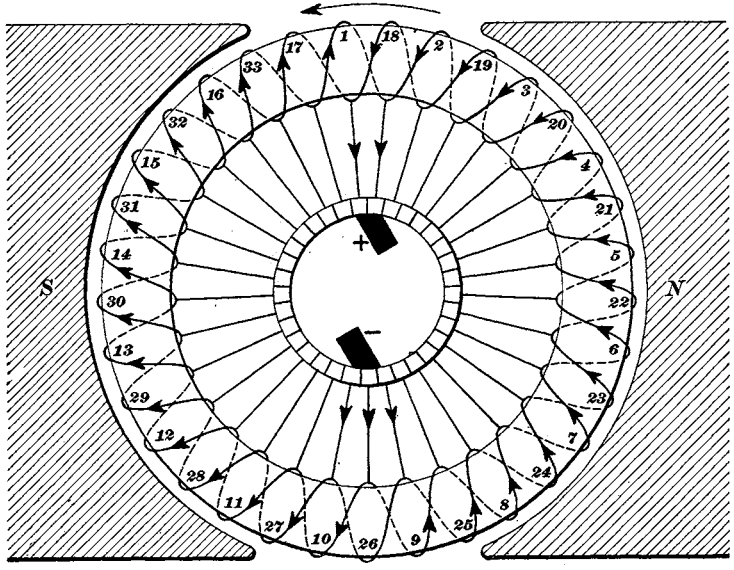


FIG. 1178.

This results from the fact that the total number of coils is divisible by the number of windings, without a remainder.

If the number of coils is so chosen that there is a remainder, then, after passing through alternate coils once around the armature, the end of the last coil connected will not con-

nect with the beginning of the coil from which the winding was started, but with one on one side or the other of it, thus starting the second winding, which ends at the beginning of the first coil of the first winding; the two windings thus form a single reentrant system.

This is illustrated in Fig. 1178, which represents a two-pole multiple-circuit multiple-wound armature having 33 coils, in which $m = 2$, as before. The coils are numbered from 1 to 33, inclusive, in the order in which they are connected. It will be seen that, after passing through alternate coils once around the armature, thus passing through 17 coils, the next coil in succession is coil *18*, immediately to the right of coil *1*, which is then the beginning of the second winding, which ends with coil *1*.

**3172.** To make a single reentrant winding, when $m = 2$, the number of coils must be odd. This being the case, the number of commutator segments is odd, and but one coil is short-circuited at a time, unless the brush has a span greater than that of two segments. In the case illustrated in Fig. 1178, coil *26* is short-circuited by the $-$brush; a moment later, the $+$brush will short-circuit coil *18*, then the $-$brush will short-circuit coil *10*, then the $+$brush coil *2*, and so on.

**3173.** In general, for this class of windings (which, as already stated, may be applied to fields having any reasonable number of pairs of poles), if the number of coils, $s$, is a multiple of the number of windings, $m$, the conductors will connect together into $m$ separate reentrant systems; while, if the number of coils is mutually prime with $m$, the conductors will join together into a single reentrant system. For example, a multiple-circuit multiple-wound armature where $m = 3$ is to have in the neighborhood of 50 coils. If 48 or 51 coils is the number used, three separate reentrant systems will result, each containing $\frac{48}{3} = 16$ or $\frac{51}{3} = 17$ coils. If 49 or 50 coils are used, a single reentrant system will result. When $m = 4$, or any even number, the number of

reentrant systems that will result with any given number of coils, $s$, will be equal to the *greatest common factor* of $m$ and $s$. Thus, when $m = 4$ with 48 coils, the greatest common factor being 4, that number of separate reentrant systems will result; with 49 coils, the greatest common factor is 1, and one reentrant system will result. With 50 coils, however, the greatest common factor is 2, so that two separate reentrant systems will result, each made up of 2 of the 4 windings. (Compare this with Art. 3171.)

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### MULTIPLE-WOUND TWO-CIRCUIT RING WINDINGS.

**3174.** The application of the principle of multiple windings to this form of armature winding is not materially different from the cases just considered.

In the single winding, described in Arts. 3129 to 3133, the number of coils in the winding is found from formula 481, $s = p\,y \pm 1$, the last term ($\pm 1$) being introduced in order that the winding should form a *single* two-circuit winding. To apply this formula to multiple-wound two-circuit windings, it is only necessary to substitute $m$, the number of separate windings desired, for 1, which gives the following formula :

$$s = p\,y \pm m. \qquad (487.)$$

If $y$ (the pitch) is a multiple of $m$, then $s$ will also be a multiple of $m$, and, as in the multiple-circuit windings, $m$ separate reentrant systems will result ; while if $y$ and $m$ are mutually prime, then $s$ will not be a multiple of $m$, and a single reentrant system will result. In fact, the number of separate reentrant systems which will result with any given number of coils will be equal to the greatest common factor of $m$ and $y$.

**3175.** For example, a four-pole two-circuit ring winding, with a pitch of 11 and 3 windings ($y = 11$, $m = 3$) could have $s = p\,y \pm 3 = 22 \pm 3 = 25$ or 19 coils, and 11 and 3 being mutually prime, a single reentrant system would result with either number. Fig. 1179 represents the above case,

25 being the number of coils used. It will be seen that this winding is of the same type as the single winding illustrated in Fig. 1166. In this case the coils are numbered from 1 to 25; in addition, the numbers *1'*, *2'*, *3'*, etc., show the order in which the successive coils are connected. This being a

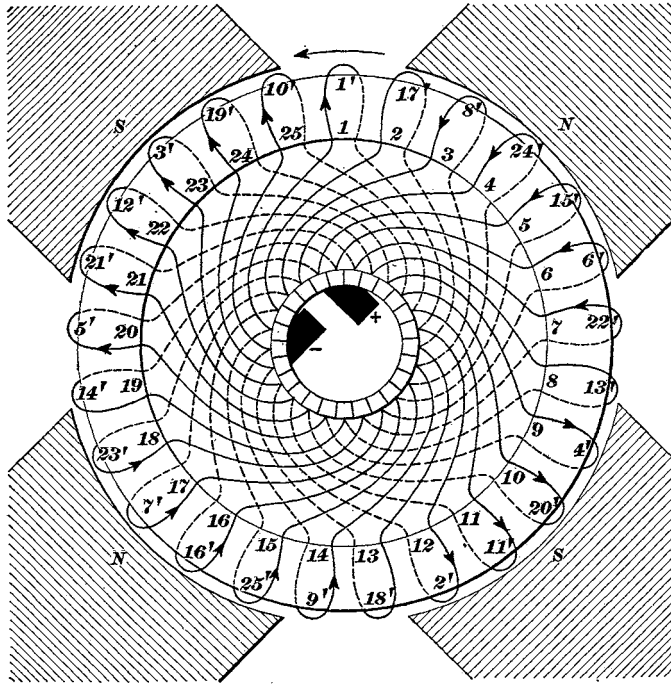


FIG. 1179.

triple winding, the brushes are made of the same span as three segments; the +brush short-circuits coils *8* and *19*, and the −brush short-circuits coils *2* and *13*, the rest of the coils having arrow-heads showing the direction of the current in them.

Each of the three windings of this example being a two-circuit winding, there are six circuits through the armature. On tracing these out, starting from the −brush, it will be

found that the various coils are divided among the circuits as follows:

$$-\left\{\begin{array}{l}\left\{\begin{array}{l}1-12-23-9-20\\15-\ 4-18-7\end{array}\right\}\\\left\{\begin{array}{l}25-11-22\\14-\ 3-17-6\end{array}\right\}\\\left\{\begin{array}{l}24-10-21\\16-\ 5\end{array}\right\}\end{array}\right\}+$$

This indicates an extreme irregularity in the number of coils in each circuit, but this is only due to the small number of coils necessarily used in the diagram. In any winding as actually used the irregularity would be almost inappreciable.

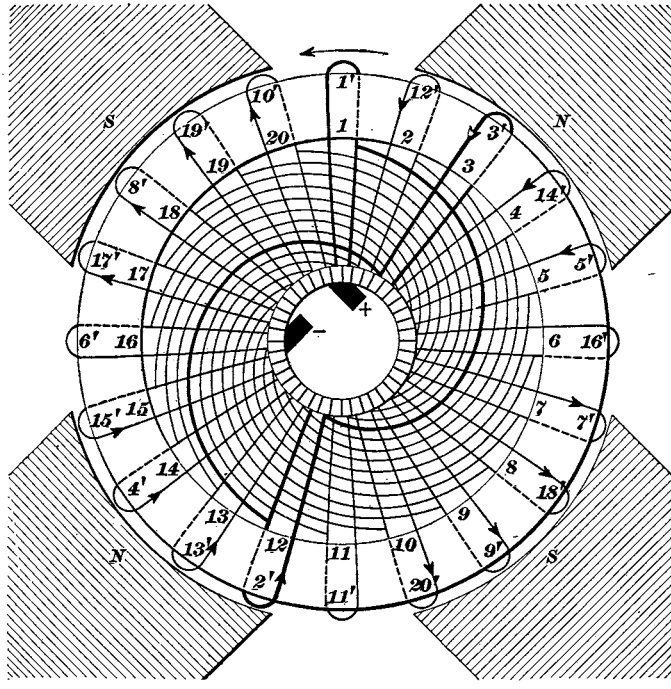


FIG. 1180.

**3176.** Fig. 1180 is a diagram of a four-pole two-circuit double-wound armature of the same type as that illustrated

in Fig. 1167. For this type of two-circuit ring winding, formula **487** is used; but to obtain an even distribution of potentials around the commutator only the —sign should be employed; i. e., $s = p\,y - m$. In this case $y = 11$; hence, $s = 22 - 2 = 20$. As $y$ and $m$ are in this case also mutually prime, the winding forms a single reentrant system. As in Fig. 1179, the coils are numbered *1*, *2*, *3*, etc., and the numbers *1'*, *2'*, *3'*, etc., show the succession in which the coils are connected. Coils *1*, *12*, and *3*, and their connections, are drawn in heavier lines than the rest, to better show the plan of connection.

Although this is a double winding, the brushes must be made of a span equal to at least that of 3 segments, as shown, in order that they may be in connection with both windings all the time. This width is necessary because each coil is connected to two adjacent segments.

In the position shown, the +brush short-circuits coils *1* and *11*, and the —brush short-circuits coils *16* and *6*; the direction of the current in the remaining coils is indicated by the arrow-heads, as before. The four circuits of this armature are made up as follows, starting from the —brush:

$$-\left\{\begin{array}{l}\left\{\begin{array}{l}17-8-19-10\\15-4-13-\ 2\end{array}\right\}\\ \left\{\begin{array}{l}7-18-\ 9-20\\5-14-\ 3-12\end{array}\right\}\end{array}\right\}+$$

This winding is much more regular than that shown in the previous figure, but this is not an essential feature of this form of winding, being due to the even number of coils and windings.

**3177.** In case it is desired to make the cross-connections a part of the commutator construction, which is usually more desirable, the angular span of the cross-connections should be the same throughout, in order that the cross-connections may be symmetrical.

With the winding as shown, this is not the case, for the leading segment of coil *1* is connected to the *19th* segment

to the right, while the following segment of the same coil is connected to the *21st* segment, also to the right.

If, instead of connecting the two ends of each coil to adjacent segments, they are connected to two segments which are separated by a third, the inequality in the spans of the cross-connections disappears, and they become symmetrical. This, however, causes the leads from the armature coils to the commutator segments to cross, requiring extra precautions in insulating.

In case the winding were triple, quadruple, etc., the two ends of each coil would be connected to two segments separated by 2, 3, etc., others; that is, in general, the two commutator segments to which each coil of the $m$ windings is connected would be separated by $m - 1$ other segments, if it be desired to make the cross-connections a part of the commutator construction.

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**MULTIPLE-WOUND MULTIPLE-CIRCUIT DRUM WINDINGS.**

**3178.** The conditions governing the multiple-circuit multiple-wound ring windings also apply to this class; in addition, the influence of the difference between the ring and the drum form of coil must be taken into account. As each coil of the drum winding is made up of *two* active parts, each occupying a winding space, the number of winding spaces, $w$, must be *even*.

The back pitch, which determines the number of winding spaces included between the two active parts of a coil (see Art. **3139**), needs only to be made of such value that the two parts of the coil shall not be in any one field at the same time, which implies that the angular span of the coil should not be much greater or less than $\frac{360^\circ}{2p}$.

The front pitch, which determines the number of winding spaces included between similar parts of two successive coils, is determined by the number of separate windings used. In the multiple-circuit *single-wound* drum winding, the front pitch = back pitch $\pm$ 2; that is, a winding space, belonging to another part of the winding, intervenes between the adjacent parts of successive coils.

In the multiple windings, in addition to the winding space for another coil of the *same* winding, there must also be included between the adjacent parts of successive coils two winding spaces for each of the *other* windings. Consequently, the difference between the front and back pitches must be $2\,m$. In practice, the front pitch is made less than the back pitch for reasons already given. (Art. **3145.**) Both pitches must be odd, and the front pitch must be opposite in direction to the back pitch.

**3179.** As in the multiple-circuit multiple-wound ring windings, the number of separate reentrant systems formed by the windings will equal the greatest common factor of the number of coils and the number of windings; the number of coils being equal to one-half the number of winding spaces, the number of reentrant systems is equal to the greatest common factor of $\frac{w}{2}$ and $m$. Any even number of winding spaces may be used, whatever the number of poles.

In order to prevent opposing E. M. F.'s in a coil, the number of winding spaces should be about equal to the product of the number of poles and the average of the front and back pitches. (Compare Art. **3156.**) It is usually rather better to make the number of winding spaces a little greater than this product, as in this case the end connections are a little shorter.

**3180.** Fig. 1181 shows a diagram of a four-pole multiple-circuit double-wound drum armature having 20 coils ($w = 40$). The back pitch is taken as $+13$; hence, the front pitch $= -(13 - 2\,m) = -(13 - 4) = -9$. $\frac{w}{2}$ (20) being a multiple of $m$ (2), this gives two separate reentrant systems. A single conductor is represented in each winding space, numbered *1*, *2*, *3*, etc.; the order in which the conductors making up the first of the two windings are connected is indicated by the numbers *1'*, *2'*, *3'*, etc., and the order of connection of the conductors of the second winding is indi-

cated by the numbers *1″*, *2″*, *3″*, etc. Each brush short-circuits a single coil, and the short-circuited conductors

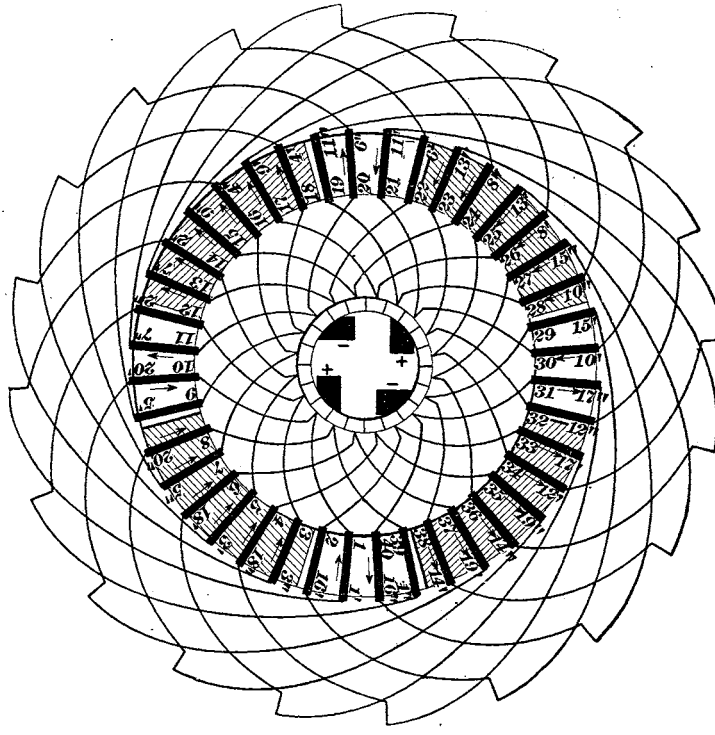

FIG. 1181.

*2*, *9*, *12*, *19*, *22*, *29*, *32*, and *39* are indicated by the absence of the arrow-heads, which on the rest of the conductors indicate the direction of the current in them.

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### MULTIPLE-WOUND TWO-CIRCUIT DRUM WINDINGS.

**3181.** The principles and formulas given for two-circuit single-wound drum windings require only slight modifications to adapt them to this class of windings.

The front and the back pitches being in the same direction may be alike or may differ by 2. In either case, each pitch must be odd; so, if both pitches are alike, the average pitch

must be odd, but if they differ by 2, the average pitch may be even.

In the single-wound two-circuit drum winding it was pointed out that, in passing through the winding, the second winding space to one side or the other of that at which the start was made would be arrived at after passing under each pole in succession, and from this the formula given for the number of winding spaces was derived.

In the multiple-wound two-circuit drum windings, in addition to this one winding space belonging to the *same* winding, two others for each of the *other* windings of the armature must also intervene between the winding space started with and that passed through after making one series of steps around the armature. From this it follows that the total number of winding spaces allowable will be given by the formula

$$w = 2\,p\,y \pm 2\,m, \qquad \textbf{(488.)}$$

$y$ being the *average* pitch, and $p$ and $m$ being the number of pairs of poles and the number of windings, respectively, as before. As in all two-circuit windings, only two brushes are necessary, although two for each pair of poles may be used if desired.

The number of separate reentrant systems formed will be equal to the greatest common factor of $m$ (the number of windings) and $y$ (the average pitch).

**3182.** In Fig. 1182 is shown a diagram of a four-pole, double-wound, two-circuit drum armature, having the same number of coils (20) as the multiple-circuit armature illustrated in Fig. 1181. In this case the pitch, both front and back, is taken as 9, and the number of winding spaces found from formula **488**, as follows:

$$w = 2\,p\,y \pm 2\,m = 36 \pm 4 = 40 \text{ or } 32.$$

In this case 40 winding spaces was the number used. As before, one conductor in each winding space is represented, they being numbered *1*, *2*, *3*, etc. Since the greatest common factor of $y$ (9) and $m$ (2) is 1, this winding results in a

single reentrant system, the order in which the conductors are connected being indicated by the numbers *1'*, *2'*, *3'*, etc. Two brushes are shown, the +brush short-circuiting the coils formed from conductors *13*, *22*, *31*, and *40*, and the —brush short-circuiting the coils formed from conductors *3*, *12*, *21*, and *30*, these being indicated by the absence of the

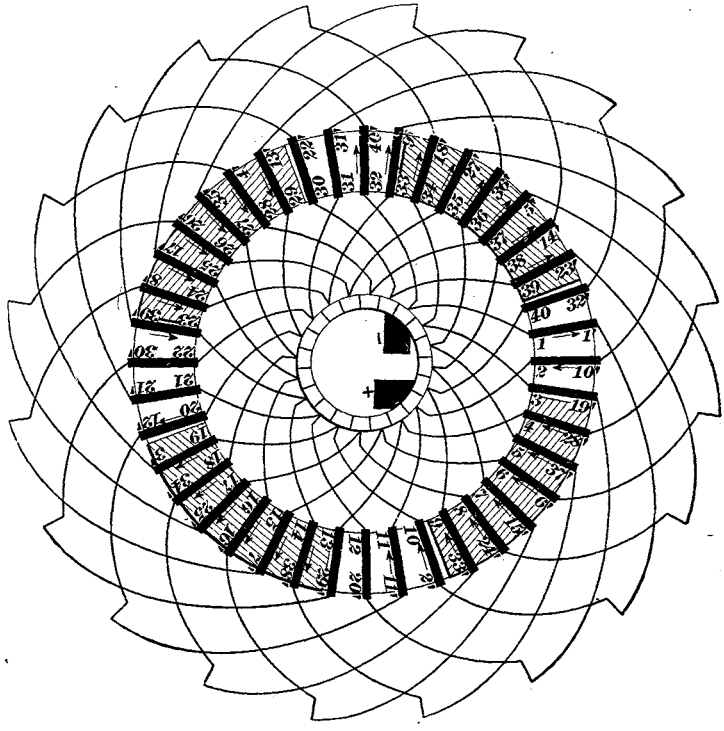

FIG. 1182.

arrows which, with the other conductors, indicate the direction of the current in them. The path of the current through the four circuits of this armature, starting from the — brush, is as follows:

$$-\left\{\begin{array}{l}\left\{\begin{array}{l}1-10-19-28-37-\ 6-15-24-33-2\\32-23-14-\ 5-36-27-18-\ 9\end{array}\right\}\\\left\{\begin{array}{l}39-\ 8-17-26-35-\ 4\\34-25-16-\ 7-38-29-20-11\end{array}\right\}\end{array}\right\}+$$

It will be seen that some irregularity is indicated, owing to the coils short-circuited by the —brush being taken wholly from the second winding. With the necessarily large number of conductors used in practice, the difference between the number of conductors in the different branches of the winding forms such a small percentage of the whole number employed as to make its effect negligible.

**3183.** One of the principal advantages of multiple winding as applied to drum armatures appears when bar windings (a single conductor per winding space, with separate end connections) are used.

In this form of winding, the bars are usually set in slots cut in the periphery of the armature core, and it is very desirable that the number of slots adopted for any particular size of armature be such that they may be used for windings giving different voltages, without change. Thus, for example, of the two windings illustrated in Figs. 1181 and 1182, the two-circuit winding (Fig. 1182) will evidently give twice the E. M. F. that the multiple-circuit winding (Fig. 1181) will with the same number of revolutions and in a magnetic field of the same strength, the only change made in the winding being in the span and arrangement of the end connectors. The same result may be attained by changing the multiple-circuit winding from a multiple-wound to a single-wound armature, which would be accomplished in this case (Fig. 1181) by reducing the back pitch to 11, or increasing the front pitch to —11. The two-circuit winding can not be so changed, however, in a four-pole machine, as an odd number of *coils* is required for the single winding (Art. **3165**); but when the number of pairs of poles is odd, as in a six-pole machine, an even number of coils may be employed for the single winding, and this may be changed to a double winding by changing the end connections, if desired, and the features of the two-circuit winding retained.

**3184.** For example; suppose that, having decided on a certain number of revolutions and a certain number of lines of force in the field, it is found that 358 conductors are

required for a six-pole, single-wound, two-circuit, bar-wound drum armature, to give 500 volts.

From formula **484**, $w = 2\,p\,y \pm 2$, the required pitch may be found; since $w = 358$ and $p = 3$, $358 = 6 \times y \pm 2$, from which $y = \frac{356}{6} = 59.3+$ or $\frac{360}{6} = 60$, which latter value would necessarily be used, fractional pitches being an absurdity. As the front and back pitches must each be odd, to have the average pitch 60, the front and back pitches may be 59 and 61, respectively.

In case it was desired to use the same armature for a 250-volt machine, the same number of conductors might be used, by so changing the pitch as to make a double winding. The proper pitch to use would be found from formula **488**, $w = 2\,p\,y \pm 2\,m$; $w = 358$ as before, $p = 3$, and $m = 2$, and $358 = 6 \times y \pm 4$; hence, $y = \frac{354}{6} = 59$, or $\frac{362}{6} = 60.33+$. 59 would be taken as both front and back pitch. It would thus be only necessary to slightly change the end connectors for the *back* pitch, to use the same armature for either a 250-volt or a 500-volt machine.

## THE MAGNETIC CIRCUIT.

**3185.** As far as the generation of the E. M. F. of the dynamo is concerned, it is only essential that the lines of force of the magnetic field be present at the points where they are cut by the conductors, and have the proper direction and distribution. However, since each line of force is continuous, forming a closed circuit, provision must be made for a complete path for the lines of force to and from the points where they are cut by the conductors, and through the magnetizing coil or coils wherein they are generated. Of course, they might be left to find their own circuit through the surrounding air, but in order to realize the large number of lines of force required with the expenditure of a reasonable amount of magnetizing force, it is necessary that the path of the lines of force be of as great a permeability as possible; i. e., through an iron or steel *magnetic circuit.*

In addition to the armature and its winding, a bipolar or multipolar dynamo must then have an iron or steel *frame*, or *field-magnet*, which completes the magnetic circuit outside the armature. This frame is made up of one or more pairs of *pole-pieces*, from (or into) which the lines of force pass to (or from) the armature through the spaces between the faces of the pole-pieces and the surface of the armature core, which are called the **air-gaps;** it must also have a part upon which the *magnetizing coils* are wound, which part is called the **field core.** The part of the frame that joins together the field cores, if more than one is used, or that joins the pole-pieces and the field cores, is called the **magnetic yoke.**

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## CONSTRUCTION OF FRAME.

**3186.** It will be seen that the object of the frame, as a whole, is to so guide the lines of force that are generated by the current in the magnetizing coils that they will enter and leave the armature at the proper points, forming the magnetic field in the air-gaps of the required distribution and density.

It is not essential to the operation of the machine that the frame be of any given form or size, so long as the lines of force are properly delivered to the armature; economy in materials or labor, mechanical strength, and other considerations determine the form and size of frame to be adopted.

**3187.** Since the magnetic circuit may be considered analogous to the electric circuit, it will be seen that in order to obtain a large number of lines of force with a moderate magnetizing force, the reluctance of the circuit must be low; that is, the iron should be of considerable cross-section and the circuit of moderate length. It should be remembered that, since the permeability of the best of iron is only, perhaps, 1,500 times that of air, a considerable number of lines of force that pass through the magnetizing coil complete their circuit around through the air without passing

through the air-gaps. To reduce this magnetic leakage as far as possible, surfaces between which there is a great difference of *magnetic potential* should be kept as far apart as the design of the magnet will allow, and made of as small area as possible. In any case, some leakage is bound to occur, and this must be provided for by making those parts of the frame through which the leakage lines pass of sufficient area for both the useful and the leakage lines. The conditions which govern the leakage will be more fully discussed later; in general, the area of the iron in the frame must be sufficient for from 15 to 50% more lines of force than are used in the armature.

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### DENSITY OF LINES OF FORCE.

**3188.** Referring to Fig. 952, it will be seen that the saturation curves there shown all rise in a nearly straight line for some distance from *0*, then curve away from the axis of the ordinates and follow another approximately straight line, which makes a much greater angle with the axis of the ordinates than does the first-mentioned line. This effect is much more marked in the case of wrought iron and cast steel than with cast iron, but in any case it will be seen from this feature of the saturation curves that the most economical density at which to work the iron of the magnetic circuit is that in the vicinity of the bend or "knee" of the curve. A much lower density could not be economically used, because a considerable increase in the number of lines of force could be obtained with comparatively little increase in the magnetizing force required; and on this account accidental small changes in the magnetizing force would produce a considerable change in the number of lines of force, so that the magnetic circuit of the machine would be in an *unstable* condition. A much higher density would not be economical, because the increase in the number of lines of force could be obtained only by a very considerable increase in the magnetizing force.

**3189.** Applying these statements to the curves given in Fig. 952, it will be seen that, in general, cast steel and wrought-iron forgings should be worked at densities of between 80,000 and 100,000 lines of force per square inch, while sheet iron may be worked higher, between 90,000 and 110,000 lines of force per square inch. With cast iron, the curves being flatter, the allowable range is somewhat greater, the usual range in practice being from 25,000 to 50,000 lines of force per square inch, the latter value being used only in the case of the best grades of soft, gray cast iron.

The best densities to use are, therefore, not those that give the maximum permeability of the iron used, as at that point the iron would be in the unstable condition referred to previously.

**3190.** From the above and from the curves referred to, it appears that for the same expenditure of magnetizing force a cast-iron magnetic circuit must have about twice the sectional area of one of cast steel or wrought iron, in order to realize the same number of lines of force, so that the cast-iron magnetic circuit would be about twice as heavy as one of steel or wrought iron; its less cost per pound, however, may often counterbalance this extra weight, and, in fact, the choice of materials for the frame, as well as almost all the other features of a dynamo, depends upon the local conditions governing each particular case.

**3191.** The density used in the air-gaps varies, but the best practice fixes it at somewhere in the neighborhood of 30,000 lines of force per square inch; this depends, however, on many other features of the design, as will be pointed out later.

In any case, the amount of the magnetizing force that is required to force the magnetic flux through the air-gaps is a large proportion of the total amount, since the permeability of the air-gaps is 1, which much more than compensates for their comparatively short length.

## FORM OF MAGNETIC CIRCUIT.

**3192.** The form of the magnetic circuit is subject to many variations; there are, however, two general classes into which they may all be divided. In the first, a single source of magnetizing force for each pair of poles (which may reside in one or more magnetizing *coils*) sends the lines of force around through a magnetic circuit, of which the air-gaps and armature directly form a part. Such an arrangement is said to have **salient poles.** In the second type, at least two magnetizing forces are necessary for each pair of poles; these magnetizing forces act in opposite directions upon a complete magnetic circuit, and the opposing lines of force cause consequent poles to appear at points on the magnetic circuit, which points are properly provided with pole-pieces, between which the armature is located. Such an arrangement is said to have **consequent poles.**

**3193.** One of the simplest forms of salient-pole bipolar field-magnets is represented in Fig. 1183. In this form the magnetizing force is supplied by the single coil shown in section at *W* and *W*. This surrounds the field core *C*, to which are attached the magnet yokes *M* and *M*, which terminate in the pole-pieces *N* and *S*. Between these pole-pieces the armature *A* revolves. The mean paths of the lines of force through the magnetic circuit (neglecting leakage lines) are indicated by the dotted lines having the arrow-heads, which indicate the direction of the lines of force, assuming the polarities of the pole-pieces to be as indicated by the letters *N* and *S*. In this figure the field core is represented as being vertical, and this type of magnet is so used in certain machines of English make. It may, however, be either vertical or horizontal, and be above, below, or on either side of the armature, as desired. The Jenney motors, the Wood bipolar machines, the Holtzer-Cabot small motors, and others

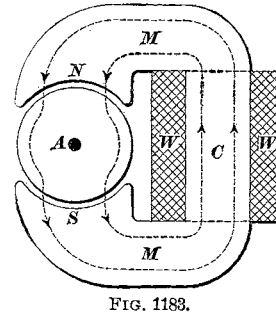

FIG. 1183.

made in this country use this type of magnets with the coil horizontal and below the armature. Further, the armature shaft may either have the direction indicated or be at right angles to that direction, if desired, without changing the character of the field-magnet. The mechanical construction in this last case would evidently be bad, and, in general, this is the principal feature which determines the disposition of the magnet frame with regard to the armature.

**3194.** A form of consequent-pole field-magnet which is derived from that just described is shown in Fig. 1184.

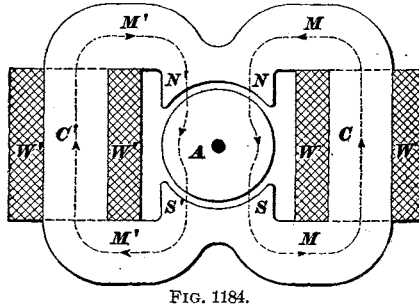


FIG. 1184.

This form of field-magnet is known as the "Manchester type," and is used by the Mather Electric Co., the Westinghouse Co., and others in this country.

This is practically the same form of magnet as that shown in Fig. 1183, with the addition of a second similar magnet situated on the opposite side of the armature $A$, as indicated by the letters $N'$, $M'$, $C'$, $M'$, and $S'$.

Assuming that the same total number of lines of force passes through the armature in each case, it follows that with the consequent-pole magnet (Fig. 1184) each half of the magnetic circuit contains half the total number of lines, and needs, therefore, to be of but half the sectional area of the frame of the salient-pole magnet, which carries all the lines of force, as is indicated by the relative proportions of the two magnets. (See Figs. 1183 and 1184.) Consequently, the weight of the frame in either case is about the same.

**3195.** In the consequent-pole magnet, the magnetic circuit in each half is approximately the same length but of half the area as that of the salient-pole magnet; its reluc-

tance is about twice as great, but since it carries half the number of lines of force, it follows that the magnetizing force required for *each half* of the consequent-pole magnetic circuit is the same as that required for the whole of the salient-pole magnet. However, the magnetizing coils on the consequent-pole magnet are of smaller diameter than those used in the salient-pole magnet, so that the weight of copper used for the magnetizing coils of the former type of magnet is not double that required for the latter type. The actual ratios of weights of copper and iron may be readily calculated for any particular case, but there are other conditions that influence the choice of the form of magnet to be used, which must be taken into account.

**3196.** Fig. 1185 shows the adaptation of these two forms of field-magnets to a multipolar machine. In the figure, the part to the left of the vertical diameter represents the salient-pole magnet, and that to the right represents the consequent-pole magnet, each being laid out as for an eight-pole magnet.

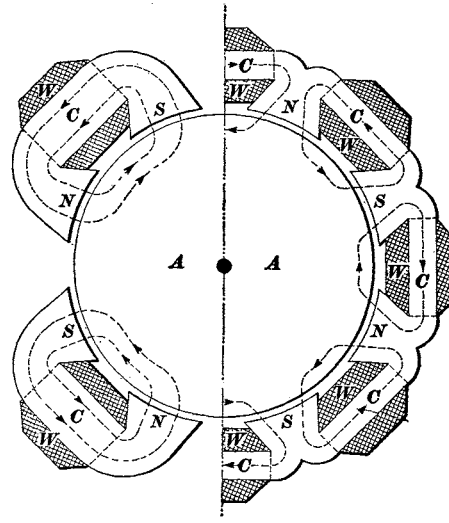

FIG. 1185.

The salient-pole magnet consists of a number of separate magnets, each with its magnetizing coil. It is, therefore, necessary to supply some separate support for these magnets. In the consequent-pole magnet, however, the whole frame is continuous, each pole-piece being supported by a field core on each side, the frame, therefore, being of sufficient mechanical strength for its own support.

In the latter form, the mean length of the magnetic circuit for each pair of poles is less than with the salient-pole magnets, which results in a slight saving in magnetizing force, other things being equal.

Of the above types of magnets for multipolar machines, the salient-pole type is used in the "Perrett" machines, built by the Electron Manufacturing Co., and the consequent-pole type is used by the Standard Electric Co., in this country, and in several types of machines made abroad.

**3197.** The two simple forms of field-magnets which have been described may be considerably modified by changing the position or increasing the number of the field coils. For example, the magnetizing coil of the salient-pole magnet (Fig. 1183) may be wound over the entire frame from pole-piece to pole-piece, as in the "ring-type" machine of the Mather Electric Co. Similarly, the magnetizing coil on each half of the consequent-pole magnet (Fig. 1184) may be wound over the entire frame from pole-piece to pole-piece, as in the "C & C" machines. In both these examples, the field cores are made approximately circular in outline.

Further, by dividing the magnetizing force between two coils, and locating these coils in the part indicated as the magnet yoke in Fig. 1183 (*M* and *M*), a type of field-magnet results which is commonly known as the **horseshoe** type, as illustrated in Fig. 1186. It will be seen that in these two forms the magnet yoke (*M*) of each corresponds to the field core of the other. This type of field-magnet is very extensively used for bipolar machines, the Thomson-Houston, Crocker-Wheeler, Connecticut, Keystone, and other makes of machines using it in the position shown, i. e., with the magnet frame beneath the armature.

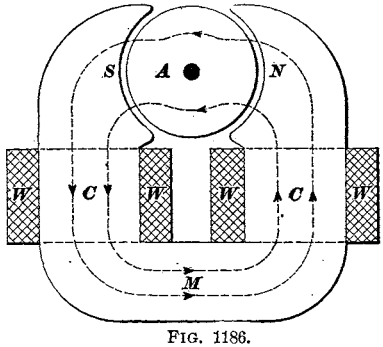

FIG. 1186.

The General Electric Co. in their Edison machines, the Commercial Electric Co., the Eddy Electric Manufacturing Co., and others, use the same form of magnet in the reverse position, i. e., with the magnet frame above the armature.

The Excelsior arc machine employs the same type of magnet, but with the armature shaft parallel to the field cores, passing, therefore, directly through the magnet yoke. The pole-pieces are necessarily modified in shape to suit the changed position of the armature, and are extended to embrace three sides of the armature, which is ring wound.

**3198.** The consequent-pole magnet that results from combining two horseshoe magnets of the types illustrated in Fig. 1186 is shown in Fig. 1187. Here the various letters have the same reference as in the previous figures. As in that previously described, the consequent-pole arrangement requires only half the cross-section of metal in each half of the magnetic circuit, but the total amount used is about the same. This is also a commonly used type of bipolar field-magnet. Among others, it is used in the Wood arc machine of the larger sizes, in the position represented in the figure, i. e., with the field cores (*C*, *C*, *C*, *C*) vertical. The Weston and the Schuyler arc machines use the same form of field-magnet, but with the field cores horizontal, and it has also been used in this same position for various special machines built by the General Electric Co. and others.

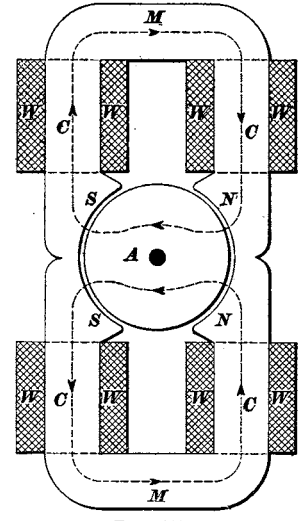

FIG. 1187.

The smaller sizes of the Wood arc machine use this form of magnet with the field cores horizontal, and with the shape of the pole-pieces modified so as to allow of the armature shaft being parallel to the field cores, it passing through and

having its bearings in the yokes (*M* and *M*). The Brush arc machine uses a similar construction, but the armature is made in the form of a ring-wound disk, and the pole faces face the end faces of the armature, as represented in the diagram, Fig. 1188. The magnet in this case might be considered to be two separate bipolar, salient-pole, horseshoe magnets.

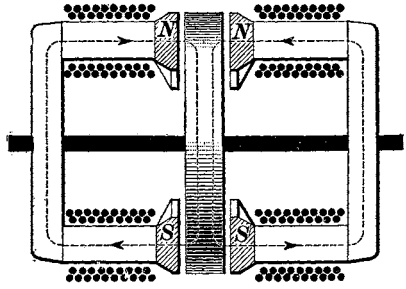


FIG. 1188.

**3199.** By carrying the magnetizing coils still further along the frame, until they are as close as possible to the ends of the pole-pieces, still another type of field-magnet results, as represented in Fig 1189.

As shown, this is a very heavy and clumsy magnet, requiring a large amount of material on account of the length of the magnet yoke, *M M*. If, however, half the material in this yoke be located on the other side of the armature, so that the magnetic circuit through the frame from field core to field core consists of two branches, a much neater and

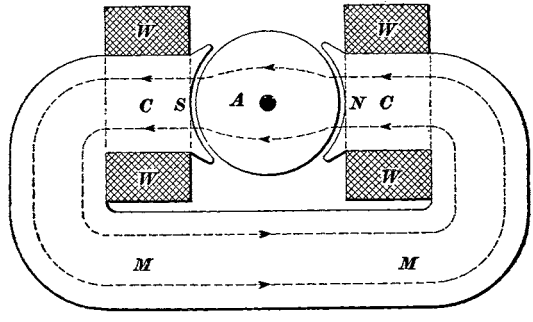


FIG. 1189.

lighter magnetic circuit, that is quite extensively used, results, as represented in Fig. 1190.

This form of circuit still has salient poles, since the poles are produced by the direct action of the magnetizing forces, and not by the opposition of two magnetizing forces.

It has the advantage that the magnetizing coils and armature are enclosed by the frame, thus affording them mechanical protection.

This type of magnet is used (in the position shown) by the makers of the "Detroit" dynamos, by the Western Electric Co., and by others in this country and abroad.

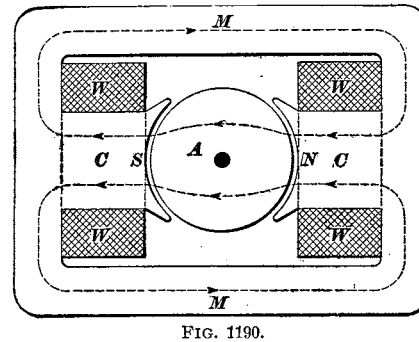

FIG. 1190.

The Thomson-Houston arc-lighting dynamos also employ this type of field-magnet, the form being modified by making the magnet yokes of a series of round, wrought-iron bars, which connect together circular flanges on the ends of the field cores, thus making the general outline cylindrical.

Eickemeyer has used it for very compact machines in which the magnetizing coils actually enclose the armature, the field cores being very short.

The same form of magnet, but with the magnetizing coils above and below the armature, was used in the old Hochhausen dynamos, also by the Thomson-Houston Company for their old "S. R. G." railway motors, and by others.

**3200.** With this arrangement of the magnetizing coils, a consequent-pole bipolar magnet is not possible; but by reversing one of the coils so that the two magnetomotive forces are opposite, two consequent poles will be formed on the magnet yokes *M* and *M*, Fig. 1190, at a point opposite the neutral spaces of the bipolar form; and by locating

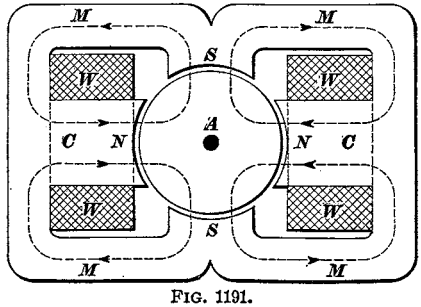

FIG. 1191.

suitable pole-pieces at these points, a four-pole magnet results, as represented in Fig. 1191. It will be seen that this magnet has one pair of salient poles *N* and *N*, and one pair of consequent poles *S* and *S*. This gives a very compact form of four-pole magnet, and is used in several types of railway motors, in the "Eddy" slow-speed stationary motors, and by other makers. The "Wenstrom" dynamos also employ a somewhat modified form of this type of field-magnet, the magnet yoke being barrel-shaped and completely enclosing the magnetizing coils and pole-pieces, spaces being left in the sides for the removal of the armature.

**3201.** By winding magnetizing coils around the consequent poles of the type of magnet illustrated in Fig. 1191, they become salient poles, giving still another type of field-magnet, illustrated in Fig. 1192. The same letters of reference are used in this figure as in the previous ones.

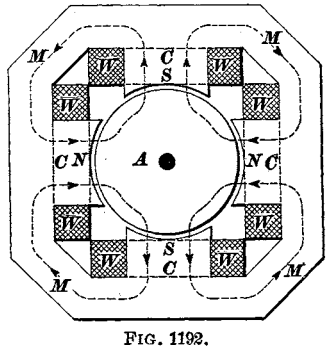


FIG. 1192.

This is a very useful form of field-magnet, and is that most generally used in this country for multipolar machines of any number of poles, almost every maker using it for multipolar generators and alternators.

The various magnet yokes form a complete ring, which is often, especially when six or more poles are used, made circular in outline. A modification of this form of magnet is used by the Siemens & Halske Company, in which the field cores project radially outward from a common hub, instead of inward, the armature revolving outside the poles of the magnet.

**3202.** The number of possible forms of field-magnets is very great, although they may all be classed as either salient or consequent pole magnets, or combinations of the two. Many of the forms of magnets which have been and

are used seem to have been designed merely with a view to getting something different from any other maker, and considerations of economy of material or of mechanical fitness, which should prevail in the selection of a design, have been largely neglected. These forms described are the basis of the designs of field-magnets in modern construction.

## METHODS OF EXCITING THE FIELD.

**3203.** The requisite number of ampere-turns for exciting the field of a dynamo-electric machine may be obtained in a variety of ways. In the first place, the current which flows through the magnetizing coils may come either from some separate external source, the machine being then said to be **separately excited,** or it may be furnished by the armature of the machine itself, it being then said to be **self-excited.** In some cases a combination of separate and self-excitation may be used. A diagram illustrating separate excitation is given in Fig. 1193. The current required is in this case supplied by the primary or secondary battery *B*, although another dynamo may be used, if desired. In order to adjust the current in the magnetizing coils to the proper value, or to vary it if necessary, an adjustable resistance *r* is included in the field circuit.

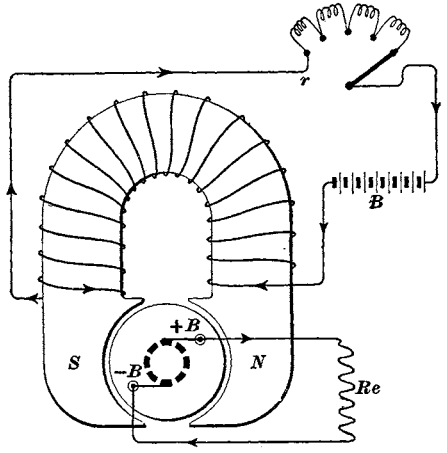

FIG. 1193.

The armature has no connection whatever with the field circuit, but supplies the external circuit, *Re*, directly.

**3204.** It is evident that with self-excitation a small or a large current may be used in the magnetizing coils, accord-

ing to the nature of the source of the current, a large or a small number of turns being used in the magnetizing coils to give the necessary magnetizing force.

Alternators are usually separately excited, since the current given out by the machine, being alternating, can not be used directly for the purpose. Separate excitation has also the advantage that variations of the output of the armature of the machine, caused by changes in the speed or of the current, do not directly affect the field excitation.

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### SERIES WINDING.

**3205.** There are three general methods by which self-excitation is accomplished. In the first, the whole of the current flowing through the armature also flows through the magnetizing coils; such a machine is said to be **series wound,** from the fact that the armature and magnetizing coils are connected in series. This arrangement is represented in the diagram shown in Fig. 1194.

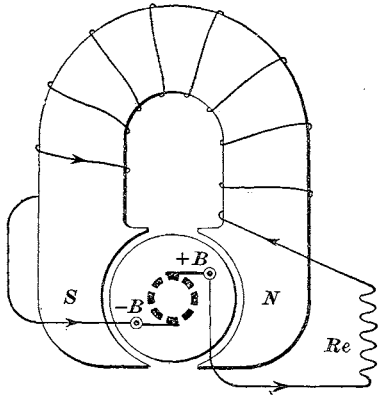


FIG. 1194.

With this arrangement, the magnetizing force acting on the magnetic circuit, consequently the number of lines of force in the magnet, varies with the current which the machine furnishes to the external circuit; therefore, when the armature is running at a constant speed, the E. M. F. which is generated in it varies as the current varies, though not necessarily in the same proportion. This is not usually desirable, since most applications of direct current require that either the E.M.F. or the current be maintained approximately constant.

**3206.** To realize either of the above conditions in a series-wound dynamo, it is necessary to adopt some method

of regulation, whereby either the effect of variations in the current on the magnetizing force of the field may be neutralized or the *effective* E. M. F. of the armature may be altered to suit the conditions. The former result may be obtained by placing an adjustable resistance in parallel with the magnetizing coil, as represented in Fig. 1195. In this diagram, $S\,F$ represents the magnetizing coil, or series field, and $R$ is the adjustable resistance, connected in parallel with the magnetizing coil, as described. It will be

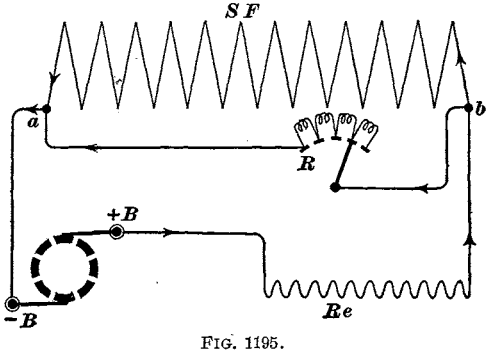


FIG. 1195.

seen that the current divides between the two branches of this part of the circuit, and by varying the resistance $R$ the proportion of the whole current that flows through the magnetizing coil $S\,F$ may be varied as required.

The method of varying the effective E. M. F. that is used in the Thomson-Houston open-coil armature has already been described (Art. **3086**). Another method of accomplishing the same result with closed-coil armatures is to shift the brushes away from the neutral point, which entails special construction and precautions against destructive sparking, etc.

**3207.** Series winding is very little employed in dynamos, except for machines designed to give a constant current, such as is used for operating lamps or other devices that are connected in series. For motors, however, series winding is very useful, since when starting up under heavy load, or whenever taking a current in excess of the normal

amount, the field strength is increased, which increases the amount of the reaction between the armature winding and the field, that is, increases the turning force of the armature.

### SHUNT WINDING.

**3208.** The second method of self-excitation consists of forming a separate circuit of the magnetizing coils, which are connected directly between the brushes, or in shunt to the external circuit, this style of winding being, therefore, known as **shunt winding.** This is illustrated in Fig. 1196. It will be seen that the magnetizing-coil circuit is in a measure independent of the external circuit (*Re*), it being exposed at all times to the full difference of potential that exists between the brushes ($+B$ and $-B$); from this it follows that changes in the current flowing in the external circuit do not affect the magnetizing force acting on the field, except as they may change the difference of potential between the brushes. Changes in the current of the external circuit do affect this quantity in several ways, namely, by varying the drop due to the resistance of the

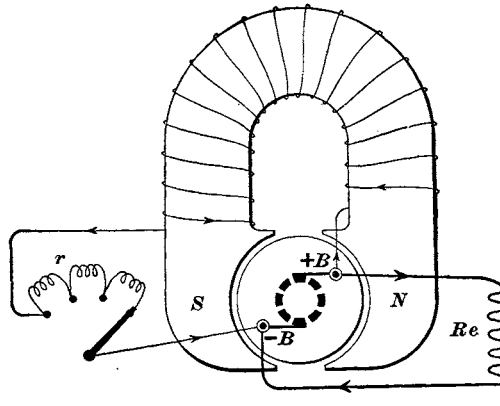


FIG. 1196.

armature winding, by varying the counter magnetomotive force of the armature winding, and by varying the length of the path of the lines of force by the variations in the amount by which they are distorted by the cross magneto-

motive force. (See Arts. **3115** and **3118.**) This last is comparatively unimportant, but the other two require careful consideration in the design of dynamo machinery, as will be pointed out.

**3209.** In a shunt-wound motor the conditions are different, the magnetizing-coil circuit being supplied directly from the mains; the magnetomotive force then depends simply upon the difference of potential between the supply mains, which is usually kept constant, so that in general a shunt-wound motor may be considered to have a constant magnetizing force acting on its field-magnet.

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### COMPOUND WINDING.

**3210.** From the above statements it will be seen that in order to maintain a constant difference of potential between the brushes of a dynamo (assuming a constant speed), the magnetomotive force of the magnetizing coils must be increased as the current increases, both to increase the number of lines of force so as to increase the E. M. F. generated, and to make up for the counter magnetomotive force of the armature winding. One way to accomplish this result is to place an adjustable resistance ($r$, Fig. 1196) in the magnetizing-coil circuit, which may be gradually cut out as the current output increases, thus reducing the resistance of the magnetizing-coil circuit, and increasing thereby the current flowing through it. This, however, requires personal attention, automatic devices for varying the resistance not being satisfactory, and in case the current from the dynamo fluctuates rapidly, it is difficult to operate the resistance with sufficient rapidity. Since the amount by which the mag-

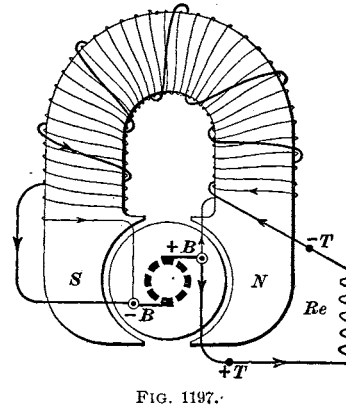


FIG. 1197.

netomotive force of the magnetizing coils must be varied is closely proportional to the current flowing, which follows from the nature of the causes which require the variation, it is possible to obtain the required variation by providing additional magnetizing coils through which the main current passes. This is known as **compound winding,** and is illustrated in Fig. 1197.

**3211.** It is evident that this is a combination of series and shunt winding, the shunt winding furnishing a constant magnetizing force and the series winding an additional magnetizing force which is proportional to the current output of the machine. This latter winding is so proportioned that it furnishes the proper increase in the magnetomotive force, as the current increases, to make up for the dropping off of the difference of potential between the brushes that would otherwise occur. For certain classes of work, a little more than this amount is provided, so that the difference of potential between the brushes rises slightly as the current output increases. In such a case the machine is said to be **over-compounded.**

**3212.** Compound winding is seldom used for motors, as either a series or a shunt winding serves for almost all conditions of operation. Nevertheless, for application to such machinery as printing-presses, a compound winding is extremely useful, as the series turns produce a powerful field at starting and at slow speed, and they may gradually be cut out or connected in various combinations to produce different working speeds without the necessity of inserting an external resistance in the armature circuit, except for starting up, when a resistance may be temporarily used.

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### BUILDING UP THE FIELD.

**3213.** Any iron, after being magnetized, retains a certain amount of residual magnetism, so that there will be a small E. M. F. generated in the armature winding when the armature is rotated and the field circuit left open; this

is utilized to start the current in the magnetizing coils. In the case of a shunt-wound dynamo, when the machine is started and the magnetizing-coil circuit closed, the small E. M. F. generated in the armature by the residual magnetism sends a small current through the magnetizing coils, producing a small magnetizing force. If this magnetizing force tends to send lines of force through the magnetic circuit in the *same* direction as the residual magnetism, the number of lines of force will be increased; this will increase the E. M. F., which increases the current in the magnetizing coils, and still further increases the number of lines of force and the E. M. F., which process continues until further increase in the magnetizing force results in so little increase in the number of lines of force that the E. M. F. generated becomes steady, the windings being so designed that this shall be the E. M. F. at which it is desired to run the machine.

It will be seen that if the external circuit is open, all of the current that the E. M. F. (due to the residual magnetism) produces flows through the magnetizing coils; if, however, the external circuit is closed, only a part of the current flows through the magnetizing coils, so that the field will "build up" more slowly than with the external circuit open, and, in fact, will not build up at all if the external resistance is low as compared with the armature resistance. From this it follows that a shunt-wound machine should be started up with its external circuit open.

A series-wound machine, on the contrary, must have its external circuit closed in order that any current may flow through the magnetizing coils, and the lower the resistance of the external circuit the more quickly will the machine build up.

From the above it will be seen that a compound-wound dynamo may be started with its external circuit either open or closed, since it has both series and shunt wound coils. Usually, however, such machines are started and brought to their full E. M. F. with the external circuit open.

**3214.** At starting, while the current is increasing in the magnetizing-coil circuit, the inductance of the magnetizing coils increases its apparent resistance, and a part of the energy supplied to the coils is stored up in the magnetic field which is being established. As soon as the current in the magnetizing coils reaches its maximum value, however, and so long as it remains constant at this value, there is no reactance present, and the entire amount of energy delivered to the coils is expended in heating the wire; that is, it requires (directly) no energy to *maintain* a magnetic field at a constant value, the field depending on the *ampere-turns* that are acting on the magnetic circuit. It is obvious, however, that in order to force the current through the wire of which the magnetizing coil is composed, energy must be expended, but this energy appears *entirely* as heat, and, consequently, is wasted as far as any practical application of it is concerned. The number of watts expended in sending the current through the magnetizing coils should, therefore, be made as small as the design of the machine will permit, both to prevent any excessive waste of energy and to prevent possible damage by the heat liberated. In practice, the loss of energy from this cause varies from about 2 per cent. of the total output of the machine in larger sizes, to 5 or more per cent. in the smaller.

**3215.** In shunt-wound machines the magnetizing coils are exposed to the full difference of potential that exists between the brushes of the machine, and, consequently, should use only a small amount of current in order that the loss in watts should be the required small percentage of the output. From this it follows that the wire used for the magnetizing coils should be of small size and of considerable length, making a large number of turns around the magnets, both to give the necessary resistance to keep the current at its proper value and to allow of this small current furnishing the requisite number of ampere-turns. In series-wound machines, however, as the total current flowing gives the magnetizing force, the magnetizing coils need to have com-

paratively few turns, which should be of correspondingly large wire, in order that the watts loss (which is equal to $C^2 R$) should be kept within the desired limits.

It will be seen that in series-wound dynamos the difference of potential between the *terminals* of the machine is less than that which appears between the brushes by the amount of the drop in the magnetizing coils.

The above remarks concerning the magnetizing coils of shunt and series wound dynamos also apply to those of compound-wound machines, since they are made up of a shunt and a series winding.

A SERIES

OF

# QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN VOL. III.

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It will be noticed that, although the various questions are numbered in sequence from **959** to **1429,** inclusive, these questions are divided into eight different sections, corresponding to the eight sections of the preceding pages of this volume. Under the heading of each section are given, in parenthesis, the numbers of those articles which should be carefully studied before attempting to answer any question or to solve any example occurring in the section.

# MACHINE DESIGN.

(ARTS. 1901–2003.)

(959) What procedure is adopted in estimating the cost of making a machine?

(960) What is a shrink rule, and why is it used?

(961) (*a*) What are chilled castings? (*b*) What is the chief difficulty encountered in using cast iron?

(962) (*a*) Name the different kinds of screw threads. (*b*) Describe the United States standard (U. S. S.) thread.

(963) Calculate the diameter at the bottom of the thread for the following U. S. S. screws: $\frac{1}{2}''$, $\frac{7}{8}''$, $1\frac{1}{4}''$, and $2''$ diameter.

(964) (*a*) Calculate the number of threads per inch for the following U. S. S. screws: $\frac{1}{4}''$, $\frac{5}{8}''$, $1''$, and $1\frac{1}{2}''$ diameter. (*b*) What is the pitch in each case?

(965) (*a*) What is the object of using multiple-threaded screws? (*b*) If a triple-threaded screw has a pitch of $\frac{1}{2}''$, what is the divided pitch?

(966) Why are triangular threads more suitable for fastenings than square threads?

(967) Calculate the nominal diameter of a wrought-iron bolt subjected to a varying tensile stress of 11,800 lb.

SUGGESTION.—See Table 28, for proper factor of safety.

Ans. $1\frac{1}{2}''$.

(968) Calculate the diameter of the bolt in the last example by taking the value of $S_t$ as 6,000 lb., as recommended in Art. **1935.** Can you suggest any reason why the diameter here obtained should be used instead of that obtained in example 967?

(969) Find (*a*) the outside diameter; (*b*) the diameter at the root, and (*c*) the number of threads in the nut for a single square-threaded screw to transmit motion to a load of 12,000 lb.

Ans. (*a*) $2\frac{1}{2}''$. (*b*) $2''$. (*c*) 10 threads.

(970) Calculate the various dimensions of a finished bolt and hexagonal nut, with washer, the bolt being $\frac{7}{8}''$ in diameter and $4''$ long under the head. Make a full-sized drawing showing nut on bolt and the bolt threaded for $1\frac{3}{4}''$ of its length. Show a hexagonal bolt head.

(971) Make a drawing of a wrench similar to that shown at *A*, Fig. 606, which will fit the nut in example 970. Take length of wrench as $16''$. Draw to a half size scale.

(972) A wrought-iron eye bolt, similar to that shown in Fig. 612, is subjected to a varying tensile stress of 2,500 lb. Calculate the values of $a$, $b$, $d$, and $d_1$. (See Table 28, for factor of safety.)

(973) (*a*) What is the object of using a jam-nut? (*b*) For what reason should the smaller nut be placed at the bottom?

(974) Make a drawing of the locking device shown in Fig. 623 to a full size scale, taking the diameter of the bolt as $1''$.

(975) What keeps the nut from turning in the devices shown in Figs. 628 and 629? Is not the principle the same in both? If so, why?

(976) Make a drawing of the knuckle joint shown in Fig. 642. Take $d$ equal to $1\frac{1}{4}''$, and make drawing half size.

(977) Calculate the dimensions of an ordinary sunk key for a shaft $4''$ in diameter. Ans. $1'' \times \frac{11}{16}''$.

(978) Calculate the dimensions of a key for a $12''$ shaft by formula **233.** Ans. $3'' \times 2''$.

(979) Calculate the dimensions of a key for a driving pulley on a $2\frac{7}{16}''$ shaft. Ans. $\frac{11}{16}'' \times \frac{7}{16}''$.

(980) Calculate the dimensions of a feather key for a shaft $1\frac{1}{2}''$ in diameter. Ans. $\frac{1}{4}'' \times \frac{3}{8}''$.

(981) A pulley transmitting 1.85 H. P. is keyed to a $2\frac{7}{16}''$ shaft running at 110 revolutions per minute. Calculate the dimensions of a key for this pulley. Ans. $\frac{7}{16}'' \times \frac{1}{4}''$.

(982) Make a drawing of a rod, cotter, and socket (all of wrought iron) similar to that shown in Fig. 658, assuming that $S_t = 6{,}000$ lb. per sq. in., and the load or pull on the rod = 7,000 lb. Make drawing half size, and take taper of cotter as $\frac{1}{3\frac{1}{2}}$.

(983) Find the diameter and length of a steel end journal supporting a load of 5 tons. Take $S_f$ as 14,000 lb. per sq. in. and the pressure per square inch of projected area as 400 lb. Ans. $3'' \times 8\frac{3}{8}''$.

(984) What should be the diameter and length of a neck journal for a steel shaft which is subjected to a total load of 15,000 lb.? Take $p$ as 1,200 lb. per sq. in. of projected area and $S_f$ as 14,000 lb. per sq. in. Ans. $2'' \times 6\frac{1}{4}''$.

(985) The diameter and length of a certain journal were calculated to be $1\frac{1}{2}''$ and $2\frac{1}{8}''$, respectively. For certain reasons it was desired to increase the length to $2\frac{1}{2}''$; what should be the new diameter? Ans. $1\frac{19}{32}''$.

(986) An 8″ shaft is subjected to a thrust of 15,000 lb. Assuming 6 collars to be used, find the diameter and thickness of each. Ans. $10\frac{7}{8}''$ and $1\frac{3}{16}''$.

(987) Find the diameter of a cast-iron pivot journal which supports a load of 1,200 lb., and turns at the rate of 90 R. P. M. Ans. $2\frac{7}{16}''$.

(988) (*a*) Find the diameter to which a 10″ solid steel shaft should be increased in order that it may have a hole through it and still be of the same strength, assuming the hole to be four-sevenths of the outside diameter. (*b*) What is the diameter of the hole? (*c*) What is the difference in weights per foot in length of the two shafts?

Ans. { (*a*) $10\frac{3}{8}''$, nearly. (*b*) 6″, nearly. (*c*) 76 lb.

(989) (*a*) Determine the pitch of a screw with triangular threads and a diameter of $3\frac{1}{4}''$; (*b*) of a screw $7''$ in diameter, with square threads; (*c*) of a screw $12''$ in diameter, with trapezoidal threads.

Ans. (*a*) .3″. (*b*) 1.4″. (*c*) 1.6″.

(990) (*a*) In each of the cases of the last example, determine the number of threads per inch. (*b*) Calculate, also, the diameter of bolt at roots of thread.

Ans. (*b*) (*a*) $2\frac{7}{8}$. (*b*) $5\frac{5}{8}''$. (*c*) $9\frac{9}{16}''$.

(991) (*a*) Explain fully by diagram or otherwise the relation between the angle of the thread, the friction between thread and nut, and the force tending to burst the nut. (*b*) For what purposes are the triangular, the square, and the trapezoidal threads best adapted, and why?

(992) What should be the diameter of a wrought-iron bolt subjected to a load varying from zero to 15,600 lb.?

Ans. $2\frac{1}{4}''$.

(993) What steady load may be safely carried by two bolts, each $4''$ in diameter? Ans. 80 tons.

(994) (*a*) Calculate the outside diameter of the lead screw of a lathe which transmits motion against a pressure of 3,600 lb. (*b*) Calculate the necessary number of threads in the nut.

Ans. (*a*) $1\frac{3}{8}''$. (*b*) 10 threads.

(995) Design and draw, full size, a finished bolt with square head and hexagonal nut, the bolt being $6''$ long and subjected to a varying load of 3,200 lb.

(996) Calculate the proportions of the locking arrangement shown in Fig. 625, assuming the diameter of the bolt to be $3\frac{1}{2}''$. Draw it half size.

(997) (*a*) Calculate the breadth and thickness of a sunk key for a shaft $3\frac{1}{2}''$ in diameter; (*b*) for a shaft $5''$ in diameter; (*c*) for a shaft $1\frac{1}{2}''$ in diameter.

Ans. (*a*) $\frac{7}{8}'' \times \frac{9}{16}''$. (*b*) $1\frac{1}{4}'' \times \frac{13}{16}''$. (*c*) $\frac{3}{8}'' \times \frac{1}{4}''$.

(998) A fly-wheel transmitting 1,000 H. P. at 50 R. P. M. is keyed to a shaft 10″ in diameter by two steel keys, each 10″ long. Calculate the size of the keys. Ans. $2'' \times 1\frac{3}{8}''$.

(999) A pulley keyed to a shaft $4\frac{1}{2}''$ in diameter drives another pulley keyed to a shaft $2\frac{3}{4}''$ in diameter. Calculate the widths and thicknesses of the two keys by formulas **234** and **235.** Ans. { Driving pulley, $1\frac{1}{16}'' \times \frac{5}{8}''$. Driven pulley, $\frac{5}{8}'' \times \frac{7}{16}''$.

(1000) Calculate the dimensions of a sliding feather key for a shaft $1\frac{3}{4}''$ in diameter. Ans. $\frac{5}{16}'' \times \frac{3}{8}''$.

(1001) A pulley transmitting 6 H. P. is keyed to a shaft $3\frac{3}{4}''$ in diameter, making 135 R. P. M. Find the breadth and thickness of the sunk key. Ans. $\frac{3}{8}'' \times \frac{5}{8}''$.

(1002) A wrought-iron rod is fastened by means of a gib and cotter into a wrought-iron socket in the same manner as shown in Fig. 656. The rod is to sustain a steady pull of 6,000 lb. Design and make a drawing. Assume a taper of $\frac{1}{24}$, and take $S_t$ as 6,000 lb. per sq. in.

(1003) Two straps each $3\frac{1}{2}''$ wide and $\frac{3}{4}''$ thick are fastened to a rod 3″ deep by a cotter and two gibs. Design the cotter and gibs and make a drawing of the arrangement. Taper to be $\frac{1}{24}$. See Fig. 661.

(1004) A wrought-iron rod is fastened by a steel cotter. The diameter of the rod is $2\frac{1}{2}''$. Calculate the dimensions of the cotter. Ans. $2\frac{1}{2}'' \times \frac{5}{8}''$.

(1005) A wrought-iron piston rod is $3\frac{1}{2}''$ in diameter where it passes through the piston. Which method will leave the rod the stronger to resist tensile stress, cutting a standard thread and using a nut, or using a cotter?

(1006) (*a*) Find the diameter and length of a cast-iron end journal subjected to a load of $2\frac{1}{2}$ tons, assuming the length to be $1\frac{1}{2}$ times the diameter, and the safe stress 4,250 lb. per sq. in. (*b*) What is the pressure per square inch of projected area? Ans. { (*a*) $3'' \times 4\frac{1}{2}''$. (*b*) 370 lb.

(1007) Find the diameter and length of a wrought-iron end journal bearing a load of 5 tons, assuming the length

equal to the diameter, and a safe stress of 8,500 lb. per sq. in. Ans. $2\frac{1}{2}'' \times 2\frac{1}{2}''$.

(1008) Calculate the dimensions of a steel end journal subjected to a load of 17,800 lb.; direction, variable. The bearing pressure is not to exceed 750 lb. per sq. in. of projected area. Ans. $3\frac{5}{8}'' \times 6\frac{1}{2}''$

(1009) Calculate the dimensions of a wrought-iron end journal sustaining a load of 1,750 lb.; direction, constant. The pressure per square inch of projected area is not to exceed 275 lb. Ans. $1\frac{5}{8}'' \times 4''$.

(1010) Calculate the dimensions of a wrought-iron end journal, assuming the length to be twice the diameter and the bearing pressure not to exceed 550 lb. per sq. in. The load on the journal is 3,750 lb. Ans. $1\frac{7}{8}'' \times 3\frac{3}{4}''$.

(1011) Calculate the dimensions of the steel journal of a car axle bearing a load of 10,000 lb., which may be considered variable in direction on account of the spring of the car. Speed of car is 40 miles per hour; diameter of truck wheel, $2\frac{3}{4}$ ft., and the allowable bearing pressure is $p = \frac{220{,}000}{N}$, where $N$ is the number of revolutions per minute. Design and draw the journal.

(1012) (*a*) Calculate the dimensions of a wrought-iron neck journal, assuming the length equal to $2\frac{1}{2}$ times the diameter. The load is 9,600 lb., variable in direction. (*b*) What is the pressure per square inch of projected area?

Ans. { (*a*) $2\frac{1}{8}'' \times 5\frac{5}{16}''$, say $5\frac{1}{4}''$. (*b*) 860 lb. per sq. in.

(1013) Find the diameter of a wrought-iron pivot running in gun-metal bearings, the load being 25 lb. and the number of revolutions 3,000 per minute. Ans. $1\frac{1}{8}''$.

(1014) What should be the diameter of a steel pivot (on gun-metal bearings) carrying a load of $4\frac{1}{2}$ tons and making 65 R. P. M.? Ans. $4\frac{3}{4}''$.

(1015) A shaft 6″ in diameter receives an end thrust of 7,800 lb. on 4 collars. Find the diameter and thickness of collars. Draw the portion of the shaft with collars. Scale $3'' = 1'$,

(1016) Calculate the diameter of a steel engine shaft 8 ft. long carrying a fly-wheel weighing 10 tons; the center of the wheel is 3 ft. from the center of one of the bearings. The engine develops 300 H. P. at 60 R. P. M., has a stroke of 48″, and a M. E. P. of 62 lb. per sq. in. Assume $S_s =$ 9,000 lb. per sq. in. Ans. $8\frac{1}{4}''$.

(1017) A line-shaft is required to transmit 90 H. P. at 110 R. P. M. The average bending moment, due to weights of pulleys, belt pull, etc., is about $\frac{3}{4}$ of the twisting moment. Assuming a wrought-iron shaft and a safe stress of 7,000 lb. per sq. in., find the diameter of the shaft. Ans. $4\frac{1}{4}''$.

(1018) The inner diameter of a hollow shaft is 6″, the outer diameter 13″. Find the diameter of a solid shaft of the same material and having the same strength. Ans. $12\frac{13}{16}''$.

(1019) In designing a propeller shaft, it is found that the proper diameter of a solid steel shaft is $16\frac{3}{4}''$. It is desired, however, to make the shaft hollow. Assuming the diameter of the hole to be $\frac{1}{2}$ the diameter of the shaft, find the inside and outside diameters of the hollow shaft. Ans. $\begin{cases} d_1 = 17\frac{1}{8}''. \\ d_2 = 8\frac{9}{16}''. \end{cases}$

(1020) Design and draw a universal joint for shafts $1\frac{1}{4}''$ in diameter. Draw full size.

(1021) Design and draw a flange coupling for a shaft $3\frac{1}{4}''$ in diameter. Draw half size.

(1022) Calculate the following for the solid flange coupling of a propeller shaft 11″ in diameter: (*a*) Number of bolts; (*b*) diameter of bolts; (*c*) diameter of bolt circle; (*d*) diameter of flange; (*e*) thickness of flange. See Fig. 674.

Ans. $\begin{cases} (a)\ 6 \text{ bolts}. \\ (b)\ 2\frac{5}{8}''. \\ (c)\ 16\frac{1}{4}''. \\ (d)\ 22\frac{3}{16}''. \\ (e)\ 3\frac{1}{4}'', \text{ nearly}. \end{cases}$

(1023) A wrought-iron pivot runs at a speed of 600 R. P. M. in gun-metal bearings. The load being 100 lb., what should be the diameter? Ans. 1″.

# MACHINE DESIGN.

(ARTS. 2004–2074.)

(1024) For what purpose are bearings bushed?

(1025) For what reason are ball and socket bearings used?

(1026) A cast-iron gear makes 120 R. P. M. and transmits 20 H. P. If the pitch diameter is 30″, what should be (*a*) the circular pitch, and (*b*) the number of teeth?

Ans. { (*a*) 1.2401″. (*b*) 76 teeth.

(1027) Compute the leading dimensions for a spur gear, working under the following conditions: Diameter of pitch circle = 4 ft. 8″; revolutions per minute = 60; horsepower transmitted = 300.

(1028) Suppose a friction wheel faced with wood to drive another 6 ft. in diameter, at 110 revolutions per minute, the force pressing the wheels together being 280 lb. Take $f$ equal to $\frac{1}{3}$ and calculate the horsepower. Ans. 5.864 H. P.

(1029) What is meant by counterbalancing a pulley?

(1030) (*a*) What is the diameter of wires composing a 1″ wire rope containing 42 wires? (*b*) What is the weight of this rope per foot of length?

(1031) What is the safe load for a crane chain, the links being forged from $1\frac{1}{4}$″ round iron? Ans. 10,312.5 lb.

(1032) When using divided bearings, how should the brasses be divided?

(1033) Design and draw a pedestal similar to the one described in Art. **2014**, and shown in Fig. 692, taking $d$ equal to 14″, and using a scale of 3″ = 1 ft.

(1034) Of what materials are gears usually made?

(1035) How many arms should be given a gear having a diameter of 56″ and a diametral pitch of $1\frac{1}{4}$″? Ans. 6 arms.

(1036) For what purposes may friction gearing be used?

(1037) When transmitting power by means of a hemp rope, what should be the ratio between the diameter of the pulley and that of the rope?

(1038) What should be the least value for the ratio of the diameter of a wire rope pulley to that of the rope?

(1039) What are gaskets, and for what are they used?

(1040) What are the seats or steps of a bearing, and for what purpose are they used?

(1041) For what purpose are loose disks used in connection with pivot bearings?

(1042) Design a pedestal similar to the one described in Art. **2011.** Take $d$ equal to $3\frac{1}{2}$″, and use a scale of 6″ = 1 ft.

(1043) (*a*) What is a hanger? (*b*) A wall bracket?

(1044) A cast gear 44″ in diameter is to transmit 21 H. P. when making 50 R. P. M. What should be the least breadth of the teeth? Ans. $2\frac{1}{8}$″.

(1045) The circular pitch of a 24″ worm wheel is .5236″; if the worm has 4 threads, what is the efficiency? Take diameter of worm as $2\frac{1}{2}$″. Ans. 62.62%.

(1046) (*a*) Of what materials are belts made? (*b*) For what situations are rubber belts preferred?

(1047) What should be the least thickness of the rim of a crowning belt pulley having a diameter of 52″ and a breadth of 10″? Ans. $\frac{3}{8}$″.

(1048) The distance between two wire rope pulleys is 420 ft. What will be the deflection of the rope midway between the pulleys, if the rope is $\frac{7}{8}$″ in diameter, is composed of 42 wires, and the tension due to its weight is 2,023 lb.? Ans. 12 ft.

(1049) What is considered to be the greatest safe rim speed of a cast-iron pulley?

(1050) What are the advantages claimed for rope belting?

(1051) What horsepower may be transmitted by a rope wheel 18 ft. in diameter which is grooved for 24 turns of $1\frac{1}{4}''$ rope? R. P. M. = 72. Ans. 484.32 H. P.

(1052) The deflection of a $1\frac{1}{4}''$ wire rope having 42 wires is 9 ft. 3″; the distance between the pulleys being 386 ft., what is the tension due to the weight of the rope?

Ans. 4,511 lb.

(1053) Calculate the dimensions of the plate link gearing chain for a working load of 5,600 lb.

(1054) Design a wall bracket similar to the one described in Art. **2019.** Take $d$ equal to $2\frac{1}{2}''$, and use a scale of $6'' = 1$ ft.

NOTE.—Pay particular attention to the last sentence of Art. **2019.**

(1055) A gear-wheel 40″ in diameter has 6 arms and a diametral pitch of $1\frac{1}{2}$. The breadth of the teeth being 6″, find the dimensions of the arms. Consider the arms as being elliptical in cross-section.

(1056) Power is transmitted by a $\frac{3}{4}''$ iron rope having 42 wires. Find ($a$) the horsepower transmitted when the speed of the rope is 5,000 ft. per min., distance between pulleys is 425 ft., and the diameter of the pulleys is 13 ft. ($b$) Find the greatest deflection in the rope.

Ans. { ($a$) 189 H. P.
( ($b$) 14.7 ft.

(1057) How many arms should be given to a 21″ gear-wheel having 84 teeth? Ans. 5 arms.

(1058) Calculate the size of the tapering arms of a 4-arm pulley, 22″ in diameter, and with an 8″ face; a double belt is to be used.

(1059) The hub of a split pulley is 7″ long and $1\frac{3}{8}''$ thick. If the hub is held by 6 bolts, what should be the diameter of the bolts? Ans. $\frac{7}{8}''$.

(1060) Design the following and draw on one plate :

1. A belt pulley similar to the one shown in Fig. 720. Take diameter equal to 48″, face 12″, and bore $2\frac{1}{2}$″. Use a scale of 3″ = 1 ft.
2. A foot-step bearing similar to that shown in Fig. 698. Take $d$ equal to 3″, and use a scale of 6″ = 1 ft.
3. A crane hook similar to that shown in Fig. 735, except that the swivel end shown at $A$ should be used instead of the eye. Take $d$ equal to $2\frac{1}{4}$″, and use a scale of 3″ = 1 ft.
4. A pipe flange as shown in Fig. 736. Take $a$ equal to 12″, and use a scale of $1\frac{1}{2}$″ = 1 ft.

NOTE.—The dots in Table 52 indicate that the last dimension above them should be used.

(1061) What is the weight of 875 ft. of $1\frac{3}{4}$″ manila rope ?

Ans. 803.9 lb.

(1062) (*a*) Calculate the horsepower which can be transmitted by a $1\frac{3}{4}$″ cotton rope at a velocity of 3,800 ft. per minute. (*b*) What is the horsepower as estimated from the diagram, Fig. 723 ? Ans. (*a*) 38.223 H. P.

(1063) (*a*) What should be the diameter of the wires composing an iron wire rope transmitting 125 H. P. at a velocity of 4,900 ft. per minute ? (*b*) What should be the diameter of the pulley ? (*c*) Of the rope ? The rope is to contain 42 wires.

Ans. (*a*) .0694″. (*b*) 9 ft. 10″. (*c*) $\frac{5}{8}$″.

# MACHINE DESIGN.

(ARTS. 2075-2131.)

(1064) (*a*) Why is the initial pressure less than the boiler pressure? (*b*) For ordinary cases, what per cent. of the boiler pressure may be assumed as the initial pressure?

(1065) Design a cross-head similar to that shown in Fig. 765, for an $8'' \times 12''$ engine. Assume that a connecting-rod like that shown in Fig. 760 is to be used, and that its length is to be six times that of the crank. Take diameter of piston rod as $1\frac{3}{8}''$, the steam pressure as 100 lb. per sq. in., and the thickness of the guides as $\frac{13}{16}''$. Scale full size.

(1066) State the boiler pressures commonly used in the different types of modern engines.

(1067) A plain slide valve is 9″ long and 16″ wide. What should be the diameter of a steel stem, if the pressure is 120 lb. per sq. in.? Ans. $1\frac{1}{4}''$.

(1068) Design a piston similar to that shown in Fig. 751, Art. **2093,** for a cylinder 20″ in diameter. Take $d$ equal to 3″, and use a scale of $6'' = 1$ ft.

(1069) What is the maximum allowable velocity of steam through the ports?

(1070) A plain slide valve is $6'' \times 8\frac{1}{4}''$ and is to be subjected to a steam pressure of 100 lb. per sq. in. What should be the diameter of a wrought-iron stem? Ans. $\frac{3}{4}''$.

(1071) How should the area of the exhaust port compare with that of the steam port?

(1072) The length of a steel piston rod is to be 32″; size of cylinder, $12'' \times 18''$; steam pressure, 100 lb. per sq. in.

Calculate the diameter of rod to nearest $\frac{1}{16}''$ by ($a$) formula **300**; ($b$) by formula **301**; ($c$) by Art. **2103.** Account for the difference in results.

Ans. ($a$) $1\frac{7}{16}''$. ($b$) $2\frac{3}{8}''$. ($c$) $1\frac{15}{16}''$.

(1073) Determine the data for a simple high-speed automatic non-condensing engine which is to develop 200 horsepower at a piston speed of about 600 feet per minute. Boiler pressure is to be 100 pounds. Take clearance as 8 per cent.

(1074) What should be the diameter of crank-shaft for a $30'' \times 60''$ Corliss engine? Ans. $12\frac{3}{4}''$.

(1075) The length of a wrought-iron piston rod for a $38'' \times 60''$ engine is to be $79''$. If the steam pressure is to be 100 lb. per sq. in., what should be the diameter of the rod? Calculate to the nearest $\frac{1}{16}''$ ($a$) by formula **300**; ($b$) by formula **301**; ($c$) by Art. **2103.** Which dimension would you take, and why?

Ans. ($a$) $6\frac{3}{8}''$. ($b$) $6\frac{15}{16}''$. ($c$) $6\frac{5}{16}''$.

(1076) ($a$) Between what limits does the clearance vary? ($b$) What is the piston clearance?

(1077) In well-designed engines, how much should the back pressure be?

(1078) Design a crank similar to that shown in Fig. 748, Art. **2090,** for a $24'' \times 52''$ Corliss engine. Use a scale of $3'' = 1$ ft.

# PRINCIPLES OF ELECTRICITY AND MAGNETISM.

(ARTS. 2201–2456.)

(1079) What chemical actions take place in a simple voltaic cell in which the electrolyte is sulphuric acid diluted with water and the electrodes are made of copper and zinc?

(1080) Find the power in watts in a closed circuit in which an electrical energy equivalent to 123,750 foot-pounds is expended in 43.5 minutes. Ans. 64.3073 watts.

(1081) The separate resistances of two branches, $A$ and $B$, of a derived circuit are 16.2 and 14.1 ohms, respectively; if the sum of the currents in the two branches is 6.37 amperes, what is the current in each branch?

Ans. $\begin{cases} \text{Current in branch } A = 2.9643 \text{ amperes.} \\ \text{Current in branch } B = 3.4057 \text{ amperes.} \end{cases}$

(1082) (*a*) Find the power in watts when 99,370,000 ergs are expended in 2.5 seconds; (*b*) also, its equivalent in horsepower.

Ans. $\begin{cases} (a)\ 3.9748 \text{ watts.} \\ (b)\ .005328 \text{ horsepower.} \end{cases}$

(1083) A wrought-iron ring of rectangular section is cut in halves and a square pole-piece of cast iron is fastened to each end of each half; the two halves are then placed together so as to form a link, leaving an air-gap of $\frac{1}{8}$ in. between the polar surfaces of

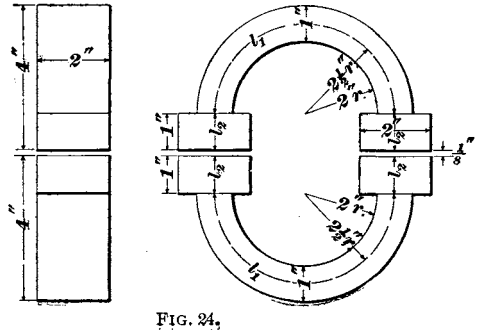


FIG. 24.

the two halves, as shown in Fig. 24. Find the magnetizing force in ampere-turns required to drive an induction of 160,000 lines of force through the magnetic circuit thus formed, using the dimensions shown in Fig. 24 and the permeabilities given in Tables 79 and 82. It is assumed that there is no magnetic leakage. Ans. 3,972.431 ampere-turns.

(1084) (*a*) In Question 1083, if the two halves of the magnet are so placed together that the polar surfaces are in contact, what will be the tractive force exerted between them when the induction is 240,000 lines of force? (*b*) What is the tractive force in pounds per square inch of contact surface?

Ans. { (*a*) 399.2568 lb.
(*b*) 49.9071 lb. per sq. in.

(1085) From what is the word *electricity* derived?

(1086) What current in amperes can be obtained from a voltaic battery in which the total electromotive force developed is 20 volts and the internal resistance is 30 ohms, when it is connected to an external resistance of 80 ohms?

Ans. .1818 ampere.

(1087) Find the power in watts in a closed circuit in which an electrical energy equivalent to 742,500 foot-pounds is expended in 4 hours and 21 minutes.

Ans. 64.3073 watts.

(1088) Two branches of a derived circuit are both made of copper wire. One branch, $A$, is a round wire 1,000 feet long and .02 in. in diameter; the second branch, $B$, is a square wire .02 in. on a side and 1,000 feet long; if the sum of the currents in the two branches is 2.6 amperes, what is the current in each branch?

Ans. { Current in $A = 1.1438$ amperes.
Current in $B = 1.4562$ amperes.

(1089) A current of 6.74 absolute units is flowing through a closed circuit; what is its equivalent in amperes?

Ans. 67.4 amperes.

(1090) What is supposed to be the cause of all electrical phenomena?

(1091) In a closed circuit, the electromotive force is 112 volts and the total resistance is 49.2 ohms; what is the current flowing in amperes? Ans. 2.2764 amperes.

(1092) Given: electromotive force = 112.5 volts; strength of current = 12.2 amperes. Find the power in watts.

Ans. 1,372.5 watts.

(1093) The separate resistances of two branches, $A$ and $B$, of a derived circuit are 49.2 and 67 ohms, respectively; if the sum of the currents in two branches is .76 ampere, what is the current in each branch?

Ans. $\begin{cases} \text{Current in branch } A = .4382 \text{ ampere.} \\ \text{Current in branch } B = .3218 \text{ ampere.} \end{cases}$

(1094) The difference of potential between two parts of a conductor is 1,764,300,000 absolute units of potential; find its equivalent in volts. Ans. 17.643 volts.

(1095) Find the power in watts expended in an electromagnet made of 65 cu. in. of thin sheet iron when the maximum magnetic density is 90,300 lines of force per square inch, and the magnetism is reversed at the rate of 133 times per second. Ans. 65.6156 watts.

(1096) (*a*) State some experiments for detecting the presence of *static charges* of electricity; (*b*) of a *current* of electricity.

(1097) A voltaic battery whose internal resistance is 36.2 ohms is connected to a copper wire having a resistance of 21.7 ohms; what is the total electromotive force in volts generated in a battery, if a current of .127 ampere flows under these conditions? Ans. 7.3533 volts.

(1098) Given: resistance = 11.8 ohms; strength of current = 19.8 amperes. Find the power in watts.

Ans. 4,626.072 watts.

(1099) The separate resistances of two branches, $A$ and $B$, of a derived circuit are, respectively, 7.19 ohms and .92 ohm; what is their joint resistance in parallel?

Ans. .8156 ohm.

(1100) The separate resistances of three branches, $A$, $B$,

and $C$, of a derived circuit are 37.3, 49.9, and 57.1 ohms, respectively; find their joint resistance in parallel.

Ans. 15.537 ohms.

(1101) The resistance of a conductor is 875,000,000 absolute units; find its equivalent in ohms. Ans. .875 ohm.

(1102) In an electromagnet there are 165,750 lines of force developed by the magnetizing force, and only 115,300 lines of force pass through the keeper, or armature; what is the per cent. leakage? Ans. 30.437% leakage.

(1103) What are the physical properties of electricity?

(1104) The total resistance of a closed circuit is 49.3 ohms; if the current is 2.73 amperes, what is the total electromotive force in volts generated? Ans. 134.589 volts.

(1105) Given: electromotive force = 78.8 volts; resistance = 2.3 ohms. Find the power in watts.

Ans. 2,699.7565 watts.

(1106) The separate resistances of two branches, $A$ and $B$, of a derived circuit are 42.1 and 98.3 ohms, respectively; what is their joint resistance in parallel?

Ans. 29.476 ohms.

(1107) What are magnets, and from what is the name derived?

(1108) In an electromagnet, the magnetic leakage is 33%; if 376,420 lines of force are developed by the magnetizing coils, how many lines of force are useful?

Ans. 252,201.4 lines of force.

(1109) Under what two conditions does electricity appear?

(1110) The electromotive force of a voltaic battery is 22.4 volts and its internal resistance is 13.4 ohms; what is the resistance of an external circuit when a current of .43 ampere is flowing through it from the battery?

Ans. 38.693 ohms.

(1111) What is the electrical equivalent of 2.33 horsepower? Ans. 1,738.18 watts.

(1112) The joint resistance in parallel of two branches, $A$ and $B$, of a derived circuit is 19.9 ohms. The current in

branch $A$ is 2.2 amperes and in $B$, 5.9 amperes; what is the separate resistance of each branch?

Ans. { Resistance of branch $A = 73.2681$ ohms.
Resistance of branch $B = 27.3203$ ohms.

(1113) State the general law for magnetic attraction and repulsion.

(1114) The magnetic leakage in an electromagnet is 61%; if 1,764,300 lines of force pass through the keeper, or armature, how many must be developed by the magnetizing coils?

Ans. 4,523,846 lines of force.

(1115) Define (*a*) *electrostatics;* (*b*) *electrodynamics.*

(1116) (*a*) What is the total resistance of a closed circuit when a current of 5.2 amperes is flowing under an electromotive force of 28.2 volts? (*b*) If the external resistance is 7 times the internal, what is the resistance of each?

Ans. { Resistance of internal circuit = .677875 ohm.
Resistance of external circuit = 4.745125 ohms.

(1117) What is the mechanical equivalent of 63,426 watts? Ans. 85.0214 horsepower.

(1118) The sum of the currents in two branches, $A$ and $B$, of a derived circuit is 23.4 amperes; if the separate resistance of $A$ is 4.5 times the separate resistance of $B$, what is the strength of the current in each branch?

Ans. { Current in branch $A = 4.2546$ amperes.
Current in branch $B = 19.1454$ amperes.

(1119) What distinction is drawn between magnets and magnetic substances?

(1120) State the law of attraction and repulsion of statically charged bodies.

(1121) How many grains of water will be decomposed in 1 hour by a current of 10 amperes? Ans. 51.7968 grains.

(1122) Give the electrical equivalent of 83.42 horsepower.

Ans. 62,231.32 watts.

(1123) The joint resistance in parallel of two branches, $A$ and $B$, of a derived circuit is 47.9 ohms; if the separate

resistance of $A$ is 2.7 times the separate resistance of $B$, what is the separate resistance of each branch?

Ans. { Resistance of branch $A = 177.23$ ohms.
Resistance of branch $B = 65.6407$ ohms.

(1124) Give the names of all the known magnetic substances.

(1125) What effect is produced in a conductor conveying an electric current when placed in a magnetic field?

(1126) What will be the sign of the static charge developed (*a*) upon a glass rod when it is rubbed with fur? (*b*) on a piece of hard rubber when rubbed with silk? (*c*) on a piece of flannel when it is rubbed against a piece of amber?

(1127) What strength of current will be required to decompose 25 grains of water in 4 hours?

Ans. 1.2066 amperes.

(1128) Give the mechanical equivalent of 3,362 watts.

Ans. 4.5067 horsepower.

(1129) The separate resistances of two branches, $A$ and $B$, of a derived circuit are 2.4 and 987.3 ohms, respectively; what is their joint resistance in parallel? Ans. 2.394 ohms.

(1130) Find the magnetic density in a bar magnet, $2\frac{1}{4}$ inches wide and 1.75 inches thick, when 103,750 lines of force pass through it.

Ans. 26,349.2 lines of force per square inch.

(1131) What takes place in a conductor when it is moved across lines of magnetic force at right angles to their direction?

(1132) For what is an *electroscope* used?

(1133) Fig. 25 represents a closed circuit consisting of a voltaic battery $B$ and two conductors $X$ and $Y$, connected in series; if the internal resistance of the battery is 17.2 ohms and the resistances of the conductors $X$ and $Y$ are, respectively, 8.2 and 11.3 ohms,

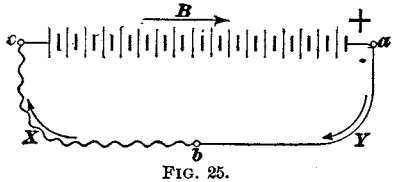

FIG. 25.

what is the total electromotive force in volts generated by the battery when a current of .75 ampere flows through the circuit? Find the difference of potential between (1) $a$ and $b$, (2) $b$ and $c$, and (3) $c$ and $a$.

Ans. { Total electromotive force developed = 27.525 volts. Difference of potential between $a$ and $b$ = 8.475 volts. Difference of potential between $b$ and $c$ = 6.15 volts. Difference of potential between $c$ and $a$ = 14.625 volts.

(1134) Find the power in horsepower units when a current of 86.3 amperes is flowing between a difference of potential of 225 volts. Ans. 26.0288 horsepower.

(1135) In Fig. 26, the difference of potential between $a$ and $b$ is 11.6 volts; if the current in branch $A$ is 6.7 amperes and the current in $B$ is 4.9 amperes, what is the separate resistance of each branch?

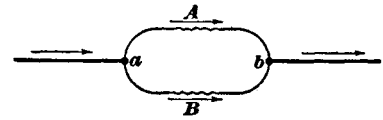

FIG. 26.

Ans. { Resistance of branch $A$ = 1.7313 ohms. Resistance of branch $B$ = 2.3673 ohms.

(1136) Find the magnetic density in a round bar magnet $\frac{1}{2}$ inch in diameter when 3,927 lines of force pass through it. Ans. 20,000 lines of force per square inch.

(1137) What electromotive force in volts is generated in a conductor which is moving across lines of force at the rate of 3,660,000,000 lines of force per minute? Ans. .61 volt.

(1138) For what is the torsion balance used in electrical measurements?

(1139) A conductor is of uniform conductivity and sectional area throughout its entire length; its total resistance is 12.6 ohms; if a current of 2.3 amperes is flowing through it, what will be the difference of potential in volts between one end and a point situated $\frac{11}{16}$ of its length towards the other end? Ans. 19.92375 volts.

(1140) The total resistance of a closed circuit is 12.3

ohms; what is the power in horsepower units when a current of 11.4 amperes is flowing through the circuit?

Ans. 2.1427 horsepower.

(1141) Referring to Fig. 26, Question 1135, the separate resistance of branch $A$ is 793 ohms; that of $B$ is 979.3 ohms; if a current of .23 ampere is flowing in the main or undivided circuit, what is the difference of potential in volts between $a$ and $b$? Ans. 100.7812 volts.

(1142) The magnetic density in a bar magnet .25 inch wide by .375 inch thick is 34,500 lines of force per square inch; find the total number of lines of force passing through the magnet. Ans. 3,234.375 lines of force.

(1143) Find the electromotive force in volts generated in a conductor moving across lines of force at the rate of 48,900,000,000 per minute. Ans. 8.15 volts.

(1144) In a torsion balance, if 4 units of electricity repelled the lever arm through an angle of 20 degrees, what quantity will be required to repel it through an angle of 45 degrees? Ans. 20.25 units of electricity.

(1145) What must have been the strength of current in amperes in a circuit through which 368,422 coulombs of electricity pass in $4\frac{1}{2}$ hours, if the flow were uniform?

Ans. 22.7421 amperes.

(1146) ($a$) In a circuit, the resistance between two points is .23 ohm; what current flowing between these points will cause a difference of potential of 48.4 volts? What is ($b$) the power in watts? ($c$) its equivalent in horsepower units?

Ans. ($a$) 210.4348 amperes.
($b$) 10,185.04 watts.
($c$) 13.6528 horsepower.

(1147) In Fig. 26, Question 1135, the difference of potential between $a$ and $b$ is 125 volts; if the separate resistance of branch $A$ is 47.41 ohms and that of $B$ is 69.8 ohms, what is the current in each branch?

Ans. Current in branch $A = 2.6366$ amperes.
Current in branch $B = 1.7908$ amperes.

(1148) The magnetic density in a round bar magnet 2 inches in diameter is 56,000 lines of force per square inch; find the number of lines of force passing through the magnet. Ans. 175,929.6 lines of force.

(1149) Two gilt balls are statically charged with + 20 and − 5 units of electricity, respectively; with what force in dynes will they attract each other when placed at a distance (*a*) of 1 centimeter from each other? (*b*) of 5 centimeters? Ans. (*a*) 100 dynes. (*b*) 4 dynes.

(1150) How many coulombs of electricity pass through a circuit in $2\frac{1}{4}$ hours, when the strength of current is 8.32 amperes? Ans. 67,392 coulombs.

(1151) Given: electromotive force = 525 volts; strength of current = 12.5 amperes. Find the power in horsepower units. Ans. 8.7969 horsepower.

(1152) The separate resistances of three branches, *A*, *B*, and *C*, of a derived circuit are 7.9, 13.3, and 25.8 ohms, respectively; find their joint resistance in parallel.

Ans. 4.1575 ohms.

(1153) The current in Fig. 27 is assumed to be flowing in the direction indicated by the arrowheads; which of the two ends, *a* or *b*, is the north pole of the solenoid? Why?

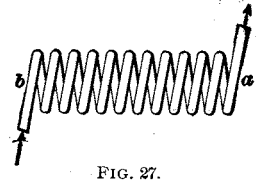


FIG. 27.

(1154) Two gilt balls, *A* and *B*, are statically charged with + 4 and − 24 units of electricity, respectively; if the balls are touched together momentarily and then placed at a distance of 2 centimeters from each other, will they attract or repel each other, and what will be the force in dynes exerted between them?

Ans. Repelled with a force of 25 dynes.

(1155) How long will it take 86,700 coulombs to pass through a circuit when the rate of flow is 10 amperes?

Ans. 2 hours 24 minutes 30 seconds.

(1156) Given : strength of current = 46.8 amperes; resistance = 4.4 ohms. Find the power in horsepower units.

Ans. 12.9183 horsepower.

(1157) The current in a horizontal conductor is flowing *from* the north *towards* the south; in what direction will the north pole of a compass needle tend to point if the compass is placed under the conductor ?

(1158) What is an electrophorus ?

(1159) How many joules are equivalent to 1 foot-pound?

Ans. 1.3563 joules.

(1160) Given : electromotive force = 225.6 volts; resistance = 15.7 ohms. Find the power in horsepower units.

Ans. 4.3455 horsepower.

(1161) The separate resistances of three branches, $A$, $B$, and $C$, of a derived circuit are 63.2, 76.5, and 88.9 ohms, respectively; if the sum of the currents in the three branches is 5.7 amperes, find the current in each branch.

Ans. { Current in branch $A = 2.2467$ amperes.
Current in branch $B = 1.8561$ amperes.
Current in branch $C = 1.5972$ amperes.

(1162) A conductor carrying a current of electricity is placed in a horizontal position pointing north and south; if the north pole of a compass needle tends to point towards the east when the compass is placed under the conductor, in which direction is the current flowing in the conductor ?

(1163) What will be the sign of the static charge left on the cover of an electrophorus if the cake is made of sulphur instead of resin and it is rubbed with a piece of silk ?

(1164) (*a*) How much energy in *joules* is expended in a circuit during $1\frac{1}{4}$ hours when the strength of current is 14.2 amperes and the resistance of the circuit is 8 ohms ? (*b*) What is its equivalent in foot-pounds ?

Ans. { (*a*) 7,259,040 joules.
(*b*) 5,352,090.192 ft.-lb.

(1165) If the resistance of 1 mile of round copper wire $\frac{1}{16}$ inch in diameter is 14 ohms and the conductivity of cop-

per is 6.08 times the conductivity of iron, what is the resistance of 1,000 feet of round iron wire $\frac{1}{16}$ inch in diameter?

Ans. 16.1212 ohms.

(1166) If the separate currents in three branches, $A$, $B$, and $C$, of a derived circuit are 7.7, 23.9, and 15 amperes, respectively, and their joint resistance in parallel is 3.2 ohms, what is the separate resistance of each branch?

Ans. { Resistance of branch $A = 19.3662$ ohms.
Resistance of branch $B = 6.2393$ ohms.
Resistance of branch $C = 9.9413$ ohms.

(1167) The mean length of a magnetic circuit produced by a solenoid is 10 inches and its sectional area throughout is 3.2 square inches. The solenoid contains 110 complete turns around which a current of 42 amperes is circulating; find ($a$) the intensity of magnetomotive force, and ($b$) the total number of lines of force produced by the solenoid.

Ans. { ($a$) $\mathbf{H} = 1{,}474.704$.
($b$) 4,719.0528 lines of force.

(1168) A charge of 400 units of electricity is imparted to a sphere 4 inches in diameter; what is the electric density of the charge per square inch over the surface?

Ans. 7.9577 units of electricity per square inch.

(1169) The electrical energy expended in a closed circuit in $2\frac{1}{2}$ hours is equivalent to 5,326,824 foot-pounds; if the electromotive force is 220 volts, what is the strength of the current flowing in the circuit? Ans. 3.6489 amperes.

(1170) The resistance of mercury is 59 times that of copper; what are their relative conductivities?

(1171) In the derived circuit, Fig. 28, the sum of the currents in the three branches is 67.4 amperes, and the separate resistances of the branches $A$, $B$, and $C$ are .2, 1.9, and 2.1 ohms, respectively; find the difference of potential between $a$ and $b$. Ans. 11.22884 volts.

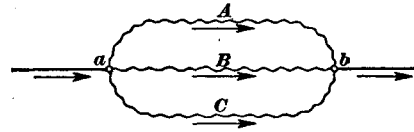

FIG. 28

(1172) If the intensity of the magnetomotive force in a

solenoid is 360 and the mean length of magnetic circuit is 12 inches, what is the magnetizing force in *ampere-turns?*

Ans. 1,353.383 ampere-turns.

(1173) If the inner coating of a Leyden jar is electrified with a negative charge, what is the sign of the *free* charge on the outside coating?

(1174) What is the resistance of a closed circuit in which the electrical energy expended in 15 minutes is equivalent to 984,650 foot-pounds and the total electromotive force generated is 115 volts? Ans. 8.9125 ohms.

(1175) The resistance of mercury is 62.73 times that of silver; what is the resistance in ohms of a round silver wire .02 inch in diameter and 1,000 feet long?

Ans. 22.6159 ohms.

(1176) In a derived circuit as shown in Fig. 28, the difference of potential between $a$ and $b$ is 225 volts; if the currents in the three branches $A$, $B$, and $C$ are, respectively, 17, 39, and 23 amperes, what is the separate resistance of each branch?

Ans. { Resistance of branch $A = 13.2353$ ohms.
Resistance of branch $B = 5.7692$ ohms.
Resistance of branch $C = 9.7826$ ohms.

(1177) The intensity of magnetomotive force around a piece of iron is 600 and the magnetic density produced is 54,300 lines of force per square inch; find the permeability at that stage of magnetization. Ans. Permeability = 90.5.

(1178) Define a *continuous current* of electricity.

(1179) Give the definition of a *watt.*

(1180) What is the resistance in ohms of a round column of mercury 72.3 inches high and .04 inch in diameter?

Ans. 2.1368 ohms.

(1181) In a derived circuit as shown in Fig. 28, the difference of potential between $a$ and $b$ is 108 volts; if the separate resistance of the three branches $A$, $B$, and $C$ are, respectively, 52.2, 73, and 64 ohms, find the current in each branch.

Ans. { Current in branch $A = 2.069$ amperes.
Current in branch $B = 1.4795$ amperes.
Current in branch $C = 1.6875$ amperes.

(1182) The permeability of a piece of steel is 850 when the magnetic density is 59,500 lines of force per square inch; find the intensity of magnetomotive force required to produce that density. Ans. $\mathbf{H} = 70$.

(1183) Give three methods for producing a difference of electrical potential.

(1184) How many horsepower units to a watt?

Ans. .00134 horsepower.

(1185) If the resistance of 1,000 feet of round copper wire .1 inch in diameter is 1 ohm, find the resistance of 2,000 feet of square copper wire .1 inch on a side.

Ans. 1.5708 ohms.

(1186) Find the equivalent energy in *foot-pounds* of 600,000,000 ergs. Ans. 44.238 foot-pounds.

(1187) The intensity of magnetomotive force in a piece of wrought iron is 180 and the permeability of the iron when magnetized is 450; what is the magnetic density produced in the iron?

Ans. Magnetic density = 81,000 lines of force per square inch.

# ELECTRICAL MEASUREMENTS.

(ARTS. 2457-2549.)

NOTE.—All readings and measurements given in the following examples are to be considered as accurate between 1.0 and 0.1% only, except where noted; the answers to the examples should be worked out accordingly.

(1188) If a tangent galvanometer with a resistance of 690 ohms gives a deflection of 68° with a current of .06 ampere, what will be its deflection with the same total current if shunted with a resistance of 500 ohms?

Ans. 46° 7′ +.

(1189) A tangent galvanometer is constructed with the following dimensions:

Mean diameter of coil $9\frac{7}{16}$ inches (24 centimeters).

Coil in three sections,

| | |
|---|---|
| Section I | 6 turns; |
| Section II | 3 turns; |
| Section III | 1 turn. |

(*a*) What is the force in dynes that would act on a unit magnetic pole if placed at the center of the coil when 1 ampere is flowing through Section III of the coil? (*b*) What deflection of the needle (in degrees) will that current cause if the instrument be set up in the city of Washington?

Ans. { (*a*) .05236 dyne. (*b*) 14° 40′ +.

(1190) What office does a *controlling magnet* perform when used with a galvanometer?

(1191) What would be the resistance in *ohms* of a plate of mica 10 inches square and $\frac{1}{8}$ inch thick, calling the $\frac{1}{8}$ inch dimension the *length* of the piece of mica?

Ans. 41,340,000,000 ohms.

(1192) What is the principle of a Wheatstone bridge? (Draw a diagram to explain the principle, pointing out the various connections and their uses.)

(1193) (*a*) If a controlling magnet be used with the galvanometer in example 1189, how much will $H$ be increased by that magnet if a current of 4.2 amperes through Section II produces a deflection of only 40 degrees, the instrument being located in Philadelphia? (*b*) What would be the deflection under the foregoing conditions if the polarity of the controlling magnet be reversed?

Ans. { (*a*) .5923 line of force per sq. cm.
( (*b*) 58° 53′.

(1194) Define (*a*) an ammeter; (*b*) a voltmeter; (*c*) a wattmeter.

(1195) What is meant (*a*) by *damping* the moving parts of a galvanometer? (*b*) By a *dead-beat* galvanometer?

(1196) What are the three principal effects of an electric current, and how are these effects affected by changes in the current?

(1197) A coil of wire 20 feet long is submerged in a metallic tank nearly full of slightly acidulated water, to such depth that 1 foot of each end of the wire projects above the surface. A galvanometer is connected in series with the wire and a battery of 100 cells, in series, all of the same kind. The other end of the cell circuit is connected to the tank. [See Fig. 29 (*b*).] Under these conditions the galvanometer

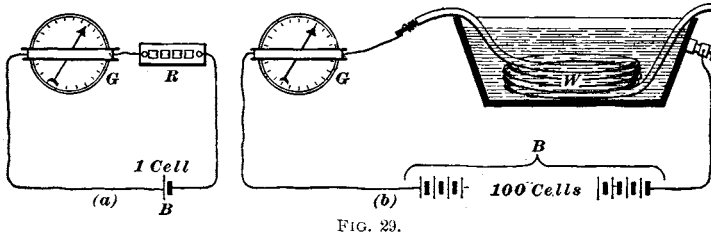


FIG. 29.

is deflected 59 degrees. When the battery is reduced to 1 cell, and the tank and wire replaced by the known adjustable resistance $R$, Fig. 29 (*a*), this resistance must be adjusted

to 11,800 ohms to give the same deflection of the galvanometer (59 degrees). What is the insulation resistance of the wire in megohms per yard?

Ans. 7.08 megohms per yard.

(1198) What are some of the advantages of the D'Arsonval form of galvanometer?

(1199) Fig. 30 represents a "slide wire" bridge in which the wire *a b* is just 1 meter long. Beneath this wire is a scale divided into *millimeters* (not shown in the figure). *R* is a known resistance of 10 ohms, and *X* an unknown resistance. When the connections are made as shown, it is found that the contact piece *n* must be moved along the wire until it is 26.2 *centimeters* from *a* in order that the galvanometer *G* give no deflection; what, then, is the resistance of *X*? Ans. 28.17 ohms.

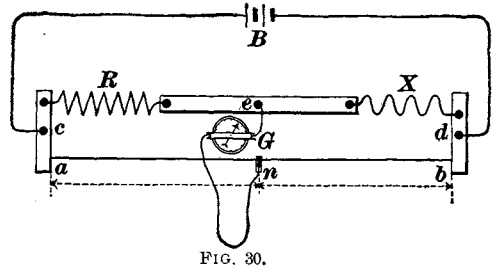

FIG. 30.

(1200) What would be the force in dynes exerted on a unit magnet pole at the center of a coil of two turns, and of 22 cm. diameter, if a current of 2.6 amperes passes through the coil? Ans. .29703 dyne.

(1201) A tangent galvanometer is connected in series with a battery furnishing a constant current, and with the copper positive and negative plates of a copper-depositing apparatus. The current is sent through the bath for 1 hour and 40 minutes, the galvanometer needle indicating a deflection of 42 degrees. If, at the end of this time, the weight of the copper negative plate has increased 2.26 grams over its original weight, what is the galvanometer constant? Ans. 1.2731.

(1202) By which of the three principal effects of an electric current may the absolute value of the strength of a current be determined?

(1203) (*a*) What would be the resistance at 10° C. of a saturated solution of copper sulphate, measured between two metallic plates 6 inches × 8 inches, which form the *ends* of a box 4 inches × 6 inches × 8 inches, filled completely full of the liquid? (*b*) What would be the resistance between the two plates if the copper sulphate solution be replaced with a solution of sal ammoniac, the solution being of such strength as to give the maximum conductivity?

Ans. { (*a*) .9616 ohm.
(*b*) .082047 ohm.

(1204) A galvanometer has two coils, one of 120 and one of 180 ohms resistance; what would be the multiplying power of a shunt of 20 ohms when used in parallel, (*a*) with the 120-ohm coil? (*b*) with the 180-ohm coil? (*c*) with both coils in series? Ans. (*a*) 7; (*b*) 10; (*c*) 16.

(1205) The diagram in Fig. 31 represents a circular form of resistance-box arranged to be used as a Wheatstone bridge, $X$ being the unknown resistance. (*a*) Draw a diagram showing the proper connections of the battery and galvanometer, and point out (by suitable lettering) the upper and lower balance arms and the adjustable arm. (*b*) If the galvanometer shows no deflection when a current is sent through the bridge with the resistance-coils in circuit as represented, what is the resistance of $X$?

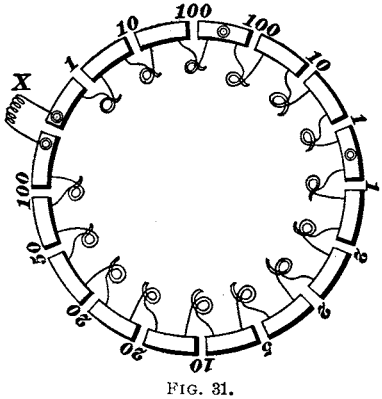

FIG. 31.

Ans. (*b*) 210 ohms.

(1206) If the resistance-coils of the above bridge were made of an alloy having practically no temperature coefficient, and the resistance $X$ be of copper wire, what would be the difference in the results between a measurement of its resistance taken in winter at a temperature of 45° F. and

one taken in summer at a temperature of 91° F., the measurement in example 1205 being taken at the latter temperature?

Ans. 18.95 ohms.

(1207) (*a*) What is meant by the *insulation resistance* of a conductor? (*b*) What is a *petticoat insulator?*

(1208) For testing its magnetic qualities with a ballistic galvanometer, step-by-step method, a ring of iron, 5 inches

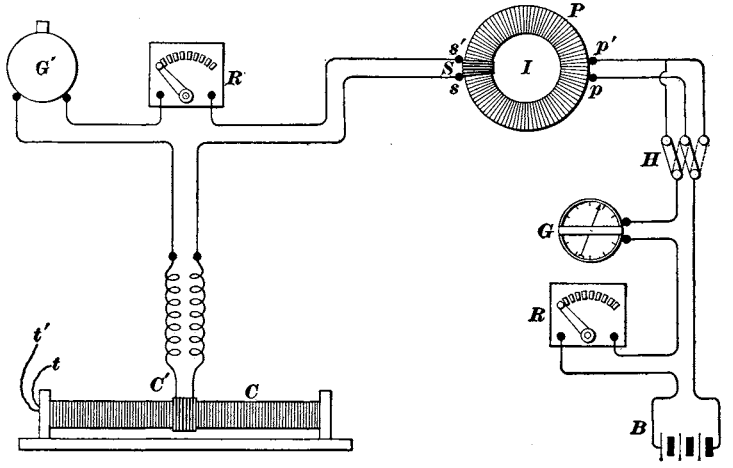


FIG. 32.

inside diameter, $6\frac{1}{2}$ inches outside diameter, and 1 inch thick, is wound evenly with 800 turns of No. 18 insulated wire, and connected in circuit as shown at *I*, in Fig. 32.

The parts of the *primary* circuit are: the primary coil *P* on the iron ring, .8 ohm; the battery *B* internal resistance is 1.2 ohms; adjustable rheostat *R*, 40 ohms in ten steps of 4 ohms each; balance of primary, including connections, has a resistance of 1.1 ohms. The battery *B* has 6 cells, each furnishing a constant E. M. F. of 1.9 volts.

The parts of the *secondary* circuit are: ballistic galvanometer *G'*, with resistance of 500 ohms; adjustable rheostat *R'*, whose resistance is set constant at 500 ohms; resistance of balance of circuit, including both secondary coils *C'* and *S*, is 10 ohms.

The ballistic galvanometer has been calibrated, and it has been found that 1 line of force in the coil $S$ will cause a galvanometer deflection of .01297 division on the scale.

The following readings were taken, with the different resistances of $R$ noted:

| Resistance of $R$. Ohms. | Deflection of Spot of Light. Divisions. |
|---|---|
| 40 | 92.5 |
| 36 | 21.5 |
| 32 | 15.5 |
| 28 | 19.0 |
| 24 | 17.0 |
| 20 | 27.0 |
| 16 | 31.0 |
| 12 | 33.5 |
| 8 | 45.0 |
| 4 | 58.5 |
| 0 | 126.5 |

NOTE.—It will be sufficiently accurate to work out the results for the number of lines of force, their density, etc., using three significant figures. It would not be feasible to plot the curve with a greater degree of accuracy than this.

($a$) From these readings and the data given, work out the magnetomotive force **H** of the primary coil of the iron ring, and the resulting density of lines of force **B** in the iron ring; from these results plot a *magnetization curve* on cross-section paper showing the magnetic qualities of this particular sample of iron. ($b$) What kind of iron does the sample appear to be, from the form of the curve?

NOTE.—The cross-section paper on which this and similar curves should be plotted should be ruled into quite fine subdivisions, and be reasonably accurate. The best paper to use has its lines ruled in orange or red ink on bond-paper, which, being semitransparent, allows of duplicates of curves being made by the "blue printing" process.

A very convenient size for the rulings is that in which the divisions are 2 millimeters apart. Every fifth line then measures 1 cm., and is ruled slightly heavier, and every second one of these heavier lines is ruled heavier still; thus, the fifth and tenth lines are readily distinguished from each other and from the intermediate divisions.

In plotting curves on this paper, one of the heaviest lines should be selected near the left-hand edge and one near the lower edge of the sheet to serve as the zero lines or *axes of the ordinates*. Calling these lines

0, each of the heaviest lines along the ordinates and abscissas should be given their proper values, care being taken that these values be such that the *intermediate* divisions have some convenient value, as 1, 2, or 5 of the units selected, and not some number, such as 3, 7, or 9, which would be found to make it very difficult to locate the points of the curve properly.

For instance, in this example the value of each heavy line of the ordinate should be 10,000 **B**, and of the abscissas 100 **H**; thus, the intermediate divisions will each have a value, in the one case of 1,000 **B** and in the other of 10 **H**. This will not carry the curve up to the top of the sheet, if a standard size sheet (8 in. × 10 in.) be used, but any other scale would make the values of the small divisions some odd numbers, which would make the curve difficult to plot, as a trial will demonstrate.

Cross-section paper prepared as described above may be obtained of dealers in artists' supplies, or from The Technical Supply Co., Scranton, Pa., who will supply it in standard 8 in. × 10 in. sheets at the rate of 25 sheets for 50 cents. This number of sheets will be sufficient to cover the work of this character which will appear in this Course.

(1209) (*a*) How are the heating effects of a current usually utilized in measuring instruments? (*b*) Give an example of an instrument constructed on this principle.

(1210) If the resistance of a piece of a certain metal 1 inch long and 1 inch wide and 1 inch thick is .00000824 ohm at 0° C., what is its *specific resistance?*

Ans. .00002093 ohm, or 20.93 microhms.

(1211) Through what angle must the coil of a sine galvanometer be turned in order that the plane of the coil shall coincide with the axis of the needle, if the coil be 24 cm. in diameter, be of 8 turns, and have a current of .362 ampere flowing through it? The needle is supposed to be about 1 cm. long, and the location of the instrument, Chicago, Ill.

Ans. 55° 30′.

(1212) The diagram, Fig. 33, represents a form of Wheatstone bridge. When the resistances in the balance arms and adjustable arm have been cut in circuit by withdrawing plugs until, as represented in the figure, the galvanometer shows no deflection as the keys $k$, $k'$ are pressed; what is the resistance of $X$? Ans. 7.23 ohms.

(1213) The positive brush of a dynamo giving a constant potential of 115 volts is connected through a voltmeter of 18,000 ohms resistance to the ground. The deflection of the voltmeter needle is 17.5 volts (the scale being divided

so that the readings are 1 volt per division). What is the insulation resistance between the *negative* brush and the ground? Ans. 100,287 ohms, or, practically, .1 megohm.

(1214) A column of mercury contained in a glass tube is included in a certain circuit, being connected in series with

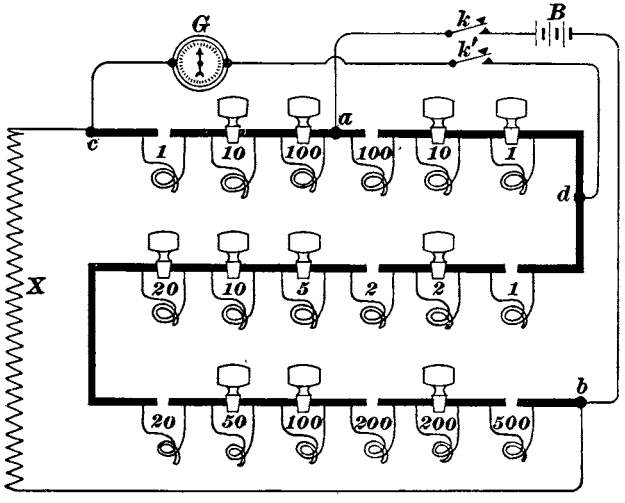


FIG. 33.

a coil of copper wire. At 15° C., the drop in volts through the mercury and through the copper wire is identical with a given current. What would be the ratio of the drops through each at 62° C., with the same current?

Ans. $\frac{1.04136}{1.1824}$.

(1215) What must be the resistance of a shunt to reduce the reading (with the same *total* current) of a tangent galvanometer of 400 ohms resistance from 58° to 31°?

Ans. 240.5 ohms.

(1216) An unknown resistance $X$ is connected in parallel with a known resistance $A$ of 196 ohms. In series with the two is a known resistance $B$, of 77 ohms. On sending a current through the resistances, the drop through the resistance $B$ is 5.6 volts, and through the resistances $A$ and $X$

in parallel is 4.1 volts. (*a*) What is the resistance of *X*? (*b*) What current is flowing through *A* and *X* in parallel?

Ans. { (*a*) 79.135 ohms. (*b*) .07273 ampere.

(1217) What must be the product of the number of turns in a coil of $19\frac{11}{16}$ inches diameter, and the amperes in each turn, in order that a force of .7 dyne be exerted in a unit magnetic pole in the center of the coil? Ans. 27.855.

(1218) An unknown resistance is connected in series with a resistance of 41 ohms, and a current sent through the two. The drop of potential through the unknown resistance is 7.54 volts, and through the known resistance 10.66 volts. (*a*) What is the value of the unknown resistance in ohms? (*b*) What current is flowing through the two resistances?

Ans. { (*a*) 29 ohms. (*b*) .26 ampere.

(1219) How does a current of electricity manifest itself when passing through water?

(1220) How may the force be measured which is exerted by a current of electricity, circulating in a coil of wire, on a small magnet of unknown strength, suspended at the center of the coil?

(1221) If a piece of copper rod be connected, as shown in Fig. 34, the points *D* and *C* being 25 inches apart, what is the resistance per foot of the rod, if the readings of the instruments be as follows: Amperes, measured by the ammeter *A*. = 35.4; volts, measured by the millivoltmeter *V*. = .00875?

Ans. .00011866 ohm.

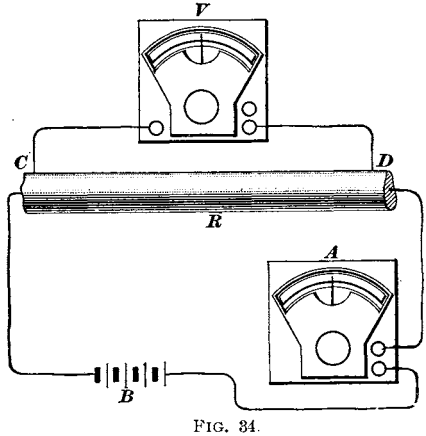

FIG. 34.

(1222) A galvanometer of 1.086 ohms resistance gives a deflection of 32° with

a current of .062 ampere. (*a*) What must be the resistance of a shunt which will cause a total current of .558 ampere to give the same deflection of the galvanometer? (*b*) What is the multiplying power of the shunt? (*c*) What must be the value of a *compensating resistance* designed for this galvanometer and shunt?

Ans. { (*a*) 135.75 ohms. (*b*) 9. (*c*) 965.33 ohms.

(1223) A current of electricity passed through a body of acidulated water causes it to lose in weight 2.1 grams in 2 hours. What was the value of the current in amperes?

Ans. 3.1280 amperes.

(1224) On what factors depends the force exerted by a current, flowing in a conductor, on a magnet pole in the vicinity?

(1225) In Fig. 35, *B* is a battery, *A M* an ammeter, *V M* a voltmeter, and *a b c d* a resistance. (*a*) What is the calculated resistance of the part *b c*, if the ammeter indicates 2.3 amperes and the voltmeter 4.9 volts, providing the instruments are not accurate within 1%? (*b*) What would be the calculated resistance if the instruments were correct within between 1% and .01%?

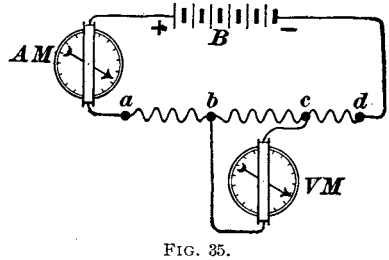

FIG. 35.

Ans. { (*a*) 2.13 ohms. (*b*) 2.13043.

(1226) The tangent galvanometer used in example 1189 is afterwards provided with a fiber suspension and a mirror, and a straight scale 4 feet long is used with it (see Fig. 36). The center of the scale is $2\frac{1}{2}$ feet away from the mirror *M*, and the scale is parallel to the normal plane of the mirror. The lamp *L* being located back of the center of the scale, the zero position of the reflected spot of light is in the center

of the scale, and the scale is divided into inches, measuring each way from this zero. (*a*) What current in Section I of the galvanometer coil will cause the spot of light to move just to the end of the scale, the instrument being in New York, and no controlling magnet used? (*b*) What current will cause the spot of light to move 12 inches; that is, half way to the end of the scale? (*c*) 6 inches?

Ans. { (*a*) .2055 ampere. (*b*) .1128 ampere. (*c*) .05794 ampere.

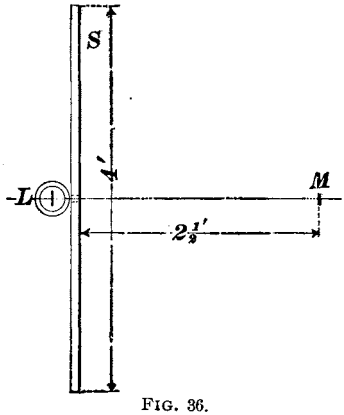


FIG. 36.

(1227) A certain telegraph-line has its poles 120 feet apart, and there are 440 poles. The line is connected up to a resistance testing apparatus, as represented in Fig. 37, in which $R$ is a known resistance of 15,000 ohms; $G$ is a standard tangent galvanometer; $B$ is a battery; $K$ is a switch which may make connection between the battery and

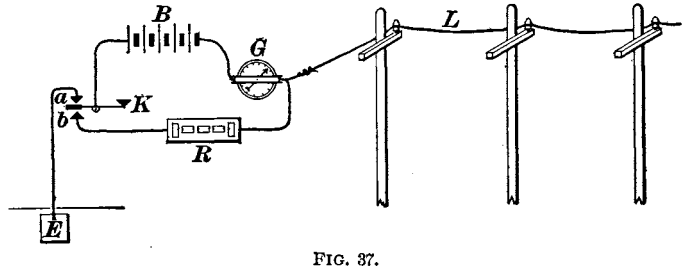


FIG. 37.

either the resistance $R$ or an earth connection $E$. On connecting with the earth-plate, the deflection of the galvanometer is 30° 30′; on connecting with the resistance $R$, the deflection is 69°. (*a*) What is the insulation resistance of the line in megohms? (*b*) What is the insulation

resistance in megohms per mile? (*c*) What is the insulation resistance in megohms per pole?

Ans. { (*a*) .06633 megohm. (*b*) .6633 megohm. (*c*) 29.2 megohms.

NOTE.—This method of testing resistance is *not* accurate within 1%.

(1228) What is a reflecting galvanometer?

(1229) Draw a diagram showing a method of measuring the insulation resistance of a piece of wire (*a*) with a bridge; (*b*) with a Weston voltmeter.

# BATTERIES.

(ARTS. 2550–2836.)

(1230) Define a *battery.*

(1231) Define (*a*) a *salt;* (*b*) an *acid;* (*c*) a *base.*

(1232) (*a*) What is the cause of the E. M. F. of a cell? (*b*) How is the current from a cell maintained?

(1233) What is necessary in order that a cell should give a high E. M. F.?

(1234) What are the principal features of a Daniell cell of the gravity form?

(1235) Assuming no local action, what is the consumption of zinc per ampere-hour in any primary cell?

Ans. 1.218 grams.

(1236) Given a battery of 12 cells, each of which gives an E. M. F. of 2 volts and has an internal resistance of 1 ohm, what should be the grouping of these cells to give the maximum current through an external circuit whose resistance is 3 ohms, and what will be the value of that current?

Ans. 2 sets in parallel, 6 cells in series in each set, would give a maximum current of 2 amperes.

(1237) Two oxides of mercury are represented by the formulas $Hg_2O$ and $HgO$, respectively. What would be the proper names to apply to these oxides?

(1238) What relation exists between the electrical energy obtained from a cell and the chemical energy liberated by the actions therein?

(1239) What is meant (*a*) by *polarization* of a cell? (*b*) by *depolarization?*

(1240) Name some of the more important applications (*a*) of primary batteries; (*b*) of secondary batteries.

(1241) Which plates of an accumulator are liable to buckle?

(1242) An electric-lighting plant has an average load of 2,000 amperes during the day of twenty-four hours. A storage-battery, with an efficiency of 80 per cent., is run in conjunction with the generating plant, and, according to the load diagram, furnishes 6,000 ampere-hours to the line during the day. (*a*) How many ampere-hours does the dynamo plant generate during a day? (*b*) What is least allowable capacity of the generating plant?

Ans. { (*a*) 49,500 ampere-hours.
(*b*) 2,062.5 amperes.

(1243) What is a chemical action, and what are the two kinds of chemical action that occur?

(1244) What is the effect on the E. M. F. of a cell if more than one chemical action takes place?

(1245) Give an example of a cell in which there is no depolarizer.

(1246) (*a*) Why should a gravity Daniell cell be used only when the current is required continuously? (*b*) Why should a cell with a non-depolarizing electrolyte be used only when the current is required intermittently?

(1247) What is meant by the *sulphating* of an accumulator?

(1248) What causes an accumulator plate to buckle?

(1249) Name the principal disadvantages of propelling street-cars by accumulators.

(1250) How is the E. M. F. of a cell affected if both substances used as the anode and cathode, respectively, are acted upon by the electrolyte?

(1251) (*a*) Why are primary batteries not used on a large scale as sources of electrical energy? (*b*) Why are they used at all?

(1252) (*a*) What is meant by *gasing* in speaking of an accumulator? (*b*) What does this phenomenon indicate?

(1253) A certain country house is equipped with 32 incandescent lamps, each lamp requiring 1 ampere at 52 volts. Of these 32 lamps, 2 burn for 10 hours per day, 6 burn for 5 hours per day, and the balance average 1 hour per day each. (*a*) How many accumulators of what capacity should be installed to furnish the current for lighting these lamps if the accumulators are to be charged once every week? (*b*) About how much floor space would be required for this plant if the cells are arranged in two tiers?

Ans. { (*a*) 28 cells, 518 ampere-hours capacity.
(*b*) 17 square feet (about).

(1254) What is an amalgam?

(1255) (*a*) What two methods of depolarization are in use? (*b*) Which is preferable? (*c*) Why?

(1256) (*a*) What kind of cells are the Grove and Bunsen? (*b*) Explain this class of cells.

(1257) How are accumulators rated?

(1258) On what does the capacity of an accumulator depend?

(1259) (*a*) What is the nature of a chemical action? (*b*) How does the energy of such action usually appear? (*c*) What is meant by the *heat of formation* of a substance?

(1260) (*a*) Into what five classes may primary batteries be divided? (*b*) Give the main features of each class.

(1261) Describe a crowfoot gravity cell.

(1262) What are the principal chemical actions which take place in an accumulator cell (*a*) on charging? (*b*) on discharging?

(1263) What is the cause of the loss in an accumulator, indicated by the fact that it requires more watt-hours to charge it than it will give when discharged?

(1264) (*a*) What is the *symbol* of a chemical element? (*b*) Why are the symbols assigned to the elements? (*c*) What is the *chemical formula* of a substance, and what do the various terms in the formula mean?

(1265) Name one disadvantage of bichromate cells.

(1266) What is the Faure process of making accumulator plates?

(1267) Why is the output of an accumulator in ampere-hours less at a high rate of discharge than at a low rate?

(1268) Why is long-continued overcharging sometimes beneficial to accumulators?

(1269) What is meant by (*a*) the *atomic weight* of an element? (*b*) the *chemical equivalent?* (*c*) the *valency?* (*d*) the *atomicity?*

(1270) What is the effect on the E. M. F. (*a*) of using various metals for the anode in cells of the class given in Art. **2602?** Why? (*b*) of using various metals for the cathode? Why? (*c*) What is the advantage of using a large porous carbon cathode in cells of the class given in Art. **2602?**

(1271) What is *potassium zincate?*

(1272) What is a *dry battery?*

(1273) What is the Planté process of forming accumulator plates?

(1274) Why will an accumulator recover its original E. M. F. if the discharge is stopped?

(1275) (*a*) What are the principal advantages of accumulators when used in central stations? (*b*) Describe the two general plans on which accumulators are installed in central stations.

(1276) The formula of water is $H_2 O$. (*a*) If the oxygen of this compound be replaced by *iodine*, what should be the formula of the resulting compound? (*b*) Why?

(1277) When a liquid is decomposed by the passage of a current through it, why do not the products of the decomposition appear all through the liquid, instead of at the anode and cathode only?

(1278) What are the requirements of a *standard cell?*

(1279) Into what two general classes may accumulators be divided?

(1280) What is meant by the ampere-hour efficiency of an accumulator?

(1281) (*a*) Mention the principal types of accumulators of the bimetallic class. (*b*) Why are they not more extensively used?

(1282) (*a*) What are the principal advantages of the Phillips-Entz accumulator? (*b*) What are the principal disadvantages?

(1283) What is (*a*) a *chemical element?* (*b*) a *chemical compound?* (*c*) Which of the elements are ordinarily gases? (*d*) Which are liquids?

(1284) A current of 4 amperes is passed for 10 minutes through two electrolyte baths in series. The first contains a solution of cuprous chloride, $Cu\,Cl$, the second a solution of cupric chloride, $Cu\,Cl_2$. How many grams of (metallic) copper will be deposited from the solution (*a*) in the first bath? (*b*) in the second? (*c*) Why will not the same amount be deposited in both cases?

(1285) Give an example of a cell with a decomposing electrolyte.

(1286) Define an accumulator.

(1287) Which is the positive plate of an accumulator?

(1288) What types of primary cell does the Phillips-Entz accumulator resemble in action and materials used?

(1289) Describe the materials and chemical actions in the Edison-Lalande cell.

(1290) What element almost invariably occurs in substances used as chemical depolarizers?

(1291) The E. M. F. of a certain cell as measured by a voltmeter is 1.9 volts on open circuit; when connected to an external circuit whose resistance is 4.5 ohms the E. M. F. falls to 1.6 volts. What is the internal resistance of the cell? Ans. .844 ohm.

(1292) Does a storage-battery, also called an accumulator, store electricity like a Leyden jar, or does it store potential energy in a chemical form?

# APPLIED ELECTRICITY.

(ARTS. 2837–3014.)

(1293) (*a*) In telegraphing, what is the purpose of the register? (*b*) Describe its action. (*c*) What signals are recorded upon it? (*d*) How do these signals represent the alphabet?

(1294) Given a relay, a sounder, a battery, a key, a lightning-arrester, and proper switches. Sketch the circuits for a way station, making the proper connections.

(1295) Sketch and describe a ground switch.

(1296) (*a*) In a Milliken telegraph repeater, what, to a certain extent, prevents the shortening of the signals? (*b*) At the beginning of a message, are all circuits closed or open? (*c*) When the key at the western end station is operated, why do the eastern relay and sounder remain inactive?

(1297) (*a*) What is duplex telegraphy? (*b*) Make a sketch showing the connections for the differential duplex system, and explain its working. (*c*) What is necessary in regard to resistances in this system? (*d*) Explain the use of the condensers.

(1298) (*a*) By what is the power supplied in the quadruplex system of the Postal Telegraph Co.? (*b*) Describe the Jones quadruplex without reference to the text.

(1299) (*a*) Explain the Hunnings transmitter. (*b*) Explain the solid back transmitter. (*c*) What is packing? (*d*) How may it be obviated?

(1300) Explain the action of a telephone switchboard drop.

(1301) Describe the action of the Milliken repeater when repeating from the eastern to the western line.

(1302) (*a*) What is an artificial line? (*b*) What are its uses?

(1303) (*a*) What kinds of wood are used for telegraph and telephone poles? (*b*) What dimensions are usually specified in selecting poles?

(1304) What wires are used in telephone and telegraph line work? What can you say concerning the relative merits of the different kinds?

(1305) (*a*) What is telegraphy? (*b*) Sketch and explain the simplest form of a telegraphic circuit. (*c*) Why is the earth used as a return conductor?

(1306) (*a*) Why is the sounder extensively used in telegraphing? (*b*) By what are the dots and dashes distinguished upon the instrument? (*c*) Define a sounder. (*d*) Describe it in detail. (*e*) How may the sound be increased?

(1307) How does an artificial line differ from a false cable?

(1308) What do you understand by the term "sectional plating"?

(1309) (*a*) What is a grounded line? (*b*) What is a metallic circuit? (*c*) What are the advantages of the latter over the former?

(1310) (*a*) What is cross-talk? (*b*) How is it caused? (*c*) How may it be obviated?

(1311) (*a*) What are automatic repeaters? (*b*) Why is an operator needed for these repeaters?

(1312) (*a*) In the bridge method for duplex cables, what are in the sides of the bridge in place of the rheostats? (*b*) What is connected in with the receiving-instrument? (*c*) How is the key arranged? (*d*) Describe the receiving-instrument. (*e*) What constitutes the dots and dashes with this instrument?

(1313) (*a*) Describe two methods of joining telegraph or telephone wires. (*b*) Which is better? (*c*) Why?

(1314) How may the color of gold deposit be regulated in electroplating?

(1315) What is telephony?

(1316) What relation do dots in telegraphy bear to spaces and dashes?

(1317) (*a*) In what does electric welding consist? (*b*) Describe in full the process of electric welding. (*c*) Describe the principal parts of Thomson's welder.

(1318) (*a*) What is a party line? (*b*) What kinds of party lines are in common use? (*c*) Describe each.

(1319) (*a*) What is a switchboard? (*b*) How does an operator connect two subscribers? (*c*) What is a clearing-out drop?

(1320) (*a*) What is an automatic shunt for a magneto generator? (*b*) Describe its operation. (*c*) What desirable results does it accomplish?

(1321) (*a*) Describe the action of a magneto generator. (*b*) What is the action of a magneto or polarized bell?

(1322) How are the calling and the talking sets of apparatus used alternately in a telephone? Describe the Warner hook switch.

(1323) Fill in the blank spaces in Table 95, following the same method of notation as used in the part of the table which is complete.

(1324) How does the action of a battery transmitter differ from that of a magneto-transmitter?

(1325) What is the theory of the battery transmitter?

(1326) (*a*) How is it that a magneto-transmitter is used without battery? (*b*) What is the source of current?

(1327) (*a*) How is sound produced? (*b*) Explain its transmission through the air.

(1328) What forms of battery are used for telephone work?

(1329) Give a full description of the way wires are strung upon poles for telegraph-lines.

(1330) (*a*) What should be the resistance of a relay for an ordinary telegraph-line? (*b*) Give the rules for the resistances of relays in the line. (*c*) Through what space should the armature of a relay move? (*d*) In a case where the sounder does not act while the relay responds to a current in the line, what should be done?

(1331) (*a*) What is the quadruplex system of telegraphy? (*b*) Upon what changes in the line currents does it depend for its action? (*c*) How in this system does each key govern its own sounder without affecting the others?

(1332) (*a*) Why does the diaphragm of a receiver vibrate when an alternating current traverses the receiver coil? (*b*) Why does the movement of a receiver diaphragm cause currents to flow in the coil?

(1333) (*a*) Explain the construction of a false cable. (*b*) In what systems is the false cable used?

(1334) Sketch a diagram of the plug switch used in telegraphy and explain its construction.

(1335) (*a*) What is a main-line sounder? (*b*) Describe its magnets.

(1336) (*a*) What is a telegraphic key? (*b*) Explain its action.

(1337) Sketch and describe a local circuit.

(1338) (*a*) Upon what principle does the bridge duplex system of telegraphy depend? (*b*) What parts in the system are arranged the same as for the differential duplex? (*c*) What instrument in the ordinary Wheatstone bridge has the same position as the relay of this system?

(1339) How does current density affect deposits in electroplating?

(1340) In what manner may rails be welded by electricity?

(1341) What are the usual sizes for telegraph-wires?

(1342) (*a*) Describe the telegraph insulator used by the Western Union Telegraph Co. (*b*) What is the function of the petticoat?

(1343) Describe the use of the induction-coil in telephony.

(1344) Describe the use of the induction-coil in the Jones quadruplex system of telegraphy.

(1345) Trace the circuits of Wood's button repeater when the eastern circuit is repeating into the western circuit.

(1346) (*a*) Draw sketch and describe the action of the Edison repeater. (*b*) Why does not the sounder in this system act directly from the line currents? (*c*) Trace circuits when repeating from west to east.

(1347) (*a*) What is meant by the Morse system of telegraphy? How is the Morse code made up?

(1348) Why are the contact points on telegraph-keys and relays made of platinum?

(1349) (*a*) For what reason are repeaters used? (*b*) What repeaters are in use in the United States?

(1350) Make a diagram of Wood's button repeater and explain its action when repeating from east to west.

(1351) (*a*) What delay occurs in the use of a button repeater? (*b*) How may the message be made more intelligible?

(1352) (*a*) What is the purpose of a lightning-arrester? (*b*) What are the principles upon which the two principal forms depend? (*c*) Describe a plate arrester.

(1353) What problems must be met in telephone-line construction which do not occur in any other line work?

(1354) Under what circumstances does no current actually flow in the line in the Jones quadruplex system?

(1355) (*a*) What form of switches should be used in a telegraphic circuit? (*b*) What is the effect of a faulty connection?

(1356) (*a*) What is the purpose of a relay? (*b*) What are its principal parts? (*c*) Describe its action in detail.

(1357) (*a*) What is a spring-jack? (*b*) What is its function in telephony? (*c*) What is its function in telegraphy? (*d*) Show how a spring-jack is associated with a drop on a telephone-line.

(1358) (*a*) Name the characteristics of sound. (*b*) Define each. (*c*) Give examples of various differences in familiar sounds, stating to what characteristics these differences are due.

(1359) With what does electrometallurgy deal?

# APPLIED ELECTRICITY.

(ARTS. 3015-3215.)

(1360) (*a*) By what distribution of field may a conductor be moved in a circular path and yet cut lines of force at a uniform rate and angle? (*b*) What is this called?

(1361) A conductor 22 cm. long is located in a magnetic field whose density is 8,000 lines of force per square centimeter, the conductor being in a plane at right angles to the lines of force. Its ends are connected to an external circuit, the total resistance (external and internal) being .2 ohm. The conductor is moved through the field at a uniform velocity of 90,000 cm. per minute, in a direction at right angles to the lines of force and to the length of the conductor. (*a*) What is the rate at which electrical energy in watts is expended in the circuit? (*b*) What is the mechanical force in dynes necessary to apply to the conductor to move it through the field (neglecting friction and other mechanical losses)? (*c*) What is the rate at which mechanical work in watts is done upon the conductor?

Ans. { (*a*) 34.848 watts. (*b*) 232,320 dynes. (*c*) 34.848 watts.

(1362) (*a*) What is meant by laminating an armature core? (*b*) Why is it necessary to do this?

(1363) (*a*) What is the source of the magnetic field most generally used in dynamo-electric machinery? (*b*) Why?

(1364) What becomes of the electrical energy given to a conductor which is being moved in a magnetic field by reason of a current being sent through it?

(1365) A conductor 13 inches long is moved in a circular path of 8 inches radius, parallel to the axis of rotation,

through a magnetic field, whose lines of force are parallel, at right angles to the axis of rotation of the conductor. The field has a uniform density of 51,000 lines of force per square inch. What is the maximum E. M. F. generated in the conductor when rotated at 900 revolutions per minute?

Ans. 5 volts, practically.

(1366) (*a*) What is the difference in the arrangement of the winding between a drum-wound disk armature and a drum-wound cylinder armature? (*b*) What necessitates this difference?

(1367) What is the difference in the manner in which two conductors must be connected in series in order that their E. M. F.'s may add together, in one case the E. M. F.'s being 180° apart, and in the other they being in phase?

(1368) Suppose that the conductor in example 1361 had been moved along a line making an angle of 62° with its own length instead of a right angle, as in that example. (*a*) By what amount would the E. M. F. generated have been affected? (*b*) Why?

(1369) How may the E. M. F. generated in a conductor when moving in a circular path through the parallel lines of force of a uniform field, be calculated for positions where the conductor is not cutting the lines at right angles?

(1370) How may the instantaneous values of the E. M. F. generated in a moving conductor be graphically represented?

(1371) (*a*) Under what general heads may the character of currents used for commercial purposes be classed? (*b*) What is the distinction between them?

(1372) (*a*) In what direction does a conductor carrying a current tend to move when placed in a magnetic field with its length at right angles to the lines of force? (*b*) Suppose that the conductor is free to move (without friction) in some other direction; will it do so?

(1373) What is the general definition of a dynamo?

(1374) What is a sine curve?

(1375) (*a*) In what direction relative to the lines of force and the axis of rotation is it necessary to laminate armature cores? (*b*) How are disk armatures in which the poles of the field face the end faces of the disk laminated?

(1376) What is the distinction (*a*) between a ring-wound and a drum-wound armature? (*b*) between a cylinder and a disk armature?

(1377) What is meant by the commercial efficiency of a dynamo?

(1378) Why is the difference of potential between the terminals of a dynamo armature less than the E. M. F. generated, when the machine is delivering a current?

(1379) (*a*) What is the difference between a collector and a commutator? (*b*) In general, how does the use of each affect the relation between the character of the E. M. F. generated in the armature winding and that of the difference of potential between the brushes?

(1380) (*a*) Why is it not possible to permanently connect several armature conductors in series in an unipolar dynamo? (*b*) How may they be connected?

(1381) How is it that when two armature coils of an open-coil winding are connected in parallel at the time that their E. M. F. differs, a considerable local current does not flow through them by reason of the difference in their E. M. F.?

(1382) What are the principal requirements of an armature winding for producing *continuous* currents?

(1383) (*a*) What causes the spark at the brush, when the current in an armature coil of a closed-coil winding is reversed? (*b*) How may this sparking be prevented?

(1384) (*a*) What is meant by the counter magnetomotive force and the cross magnetomotive force of a closed-coil armature? (*b*) How are they produced?

(1385) What number of coils could be used for a six-pole

two-circuit ring winding of the form described in Art. **3129,** with a pitch of 41 ?

(1386) A certain two-pole drum winding has 52 coils, the back pitch being 49 and the front pitch —47. What particular style of drum winding would this be called ?

(1387) What is a loop winding, and why is it so called ?

(1388) (*a*) Of two triple-wound multiple-circuit ring windings, one has 111 coils and the other 112. How many separate reentrant systems will each of these windings have ? (*b*) Why ?

(1389) A certain armature core for a six-pole field has 182 slots in its periphery. (*a*) What three forms of two-circuit bar winding, with two conductors per slot and per coil, could be applied to this core ? (*b*) What would be the front and back pitches for each winding ? (*c*) What would be the *relative* E. M. F.'s of the three windings ?

(1390) What are the principal features of the "horseshoe" type of field-magnet ?

(1391) (*a*) What must be done with the magnetizing force on the field of a dynamo with a closed-coil armature, in order to maintain a constant difference of potential between the brushes ? (*b*) Why ?

(1392) (*a*) Why is it that the magnetizing coils of a shunt-wound dynamo are made up of a large number of turns of small wire ? (*b*) Why are those of series-wound machines made up of a less number of turns of larger wire ?

(1393) (*a*) Should the field-magnet shown in the diagram (see Fig. 38) be classed as a salient-pole or a consequent-pole magnet ? (*b*) Why ? (*c*) How would it alter the classification if magnetizing coils were placed on each of the *S* pole-pieces, the paths of the lines of force remaining unchanged ?

(1394) Suppose we have a triple-wound two-circuit multipolar ring winding of the form described in Art. **3176,** in which it is desired to make the cross-connections symmetrical and inside the commutator. To what commutator seg-

ments would the terminals of each coil be directly connected ?

(1395) What is meant by multiple windings, and why are they used ?

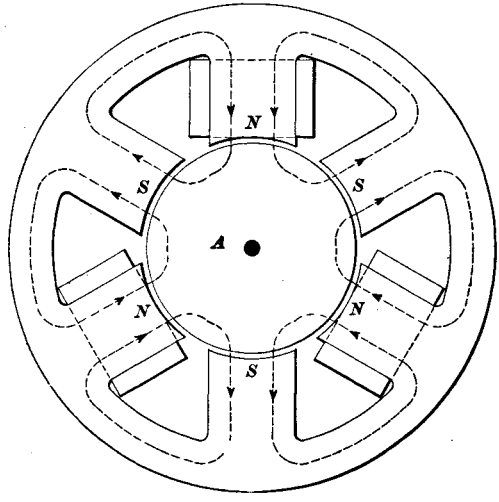


FIG. 38.

(1396) In winding drum armatures, how are the end connections carried by the shaft ?

(1397) A certain two-circuit ring-wound armature of the form described in Art. **3132** has 109 armature coils, each of four turns. It is revolved at 600 revolutions per minute in a four-pole field, in which 3,000,000 lines of force emanate from each pole face. (*a*) What is the best pitch to use for this winding ? (*b*) What is the E. M. F. generated in it under the above conditions ? Ans. { (*a*) 55. (*b*) 261.6 volts.

(1398) Why is it that a force must be applied to the winding of an armature in order to turn it in a magnetic field, when the E. M. F. generated by such motion is allowed to cause a current to flow through the winding ?

(1399) How may the E. M. F. which is necessary to

reverse the current in the coils of a closed-coil winding that are short-circuited by the brushes be applied to the coil ?

(1400) What is meant when a winding is said to be re-entrant ?

(1401) How is the effective difference of potential between the brushes of the Thomson-Houston open-coil armature varied ?

(1402) What is the distinction between open-coil and closed-coil armature windings ?

(1403) A drum-wound armature having 208 active conductors is revolved at 1,500 revolutions per minute in a bipolar field, and the E. M. F. generated is found to be 118 volts. What is the number of lines of force in the field ?

Ans. 2,270,000, nearly.

(1404) Why should the number of commutator segments used with a closed-coil armature be comparatively large ?

(1405) If a simple ring-wound armature is revolved in a magnetic field having 6 poles, alternately $N$ and $S$, how many sets of brushes must be used to collect the current, and how many paths for the current will there be through the winding ?

(1406) (*a*) In a drum winding, what is meant by front pitch and back pitch ? What is that style of drum winding called (*b*) in which the front and the back pitches are opposite in direction ? (*c*) in which they are in the same direction ?

(1407) What difference of potential can exist between adjacent conductors in a drum winding ?

(1408) In a certain two-circuit four-pole single drum winding, calculations give a difference of potential between commutator segments of 28 volts (average). (*a*) Is this a safe figure ? (*b*) How may it be reduced without changing the winding ?

(1409) A certain drum-wound armature has 554 conductors, 1 conductor per winding space, and is rotated at 300 revolutions per minute in a six-pole field, which has 5,400,000 lines of force per pole-piece. (*a*) What would be

its E. M. F. if connected as a two-circuit double winding? (*b*) What would be the front and back pitches? (*c*) What would be its E. M. F. if connected as a multiple-circuit double winding? (*d*) How many reentrant systems would the windings form in each case? (*e*) How many and what different E. M. F.'s could be obtained from this armature (by changing the end connections of the winding), using nothing beyond a *triple* winding? In working out the answer, show what different forms of windings would be used.

Ans. { (*a*) 224.4 volts.
(*b*) 93.
(*c*) 74.8.
(*d*) 1.
(*e*) 5; namely, 49.9, 74.8, 149.6, 224.4, 448.8.

(1410) (*a*) What is the purpose of the field-magnet frame of a dynamo? (*b*) Of what particular form must it be to accomplish this purpose? (*c*) Name the various parts of the frame and the use of each.

(1411) What is the essential difference between a salient-pole and a consequent-pole field-magnet?

(1412) What is meant (*a*) by a separately excited dynamo? (*b*) by a self-excited dynamo?

(1413) What becomes of the energy delivered to the magnetizing coils of a dynamo (*a*) when the current is first started? (*b*) when it has attained its maximum (steady) value?

(1414) What is the difference between shunt and series winding of self-excited dynamos?

(1415) Make a sketch showing the form of the magnetic circuit of some dynamo or motor with which you are familiar, giving the position of the magnetizing coils, and state whether it has consequent or salient poles, and why you think so.

NOTE.—If the student does not have access to any dynamo machinery, this question need not be answered.

(1416) Why is it that the two magnetic circuits of a consequent-pole, bipolar field-magnet need no more metal than the single circuit of a salient-pole magnet giving the same number of lines of force in the armature?

(1417) In a certain magnetic circuit the density of the lines of force is such that it corresponds to a point on the saturation curve of the metal of the magnetic circuit considerably below the bend of the curve. (*a*) In what condition would this magnetic circuit be said to be? (*b*) Why?

(1418) A triple-wound two-circuit ring winding has 105 coils, each of three turns. What would be the pitch used in connecting up the winding (*a*) for a four-pole field? (*b*) for a six-pole field? (*c*) What would be the E. M. F. generated in the winding in each case, if the *total number* of lines of force in the armature were 12,000,000, the armature being rotated at 600 revolutions per minute?

Ans. { (*a*) 54 or 51. (*b*) 36 or 34. (*c*) 126 volts.

(1419) What is meant (*a*) by a triple winding? (*b*) by a double winding forming a single reentrant system?

(1420) (*a*) What is the greatest possible number of winding spaces per slot in an eight-pole two-circuit slotted-drum armature? (*b*) Why?

(1421) (*a*) Would a simple ring-wound armature designed for a bipolar field give any E. M. F. if rotated in a four-pole field? (*b*) Would a simple drum-wound armature designed for a bipolar field give any E. M. F. if rotated in a four-pole field? (*c*) Why?

(1422) Why is it that in a drum winding both pitches must be odd, if they are both in the same direction?

(1423) How are the various windings of a multiple-wound armature connected in parallel?

(1424) A two-circuit ring winding of the form described in Art. **3132** is laid out for an eight-pole field, and 171 coils are decided upon. To get a regular distribution of

potentials around the commutator, what would be (*a*) the pitch? (*b*) the number of commutator segments? (*c*) the angular distance between the commutator segments that are connected together?

Ans. { (*a*) 43. (*b*) 684. (*c*) 90°.

(1425) (*a*) What is the output of a dynamo? (*b*) What is the input? (*c*) What is the commercial efficiency?

(1426) (*a*) Why is it not necessary to calculate the mechanical force required to move each conductor of a dynamo armature through the magnetic field in order to determine the power it takes to thus move them? (*b*) How may this power be otherwise calculated?

(1427) What is meant by the sparking limit of load of a dynamo?

(1428) Under otherwise the same conditions, which requires the greater amount of shifting to preserve sparkless commutation under varying loads, high or low resistance brushes? (*b*) Why?

(1429) (*a*) A four-pole single-wound two-circuit drum armature has 38 winding spaces, one conductor per winding space. Make diagrams showing two different plans of connections for this armature, showing the position of the brushes, the coils short-circuited by the brushes, and the direction of the E. M. F. in the conductors. (*b*) Name any advantages you may think one of these windings has over the other.

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