THE PENNSYLVANIA RAILROAD COMPANY

PHILADELPHIA, BALTIMORE & WASHINGTON RAILROAD COMPANY
NORTHERN CENTRAL RAILWAY COMPANY
WEST JERSEY & SEASHORE RAILROAD COMPANY

EDUCATIONAL COURSE

PAMPHLET E-2

ELEMENTARY ELECTRICITY

DIRECT CURRENT

OFFICE OF
SUPERINTENDENT OF TELEGRAPH
PHILADELPHIA
MARCH, 1913

PAMPHLET E-2

ELEMENTARY ELECTRICITY

DIRECT CURRENT

DIRECT CURRENT.

NOTE.—The table of Properties of Copper Wire on page 27 from Abbott's Electrical Transmission of Energy. Information on Insulators, pages 34 to 39, taken in part from Standard Handbook for Electrical Engineers.

DIRECT CURRENT.

It is desired to give special attention in these papers to the methods of producing electricity, the apparatus used for this purpose, methods of conveying it to the point where it will be used, the apparatus in which it will be used, and the principles governing the behavior of the apparatus under the different conditions.

Electricity is a form of energy and may be readily transformed into other kinds of energy. It may be transmitted between distant points over suitable connections, or, as is now being done to a limited extent, by wireless. These methods make it the only successful carrier of energy over long distances. The changing of electrical energy to other forms is electrical work, and the rate of this change, is electrical power.

Before proceeding further, the student should be warned against forming an erroneous idea of electricity. From the fact that a comparison is made with the water system, it might be assumed that it possessed certain dimensions, such as weight, density, etc., similar to water. Such is not the case and ideas formed on this basis will be misleading.

Electricity, according to our best authorities, is not a material substance. No matter how much power is being transmitted over a conductor, how much charge there may be in a condenser or in a storage battery, they will weigh no more than when electrically dead or disconnected and discharged. Its exact nature is unknown. The terms "current," "volume," "direction," "density," "polarity," etc., are simply arbitrary terms adopted to designate the different manifestations of its force.

To get an idea of the electric circuit it is many times compared with a water system consisting of a pressure pump, piping of various sizes, storage tank, valves, meters, gauges, etc., with which all are familiar. This differs from the electric circuit in that the water is something tangible which we can appreciate with several of our senses, as we can see it, feel it, hear it (if it is running), taste it, and sometimes smell it. We know definitely what water is composed of, how it behaves under certain conditions and the laws of nature which govern its behavior. This is more than we can say of electricity—we do not know what it is,

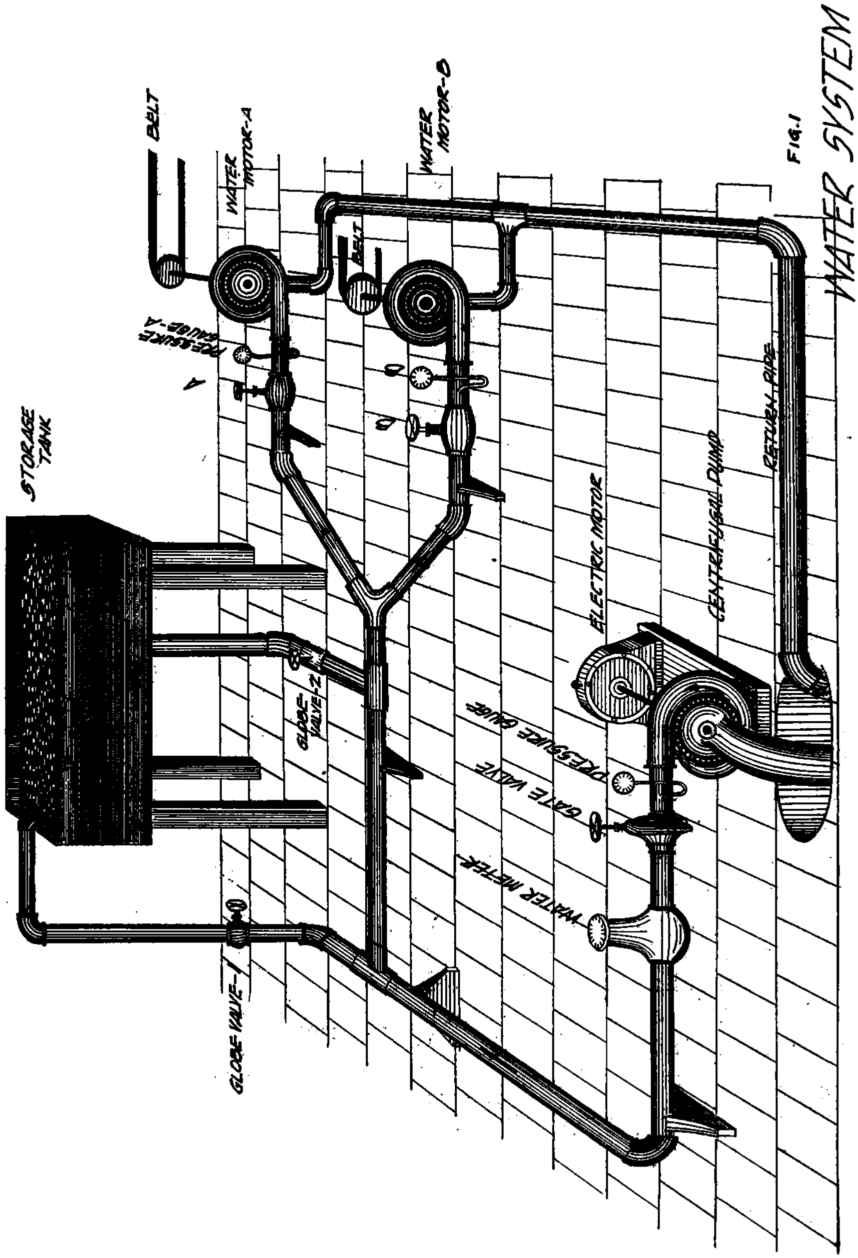

STORAGE TANK
BELT
WATER MOTOR-A
WATER MOTOR-B
BELT
PRESSURE GAUGE-A
A
B
GLOBE-VALVE-2
GLOBE VALVE-1
ELECTRIC MOTOR
CENTRIFUGAL PUMP
RETURN PIPE
PRESSURE GAUGE
GATE VALVE
WATER METER
FIG.1
WATER SYSTEM

Fig. 1.

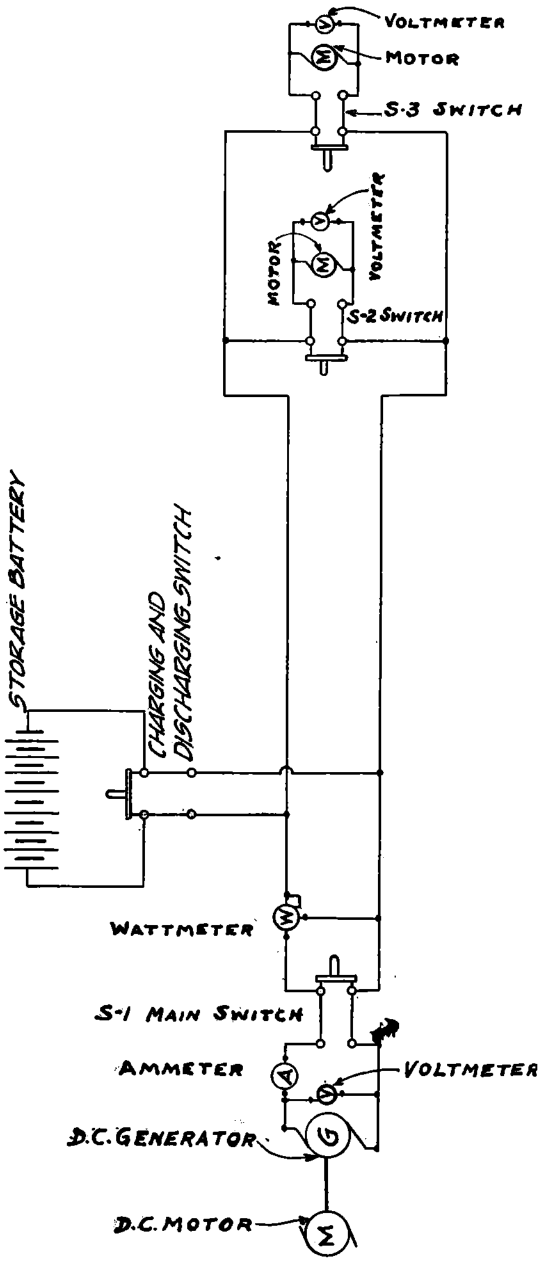


Fig. 2.
ELECTRIC SYSTEM.

but we know how it is produced for various purposes, how it behaves under certain conditions, as its laws are very well understood, and can also see the effects produced and appreciate them. For this reason, it should be considered in the same sense as light, heat or chemical action, studying the causes and effects.

The *conductors* and apparatus beyond the switch are said to be *dead* when they are cut off by the opened switch and *alive* when the current is on.

The generator, if a dynamo, corresponds to the pump in the water system, as each develops a pressure in the circuit, which is responsible for a flow through the system. Each must be driven by some power such as a steam engine, turbine, water wheel or motor. The rating of a pump is usually in terms such as gallons per hour at a given number of revolutions per minute and raising the water a given number of feet, or, what is the same thing, at a given number of pounds pressure per square inch. A generator is rated in horse-power or kilowatts when running at a given speed and developing a given electrical pressure, for example, 50 horse-power, 1000 revolutions per minute, 115 volts, 325 amperes.

The *voltmeter* in the electrical circuit registers the electrical pressure developed by the generator and corresponds to the *pressure gauge* of the water system.

Comparison of Electric with Water System.

Electric System		Water System
M—Motor	corresponds with	Motor driving pump
G—Generator	" "	Centrifugal pump.
V—Voltmeter	" "	Pressure gauge.
S-1—Main Switch	" "	Gate valve.
W—Wattmeter	" "	Water meter.
Storage Battery	" "	Storage tank.
Charging and Discharging Switch	" "	Globe valves 1 and 2.
Wiring	" "	Pipe system.
S-2—Switch	" "	Globe valve A.
M & V—Motor and Voltmeter controlled by S-2	" "	Water Motor A and Pressure Gauge A.
S-3—Switch	" "	Globe valve B.
M & V—Controlled by S-3	" "	Water Motor B and Pressure Gauge B.

The unit of electrical pressure is the *volt*, and will be constantly referred to in all electrical papers or discussions. It is a term which corresponds to the water pressure, which is in pounds per square inch.

The ordinary lighting circuit is 110 volts, while the trolley circuits are usually 500 to 600 volts, being considered dangerous.

Other terms meaning the same as electrical pressure are *tension*, *voltage*, E.M.F., which is an abbreviation of *electro-motive force*, *potential difference*. For example, it is common to speak of a high tension line, the voltage of a lighting circuit or motor, the E.M.F. of a battery, etc.

The International Volt is that E.M.F. that when steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere, and which is practically $\frac{1000}{1434}$ of the E.M.F. of a standard Clark cell at a temperature of 15° C. The Clark cell is a small cell used for standardization purposes only, as it retains a steady E.M.F. for several years if no current is drawn from it. The elements are mercury for positive electrode and amalgamated zinc for the negative electrode and the electrolyte is a solution of zinc sulphate and mercurous sulphate. It gives an E.M.F. of 1.434 volts at 15° C.

The gate valve is used to shut off the flow of water from the pump to the system and thus acts the same as the knife switch of the electrical system. It is different in this respect—with the valve the flow can be gradually reduced from the full capacity of the piping to nothing, while with the switch there are no intermediate quantities. The electric circuit is either closed through it or it is opened entirely by it.

The water meter measures directly the number of gallons which have passed through it, and is independent of the pressure per square inch, but it does not show the rate of flow at any given instant. The ammeter measures in *amperes* the rate of flow of the electric current at any instant.

The international ampere is that constant current which, when passing through a certain solution of nitrate of silver in water, will cause a deposit of silver at the rate of 0.001118 grains per second.

The product of volts and amperes is known as *watts*. The *watt* is the unit of power, and is obtained when the electro-motive force or pressure of a circuit is one volt and the rate of flow is one ampere. The term "kilowatt" means 1000 watts, and is practically $1\frac{1}{3}$ horse-power, or to be exact, 746 watts equals 1 horse-power. The power transmitted by a circuit, and the rating of power apparatus, are usually expressed in watts.

The value of the unit "horse-power" is understood to mean 33,000 foot pounds per minute. That is, a power capable of raising 33,000 pounds one foot in one minute against the force of gravitation. This was originally established by James Watt, the inventor of the steam engine, to give a rating to his engine. It was found by him to be about equivalent to the power of a strong London draught horse.

If the current was measured in a lighting circuit of 110 volts, supplying eight lamps of 40 watts each, it should be found to be approximately 2.9 amperes. This is found as follows: Each of the lamps consumes 40 watts, then the total power is 8×40, or 320 watts. These are on the 110 volt circuit, and, as stated above, watts equals volts, times amperes, then the number of amperes would be 320 divided by 110 or 2.9.

All conductors offer more or less resistance to the flow of current through them. In circuits employing alternating or pulsating current, other factors enter which will be considered later. The resistance corresponds closely to the friction offered to moving bodies. Friction is manifested by the generation of heat which, of course, requires a certain amount of energy to produce and which is usually a total loss. The unit of resistance in the electrical circuit is called the *ohm*, and is that resistance which is offered to the flow of one ampere of current if one volt pressure is required to produce and maintain that current.

The international ohm is that resistance offered to an unvarying electric current by a column of mercury 106.3 cm. long, at a temperature of melting ice, 0° C., of unvarying cross section, and weighing 14.4521 grams.

The flow of current through conductors offering a certain resistance generates heat, which is lost or dissipated in the atmosphere. This is the big loss in power transmission over long distances, but it can be very accurately calculated if the length, material, size and temperature of the conductor are known. Unlike friction, this is independent of the shape of the conductor. It can be determined by measuring the voltage required to establish and maintain a given current which should also be measured by proper instruments.

The mile-ohm is a term now used frequently by some engineers in speaking of different line conductors. This means the weight of a piece of wire a mile long that has a resistance of one ohm, and is found by multiplying the weight per mile of the material by the resistance in ohms per mile. From the wire table No. 12 BB iron wire weighs 170 pounds per mile and has a resistance of 34.12 ohms. Then $170 \times 34.12 = 5800$, the number of pounds per mile-ohm of this material and gauge. It is evident that the poorer the conductor the higher will be this weight, as the cross section will necessarily be larger to secure this low resistance. Some of the common conductors are as follows:

Soft copper	859 pounds per mile-ohm.
Hard copper	880 pounds per mile-ohm.
Aluminum	384 pounds per mile-ohm.
Iron	4700–6000 pounds per mile-ohm.

Ohm's law should be memorized as it is continually used in connection with electrical work. It is as follows: "The value of current, expressed in amperes, is invariably equal to the electro-motive force expressed in volts, divided by the resistance expressed in ohms." This may be more simply expressed by the equation:

$$\text{Current} = \frac{\text{Electro-motive Force}}{\text{Resistance}}$$

or using the units of each quantity

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

These are usually abbreviated, using "I," or as was earlier used, "C" for amperes; "E" for volts, and "R" for ohms. Then the above becomes:

From this equation: $$I = \frac{E}{R} \qquad \text{eq. (1)}$$

$$E = R\,I \qquad \text{eq. (2)}$$

and: $$R = \frac{E}{I} \qquad \text{eq. (3).}$$

so that if any two are known, the other can be determined.

Wire tables show the resistance per thousand feet and per mile of annealed and hard-drawn copper, BB and EBB galvanized iron wire and galvanized steel wire, so that from the length of wire that is to be used on a given circuit, the proper voltage can be determined to obtain a given current. In deciding upon a size of wire for a given service, consideration should also be given to the safe current carrying capacity of the wires, as shown in another table. These are limited by the heating effects of the currents.

To illustrate the application of the above formulas, take a familiar example. Ten gravity cells are connected in series, giving say 10 volts on a telegraph circuit composed of 3250 ft. of No. 10 B. & S. copper wire through two 50 ohm sounders and two keys. At a temperature of 68 degrees F. the wire has a resistance (from the wire table) of .9972 ohms per M. ft. What would be the value of the current in amperes, assuming that the internal resistance is two ohms per cell?

The total resistance, disregarding the resistance of the keys which is negligible, is the sum of the other resistances as they are all in series. This is $3.25 \times .9972 + 50 + 50 + 20 = 123.24$ ohms. Then from substitution in eq. 1

$$I = \frac{10}{123.24} = .08114 \text{ amperes.}$$

In like manner, either of the other two quantities may be found if any two are known.

Example: The internal resistance of a battery is 2 ohms, the external resistance of the circuit is 12 ohms, the current is 1.5 amperes. What is the voltage of the battery?

Solution: The total resistance of the circuit is $2+12=14$ ohms. From equation 2, the voltage is equal to the resistance multiplied by the current or $E=RI$. In this problem $R=14$ and $I=1.5$. Then $E=14\times1.5=21=$ number of volts.

Example: What is the total resistance of the circuit through which there is a current of 0.5 amperes when the E.M.F. of a battery is found to be 18 volts?

Solution: From equation 3, the resistance equals the number of volts divided by the number of amperes current, or $R=\frac{E}{I}$. By substituting the values from this equation $E=18$ and $I=0.5$. Then

$$R = \frac{18}{0.5} = 36 = \text{number ohms resistance.}$$

Watts = volts times amperes.

$$W = E \times I \qquad \text{eq. (4)}$$

From equation 4, the following equations may be obtained:

$$E=\frac{W}{I} \qquad \text{eq. (5)}$$

$$I=\frac{W}{E} \qquad \text{eq. (6)}$$

Since in equation (2) $E=RI$, we can substitute this value in equation 4 and obtain:

$$W=I^2R \qquad \text{eq. (7)}$$

The quantity I^2R in equation 7 is sometimes called the "copper loss" in a line, as it is that which is consumed by the conductors and is dissipated as heat. In the regular transmission line, this is spread over the entire length of the line and the temperature rise of the wires, if of the proper size, is so small that it could hardly be detected from the heat emitted. With the resistance coils of trolley car heating devices, electric soldering irons, glue pots, and many household devices, such as toasters, electric irons and heaters, this temperature rise is very appreciable.

From equation 7, the following equations may be obtained:

$$R=\frac{W}{I^2} \qquad \text{eq. (8)}$$

$$I=\sqrt{\frac{W}{R}} \qquad \text{eq. (9)}$$

By combining equations 1 and 4, that is, substituting the value of $I=\frac{E}{R}$ for I in equation 4 this may be written:

$$W=\frac{E^2}{R} \qquad \text{eq. (10)}$$

or

$$R=\frac{E^2}{W} \qquad \text{eq. (11)}$$

and

$$E=\sqrt{WR} \qquad \text{eq. (12)}$$

Example (*a*): How many watts of power are being furnished to run a motor if an ammeter (current measuring instrument) shows that 40 amperes are flowing and the voltmeter (pressure measuring instrument) indicates 108 volts?

Solution: From equation 4, watts are equal to the product of the number of volts and amperes, that is $W = EI$. In this problem $E = 108$ and $I = 40$, then $W = 108 \times 40 = 4320$ = the number of watts.

Example (*b*): When a wattmeter (power measuring instrument), connected in a circuit registers 50 watts and the ammeter shows 2 amperes, what is the voltage?

Solution: From equation 5, the pressure in volts is found by dividing the number of watts by the number of amperes, that is $E = \frac{W}{I}$.

From the quantities in the problem $W = 50$ and $I = 2$, then by substituting these quantities in the equation

$$E = \frac{50}{2} = 25 = \text{voltage of circuit.}$$

Example (*c*): If it was required to know the current carrying capacity that a wire must have to transmit 50 watts at 25 volts, it could be found by applying formula No. 6.

Solution: Watts = 50 and volts = 25, then by substituting these values in the equation $I = \frac{W}{E}$ the quantities above, this becomes

$$I = \frac{50}{25} = 2 = \text{the current in amperes.}$$

Example (*d*): A certain transmission line is carrying 60 amperes and the total line resistance is 10 ohms. What is the total line loss in kilowatts?

Solution: From equation 7, the watts are equal to the product of the current squared and the resistance, that is $W = I^2R$.

In this problem $I = 60$ and $R = 10$, then by substituting these values in the equation it would read as follows:

$W = 60^2 \times 10 = 60 \times 60 \times 10 = 36000$ watts; 36000 watts = 36 kilowatts.

Example (*e*): If the watts and current were the same as in example (*b*) above, that is $W = 50$ and $I = 2$, what is the resistance of the circuit?

Solution: From equation 8, the resistance is equal to the number of watts divided by the square of the current, or $R=\frac{W}{I^2}$. In this example $W=50$, $I=2$, and by substituting in the equation $R=\frac{50}{2^2}=50\div 4=12.5$ = number of ohms resistance in the circuit.

Example (*f*): What current must be provided for if it is desired to deliver 40 watts through a resistance of 8 ohms?

Solution: From equation 9, the current is equal to the square root of the number of watts divided by the number of ohms, or this may be written $I=\sqrt{\frac{W}{R}}$. In the problem $W=40$ and $R=8$. Then by substituting in the equation the quantity $I=\sqrt{\frac{40}{8}}=\sqrt{5}=2.23$ = the number of amperes in the circuit.

Example (*g*): What is the total amount of power wasted in a circuit if the voltage drop is 60 and the total line resistance is 10 ohms?

Solution: From equation 10 the total watts is equal to the square of voltage divided by the resistance, or $W=\frac{E^2}{R}$. In this problem $E=60$ and $R=10$. By substituting these values in equation 10, $W=\frac{60^2}{10}$ $=60\times 60\div 10=360.$ = number of watts lost.

Example (*h*): If the voltage of a circuit was known to be 120 and the total power supplied was 2 kilowatts (K. W.), what is the total resistance of the circuit?

Solution: From equation 11, the total resistance is equal to the square of the voltage divided by the total watts or $R=\frac{E^2}{W}$. By substituting the values of $E=120$ and $W=2000$ in the above equation the problem would be solved as follows:

$$R=\frac{120^2}{2000}=\frac{14400}{2000}=\frac{144}{20}=7.2$$ = number of ohms resistance in circuit.

Example: What will it cost to use an electric soldering iron three hours when the power costs 10 cents per kilowatt hour, if the iron is working on 110 volts and requires one ampere of current?

Solution: The total power consumed in watt-hours would be the product of volts, amperes and hours, or $110 \times 1 \times 3 = 330$ watt-hours. From page 33, one kilowatt is equal to 1000 watts. Then:

$$\frac{330}{1000} \times \$0.10 = \$.033. \quad \text{Answer.}$$

The resistance of the winding in this iron was $\frac{110}{1} = 110$ ohms. The wire had to be of such a size that it would safely carry one ampere of current and not heat up hotter than is necessary for soldering.

In the design of electrical apparatus, it should always be borne in mind that a certain amount of energy is lost as heat, depending upon the current and resistance, and that provision must be made to radiate this or else excessively high temperatures are sure to be reached. The hotter the conductor, if copper, the higher the resistance, and this keeps on increasing until the temperature is sufficiently high to ruin the insulation of some of the parts, which then allows them to short circuit. For this reason the temperature rise in the parts of a motor or generator is one of the things specified and which should be closely watched in tests of such equipment, and it is this factor which determines the maximum amount of current to be carried in a given size of wire on page 15.

As with the water system, the electric current or charge has a tendency to flow from a point of high potential or head to one of lower potential head or pressure.

The electric circuit, which is the external path from one terminal of the generator through the conductors and apparatus back to the other, is considered open or broken, if there is any break in the connections, which would prevent the current from flowing through the circuit. If there is a connection between the two terminals which allows the current to pass through between them without going through any of the apparatus except just the conductors, it is considered a short circuit. Unless protected by fuses or circuit breaker, a short circuit is very liable to injure the generator, the insulation of the conductors, and possibly set fire to the adjoining fittings if they are inflammable.

The heat increases very rapidly with increases of current, as from equation 7 it increases as the square of the current. To illustrate the meaning of this statement, let a certain conductor be carrying a current of say 5 amperes at a normal temperature of 60 degrees F. Now, if by some means these conductors become short circuited and the current increases to 20 amperes, what would be the result, if the fuses protecting the circuit did not blow out and open the circuit? The energy to be dissipated by radiation by the two currents is in the proportion of 5^2 to 20^2, or 25 to 400, from eq. 7. This means that there is sixteen times as much energy spent by the current increased to four times the original current as by the original. The temperature which would be reached by this would depend upon the surrounding temperature, whether the conductor was bare or insulated, whether or not there was a current of air passing over the conductor, and whether the wire, if bare, was bright or blackened.

This temperature rise is the determining factor in limiting the current allowable for a given size of wire as shown in table No. 1.

TABLE NO. 1.—ALLOWABLE CURRENTS IN INSULATED WIRE.

B. & S. GAUGE	CIRCULAR MILS	RUBBER INSULATION AMPERES	OTHER INSULATION AMPERES
18	1,624	3	5
16	2,583	6	8
14	4,107	12	16
12	6,530	17	23
10	10,380	24	32
8	16,510	33	46
6	26,250	46	65
5	33,100	54	77
4	41,740	65	92
3	52,630	76	110
2	66,370	90	131
1	83,690	107	156
0	105,500	127	185
00	133,100	150	220
000	167,800	177	262
0000	211,600	210	312

The lower limit is specified for rubber covered wires to prevent gradual deterioration of the high insulation by the heat of the wire, but not from fear of igniting the insulation. The question of voltage drop is not considered in the above table.

The carrying capacities of Nos. 16 and 18 B. & S. are given, but *no smaller than No. 14 is to be used, except in fixtures and flexible cords for portable lamps,* to comply with the rules of the National Board of Fire Underwriters.

This table has special reference to wiring for lighting and power circuits. For bell, annunciator, telephone and telegraph wiring, smaller sizes, as Nos. 19 and 22 B. & S. are sometimes used. These must not be run in conduit with the power wires though, as it would be dangerous, and is forbidden by the rules of the National Board of Fire Underwriters governing all electrical wiring and installations.

The apparatus in a circuit is said to be connected in series when it is so arranged that all the current passes through each piece of apparatus in the circuit, that is, connected one after the other. The total resistance of a series circuit is the sum of all the resistances in the circuit.

In the circuit shown in Fig. 3 let r_1, r_2, r_3, r_4 and r_5 (these are read "small r sub one," "small r sub two," etc.) be the resistance in ohms of the electrical conductors and each equal to one ohm, R_1, R_2, R_3, and R_4

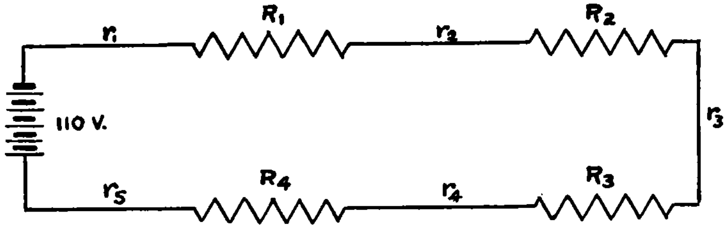


Fig. 3.
DIAGRAM OF SERIES CIRCUIT.

other resistances and each equal to two ohms. The total resistance of the circuit is the sum of these separate resistances or $5 + 8 = 13$ ohms. If the voltage of the battery is 110, then by Ohms law, eq. 1, the current flowing is $110 \div 13 = 8.46$ amperes. The current is the same in all parts of the circuit.

The value of a conductor to carry current is inversely proportional to the resistance of the conductor. That is, if one conductor has a resistance of 2 ohms and another 4 ohms, then their conducting values would be in proportion $\frac{1}{2}$ to $\frac{1}{4}$, or the one with 2 ohms resistance would be twice as good a conductor as the one having 4 ohms.

The quantity 1 divided by a number is the reciprocal of that number, thus $\frac{1}{2}$ is the reciprocal of 2 mentioned above, and is twice as good as $\frac{1}{4}$, which is the reciprocal of 4.

Conductance or conductivity is the reciprocal of resistance in ohms, and is convenient to work with in determining the current values in the different branches of a divided circuit. Its unit is called the "mho," which is ohm spelled backward.

Example: Two incandescent lamps are connected in multiple or parallel across a 110 volt D. C. circuit, one being a tungsten having a resistance of 121.2 ohms and the other a carbon having a resistance of 242.4 ohms. What is the total current flowing through these lamps?

Solution: The conductivity of one branch is $\frac{1}{121.2}$ mhos and of the other $\frac{1}{242.4}$ mhos. Then the total conductivity of the circuit will be $\frac{1}{121.2} + \frac{1}{242.4}$ or $\frac{3}{242.4}$ mhos. Their combined resistance is then $\frac{242.4}{3}$ or 80.8 ohms and the total current would be $\frac{110}{80.8}$, or 1.36 amperes.

The resistance of two conductors of the same material is inversely as their area of cross section; that is, a conductor has twice as much resistance for given length as one of the same material and same length, but twice as large cross section.

A circuit is said to be connected in multiple, parallel, shunt or divided circuit if it is so arranged that a part of the current passes through each of two or more branches. Each branch taken separately is called a shunt.

In Fig. 4 let "A" be a direct current generator 110 volts and R_1, R_2, R_3, and R_4 resistances of 5 ohms each. The resistance of the feeders "a" and "b" is so small that it may be disregarded; then the total current

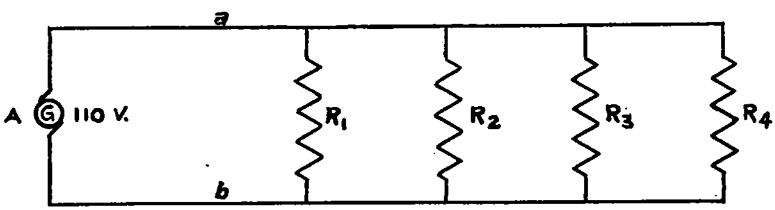


Fig. 4.
RAM OF MULTIPLE OR DIVIDED CIRCUIT.

in the circuit is obtained after first determining the resistance of the circuit. This is the reciprocal of the sum of the reciprocals of the individual resistances forming the divided circuit, or in multiple.

$$\text{Thus:}\quad R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \ldots} \qquad \text{eq (13)}$$

The quantities R_1, R_2, R_3 and R_4 represent the resistances in ohms of the various branches of the divided circuit.

The quantity $+ \ldots$ is read "plus and so on," meaning that if there were more than four branches in the divided circuit, they would be treated the same by continuing the process of adding the reciprocals or conductivities of the individual branches.

By substituting in equation 13 the values of the resistance in the different branches, we obtain,

$$R = \frac{1}{\frac{1}{5} + \frac{1}{5} + \frac{1}{5} + \frac{1}{5}} = \frac{1}{\frac{4}{5}} = 1\tfrac{1}{4} = \text{number of ohms.}$$

Then by substituting this value of R in equation 1, which is $I = \frac{E}{R}$, we have $I = \frac{110}{1.25} = 88$ amperes, total current in circuit.

Current through any of the branch circuits is found by dividing the total voltage 110 by the resistance of that branch, or $110 \div 5 = 22$, the number of amperes. This is seen to be correct, as the four resistances are equal and the total current is 88 amperes.

In some arc light, telephone and nearly all Morse telegraph systems the series circuit is employed. With this, the whole circuit is interrupted if there is a single connection broken. The method of breaking the telegraph circuit in order to have a part of a message repeated is accomplished by merely opening the circuit at any of the keys which are in series on the Morse circuit. This break is detected by the sender, as his relay or sounder fails to respond to his signals.

With the multiple or bridging connection, only that part of the circuit is thrown out of service on which the break occurs. Both methods of connection are especially adapted for certain classes of service. These circuits will be taken up further in the papers on telephone, telegraph and power equipment.

There are several symbols that are frequently used on drawings of electric circuits and with which it is well to become familiar. They are the same as used by signal, electric light, power, telephone and telegraph divisions, and have been standardized by the national engineering organizations, so that if one has occasion to read or study drawings of electrical circuits of any nature some of them are very sure to be found.

SYMBOLS AND ABBREVIATIONS.

A.C. Alternating current.

D.C. Direct current.

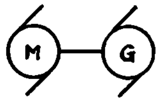
Cells in series. State number and type.

Direct current generator.

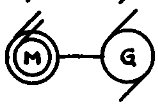
Alternating current generator.

Direct current motor.

Alternating current motor.



D.C.—D.C. Motor generator.



A.C.—D.C. Motor generator.

Ammeter.

Voltmeter.

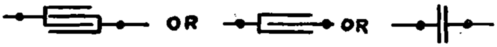
Wattmeter.


Fixed non-inductive resistance.


Variable non-inductive resistance.

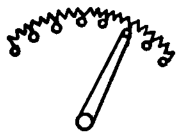

Impedance or inductive resistance.

Impedance with Iron Core.

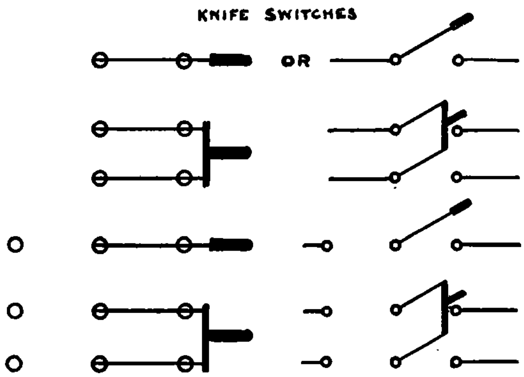


Condensers.

Fuse.



Rheostat.

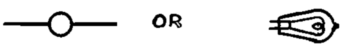


Single pole, single throw.
S. P. S. T.

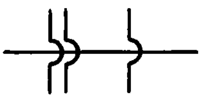
Double pole, single throw.
D. P. S. T.

Single pole, double throw
S. P. D. T.

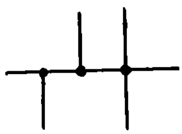
Double pole, double throw.
D. P. D. T.



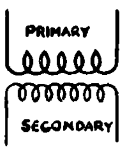
Incandescent Lamps.



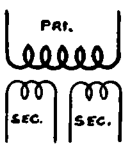
Wires cross.



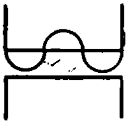
Wires join.



Transformer with one secondary.



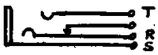
Transformer with two secondaries.



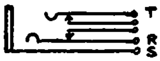
Rectifier.

Ground connection.

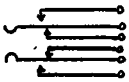
Lightning arrester.



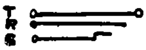
Single cut-off telephone jack.



Double cut-off telephone jack.

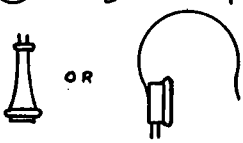


Telephone key. Breaks two and makes two contains.



Plug with tip, ring and sleeve connection.

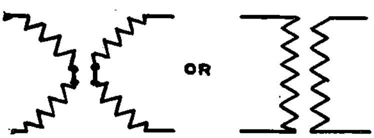
Telephone transmitter.



Telephone receiver.

Alternating current ringer.

Direct current bell.



Repeating coil or retardation coil

Thermometers.

In the different formulas, magazine articles, books on technical subjects, etc., there is frequently reference made to the different thermometer scales. The principle ones are Centigrade and Fahrenheit.

The Centigrade scale has 0° for the freezing point of water and 100° for the boiling point of water at mean atmospheric pressure at sea level, which is 14.7 pounds per square inch.

The Fahrenheit scale, which is most common, has 32° for freezing point of water and 212° for boiling point. From this it is seen that the difference between the freezing and boiling points on the Fahrenheit scale is 180°, which is equal to 100° on the Centigrade scale. This furnishes a basis for the comparison which follows:

1 Fahrenheit degree equals 5/9 degrees Centigrade.

1 Centigrade degree equals 9/5 degree Fahrenheit.

Temperature Fahrenheit equals 9/5 temperature C + 32°.

Temperature Centigrade equals 5/9 (temperature F—32°).

Table No. 2.—Comparison of Thermometer Scales.

1		2		3	
C.	F.	C.	F.	C.	F.
—40	—40	10	50	60	140
—35	—31.	15	59.	65	149.
—30	—22.	20	68.	70	158.
—25	—13.	25	77.	75	167.
—20	—4.	30	86.	80	176.
—15	+5.	35	95.	85	185.
—10	14.	40	104.	90	194.
—5	23.	45	113.	95	203.
0	32.	50	122.	100	212.
+5	41.	55	131.		

The freezing point of pure water is nearly constant for the ordinary air pressure upon its surface; at high pressures the freezing point is lowered at the rate of .0133° F. for each additional atmosphere (14.7 pounds per square inch) of pressure. Water under ice in the coldest winter weather cannot be colder than 0° C.

Wire or Conductors.

That different metals and alloys offer different resistances to the flow of current is well known. The ones with which we are most familiar are copper and iron. All of the different metals are affected by chemical impurities, mechanical treatment and by changes in the temperature to which they are subjected. It is difficult to determine the nature or extent of the impurities, except by making a careful chemical analysis of the sample in question. The mechanical treatment has reference to the methods employed in drawing the wire which fixes the structure or arrangement of particles forming it, as hard-drawn and annealed copper. These are both of the same material, but are differently treated in the process of manufacture.

Hard-drawn Wire.

The processes used in the manufacture of wire are somewhat out of the field of this paper, but it is believed that it would be desirable to have some idea regarding the methods of producing the hard-drawn copper line wire with which we are familiar.

The metal is first cast into "ingots" or "blooms" about six inches square and three or four feet long. It is then passed through a series of rolls, which change it to a long rod of small diameter, circular in cross section and three-eighths of one inch in diameter. If it is desired to produce a wire of smaller diameter, the rods are drawn through a series of dies, each reducing it by a certain amount. These dies are made of hardened steel, agate or sometimes lined with diamonds, as it is extremely important that these dies do not change by wear. For this reason the very hardest substances are necessary.

The process of pulling the wires through these dies to reduce the diameter changes greatly the structure of the metal, the rod becoming greatly compressed and hardened, which at the same time increases the tensile strength of the wire. This, however, reduces the elasticity accordingly, so that there is almost no stretch or elongation noticeable before the wire breaks when put under test. This hardening effect is very similar to the results obtained by tempering steel. The hard-drawing process increases the tensile strength to nearly double that of the annealed copper, although the resistance is increased two to four per cent. The effect of the hard-drawing process seems to be confined principally to a very thin layer or the skin on the surface of the wire, as any slight scratch, nick or cut having a tendency to destroy or cut through this skin very greatly reduces the strength of the wire. If the specimen so punished is put under test, it is very sure to break at the point where this cut or nick occurred, and the entire effect of the hard drawing, which was primarily to increase tensile strength, will be lost. This brings us to the point that it was desired to bring out, that "Hard-drawn Copper Wire must be Handled Carefully" to prevent injury to this surface skin.

The increase in tensile strength produced by the hard-drawing processes is more marked in the smaller than in the larger gauges, as the wire has been subjected to the drawing process a few more times. Thus the smaller sizes have a higher tensile strength per square inch than the larger sizes. The soft-drawn copper wire has a tensile strength of about 34,000 pounds per square inch, while hard-drawn is 50,000 pounds for 0000 and 00; 55,000 for No. 0; 57,000 for No. 1 and 60,000 for the smaller sizes.

In this drawing process, a lubricant of tallow or soapy water is used on the wire. When the wire is received from the factory, it sometimes has a thin film of grease on the surface; this is more noticeable in cold weather. It should be carefully removed at the ends when making a splice in order to prevent the wire from slipping in the sleeve. The wire should not be scraped to remove this film, as the wire would doubtless be injured sufficiently to reduce the tensile strength, but it may be removed by wiping with a coarse cloth, waste or burlap.

Iron Wire:

There are three kinds of galvanized wire used for line construction, as shown in the wire tables, and which are regular commercial products. The galvanizing of the three kinds E. B. B., B. B. and Steel are all the same, but the difference is in the quality of the wire itself. "E. B. B." is an abbreviation for "Extra Best Best," and is the best conductor of the three, having the lowest resistance, but the lowest tensile strength. It is used largely by some telegraph companies and some railway companies for telegraph line construction. It has a weight of 4700 to 5000 pounds per mile-ohm, and is the softest of the three. "B. B." is an abbreviation for "Best Best" and is somewhat inferior to the E. B. B. as an electrical conductor, having a higher resistance, but is better mechanically, as its tensile strength is higher. The weight per mile-ohm is 5600 to 6000 pounds. This grade is used largely by telephone companies, especially in the rural districts.

"Steel" wire is the poorest conductor, but has the highest tensile strength. It is many times used on comparatively long spans when iron wire is used in the regular line construction, as it is much stronger. As a general rule high strength in a conductor is obtained at the expense of conductivity, that is, for the same material the higher the strength the higher the resistance. It weighs 6500 to 7000 pounds per mile-ohm.

The galvanizing process consists in cleaning the wire by immersing or "pickling" the wire for some time in a dilute solution of sulphuric acid (oil of vitriol) and passing the wire slowly through a bath of melted zinc, or spelter as it is sometimes called. The surface of the zinc is covered with a flux of sal-ammoniac or similar compound which helps the coating to adhere to the wire. When the wire comes from this bath the excess zinc is removed, leaving the wire covered with a continuous coating of zinc, which is comparatively free from rusting in many climates. If the iron was not properly cleaned, the flux on the surface of the melted zinc not right or metal not of the proper temperature, the coating is apt to be uneven, rough or lumpy. These imperfections should be watched for when inspecting this material.

Test for galvanizing is made by immersing the sample for one minute in a dilute solution of copper sulphate, 36 parts by weight of crystals and 100 parts by weight of water, and then wiping dry. This operation should be repeated four times before any red spots occur on the wire. The sample should be rinsed in clean water and wiped dry after each operation. The red spots are deposits of copper on the exposed iron surface after the zinc coating has been destroyed. Do not use the solution for more than one test.

Approximate weight of iron wire may be found by dividing circular mils (diameter in thousandths squared) by 72, which will give pounds per mile. Pounds per thousand feet found by dividing circular mils by 380. It is nearly seven-eighths the weight of copper wire of same diameter.

TABLE NO. 3.—PROPERTIES OF COPPER WIRE.

Number B. & S. Gauge.	Diameter "d" in Mils. 1 Mil. = .001 Inch.	AREA IN		WEIGHT PER UNIT OF LENGTH. SPECIFIC GRAVITY, 8.89.				RESISTANCE IN INTERNATIONAL OHMS AT 68° F. ACCORDING TO MATTHIESSEN'S STANDARD OF RESISTIVITY.					Tensile Sgth. in Pounds.		Elong. % in 1 Foot.		Safe Cur. Amperes.		Turns per Lin. In. Cotton Covered.	Temperature Coefficients.	
		Circular Mils d^2.	Square inches $d^2 \times .7854$.	Pounds per 1000 Feet.	Pounds per Mile.	Feet per Pound.	Ohms per Pound Annealed.	Ohms per 1000 Ft. Annealed.	Ohms per 1000 Ft. Hard-Drawn.	Ohms per Mile. Annealed.	Ohms per Mile. Hard-Drawn.	Feet per Ohm Annealed	Annealed.	Hard-Drawn.	Annealed.	Hard-Drawn.	Bright Wire Paneled.	Black Wire in Free Air.		Temp. in Deg. C.	Resistance per Mil-Foot; Ohms.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0000	460.000	211600.00	.166190	640.5	3381.4	1.561	.00007639	.04893	.050036	.25835	.26419	20440	5650	9975	45.0	5.00	146.0	346.0	1.6	0	1.00000
000	409.642	167806.43	.131794	508.0	2682.2	1.969	.0001215	.06170	.063094	.32577	.33314	16210	4475	7900	45.0	5.00	127.0	292.0	1.6	1	1.00387
00	364.796	133076.66	.104518	402.8	2126.8	2.482	.0001931	.07780	.079558	.41079	.42007	12850	3550	6250	45.0	4.00	110.0	247.0	1.8	2	1.00776
0	324.861	105534.50	.082887	319.5	1686.9	3.130	.0003071	.09811	.10033	.51802	.52973	10900	2800	4950	45.0	4.00	95.0	209.0	2.8	3	1.01166
1	289.296	83692.67	.065732	253.3	1337.2	3.947	.0004883	.1237	.12649	.65314	.66790	8083	2225	3925	42.0	4.00	83.0	177.0	3.2	4	1.01558
2	257.626	66371.31	.052128	200.9	1060.6	4.977	.0007765	.1560	.15953	.82368	.84239	6410	1750	3125	39.0	3.00	72.0	148.0	3.4	5	1.01950
3	229.422	52634.37	.041339	159.3	841.09	6.276	.001235	.1967	.20114	1.0386	1.0621	5084	1400	2450	36.0	3.00	63.0	127.0	3.9	6	1.02343
4	204.307	41741.32	.032784	126.4	667.39	7.914	.001936	.2480	.25361	1.3094	1.3392	4031	1100	1950	33.0	2.50	55.0	108.0	4.5	7	1.02738
5	181.941	33102.37	.025999	100.2	529.06	9.980	.003122	.3128	.31987	1.6516	1.6889	3197	875	1550	30.5	2.50	48.0	91.0	5.0	8	1.03134
6	162.022	26251.37	.020618	79.46	419.55	12.58	.004963	.3944	.40332	2.0825	2.1295	2535	700	1225	28.0	2.00	42.0	78.0	5.6	9	1.03531
7	144.285	20818.35	.016351	63.02	332.75	15.87	.007892	.4973	.50854	2.6258	2.6850	2011	550	975	26.0	2.00	37.0	66.0	6.2	10	1.03929
8	128.490	16509.64	.012967	49.98	263.89	20.01	.01255	.6271	.64127	3.3111	3.3859	1595	425	775	24.0	1.75	32.0	56.0	7.0	11	1.04328
9	114.434	13092.75	.010283	39.63	209.24	25.23	.01995	.7908	.80876	4.1753	4.2769	1265	325	600	21.5	1.75	28.2	48.0	7.5	12	1.04728
10	101.897	10383.02	.0081548	31.43	165.95	31.82	.03173	.9972	1.0199	5.2657	5.3848	1003	275	475	19.0	1.50	24.9	41.0	8.5	13	1.05129
11	90.743	8234.11	.0064656	24.93	131.63	40.12	.05045	1.257	1.2854	6.6369	6.7869	795.3	200	375	17.5	1.50	21.9	35.0	9.7	14	1.05532
12	80.808	6529.95	.0051287	19.77	104.39	50.59	.08022	1.586	1.6218	8.3741	8.5633	630.7	175	300	16.0	1.25	19.3	30.0	11.2	15	1.05935
13	71.962	5178.48	.0040672	15.68	82.791	63.79	.1276	1.999	2.0443	10.555	10.794	500.1	125	225	14.5	1.20	17.0	25.8	12.0	16	1.06339
14	64.084	4106.72	.0032254	14.43	76.191	80.44	.2028	2.521	2.5779	13.311	13.612	396.6	100	200	13.0	1.25	15.0	22.2	13.0	17	1.06745
15	57.069	3256.78	.0025579	9.858	52.050	101.4	.3225	3.179	3.2508	16.785	17.165	314.5	80	150	12.0	1.25	13.3	19.1	15.3	18	1.07152
16	50.821	2582.74	.0020285	7.818	41.277	127.9	.5128	4.009	4.0996	21.168	21.646	249.4	60	125	11.0	1.25	11.8	16.5	16.7	19	1.07559
17	45.257	2048.29	.0016087	6.200	32.736	161.3	.8153	5.055	5.1692	26.691	27.294	197.8	50	90	10.0	1.25	10.4	14.2	17.7	20	1.07968
18	40.303	1624.30	.0012757	4.917	25.960	203.4	1.296	6.374	6.5180	33.655	34.416	156.9	40	70	9.0	1.25	9.2	12.3	19.5	21	1.08378
19	35.890	1288.13	.0010117	3.899	20.595	256.5	2.061	8.038	8.2196	42.441	43.400	124.4	30	60	8.0	1.20	8.2	10.7	22.7	22	1.08788
20	31.961	1022.53	.00080231	3.092	16.324	323.4	3.278	10.14	10.372	53.539	54.749	98.66	25	45	7.0	1.20	7.2	9.2	27.0	23	1.09200
21	26.463	810.12	.00063626	2.452	12.946	407.8	5.212	12.78		67.479		78.24	23	39	6.0	1.00			31.0	24	1.09612
22	25.346	642.45	.00050457	1.945	10.268	514.2	8.287	16.32		85.114		62.05	21	32	5.0	1.00			34.4	25	1.10026
23	22.572	509.49	.00040015	1.542	8.142	648.4	13.18	20.32		107.29		49.21	18	26	5.0	1.00			38.2	26	1.10440
24	20.101	404.04	.00031733	1.223	6.457	817.6	20.95	25.63		135.33		39.02	16	20	5.0	1.00			42.3	27	1.10856
25	17.901	320.42	.00025166	.9699	5.121	1031	33.32	32.31		170.59		30.95	12	16	5.0	1.00			47.0	28	1.11272
26	15.940	254.10	.00019958	.7692	4.061	1300	52.97	40.75		215.16		24.54							52.0	29	1.11689
27	14.196	201.52	.00015827	.6100	3.221	1639	84.23	51.35		271.29		19.46							57.0	30	1.12107
28	12.642	159.81	.00012551	.4837	2.554	2067	133.9	64.70		242.09		15.43							63.4	40	1.16332
29	11.258	126.74	.000099536	.3836	2.025	2607	213.0	81.70		431.37		12.24							70.1	50	1.20625
30	10.025	100.51	.000078936	.3042	1.606	3287	338.6	103.0		543.84		9.707							77.1	60	1.24965
31	8.928	79.70	.000062599	.2413	1.274	4145	538.4	129.9		685.87		7.698							84.6	70	1.29327
32	7.950	63.20	.000049643	.1913	1.010	5227	856.2	163.8		864.87		6.105							92.7	80	1.33681
33	7.080	50.13	.000039368	.1517	.801	6591	1361	206.6		1090.8		4.841							101.6	90	1.37995
34	6.305	39.75	.000031221	.1203	.635	8311	2165	260.5		1375.5		3.839							112.1	100	1.42231
35	5.615	31.52	.000024759	.09543	.504	10482	3441	328.4		1734.0		3.045							119.7		
36	5.000	25.00	.000019635	.07568	.400	13217	5473	414.2		2187.0		2.414							130.6		
37	4.453	19.83	.000015574	.06001	.317	16666	8702	522.2		2757.3		1.915							140.6		
38	3.965	15.72	.000012345	.04759	.251	21015	13870	658.5		3476.8		1.519							151.0		
39	3.531	12.46	.0000097923	.03774	.199	26500	22000	830.4		4384.5		1.204							163.4		
40	3.145	9.88	.0000077634	.02993	.158	33416	34980	1047.0		5528.2		.955							177.6		

TABLE NO. 4.—COMPARISON OF WIRE GAUGES.

NUMBER	AMERICAN OR B. & S. Diameters in Mils.	AMERICAN OR B. & S. Areas, Circular Mils.	B. W. G. OR STUB'S Diameters in Mils.	B. W. G. OR STUB'S Areas, Circular Mils.	N. B. S., B. I. S. OR E. L. S. Diameters in Mils.	N. B. S., B. I. S. OR E. L. S. Areas, Circular Mils.
0000	460	211,600	454	206,116	400	160,000
000	410	168,100	425	180,625	372	138,384
00	365	133,225	380	144,400	348	121,104
0	325	105,625	340	115,600	432	104,976
1	289	83,521	300	90,000	300	90,000
2	258	66,564	284	80,656	276	76,176
3	229	52,441	259	67,081	252	63,504
4	204	41,616	238	56,644	232	53,824
5	182	33,124	220	48,400	212	44,944
6	162	26,244	203	41,209	192	36,864
7	144	20,736	180	32,400	176	30,976
8	128	16,384	165	27,225	160	25,600
9	114	12,996	148	21,904	144	20,736
10	102	10,404	134	17,956	128	16,384
11	91	8,281	120	14,400	116	13,456
12	81.	6,561	109	11,881	104	10,816
13	72	5,184	95	9,025	92	8,464
14	64	4,096	83	6,889	80	6,400
15	57	3,249	72	5,184	72	5,184
16	51	2,601	65	4,225	64	4,096
17	45	2,025	58	3,364	56	3,136
18	40	1,600	49	2,401	48	2,304
19	36	1,296	42	1,764	40	1,600
20	32	1,024	35	1,225	36	1,296
21	28.5	812.3	32	1,024	32	1,024
22	25.3	640.1	28	784	28	784

TABLE NO. 5.—DOUBLE GALVANIZED TELEGRAPH AND TELEPHONE WIRE.

NUMBER. Birmingham Wire Gauge	Diameter in Inches	Weight in Pounds per Mile.	Put Up in Bundles of	APPROXIMATE BREAKING STRAIN IN POUNDS E. B. B.	APPROXIMATE BREAKING STRAIN IN POUNDS B. B.	APPROXIMATE BREAKING STRAIN IN POUNDS Steel	AVERAGE RESISTANCE IN OHMS AT 68 DEGREES F. E. B. B.	AVERAGE RESISTANCE IN OHMS AT 68 DEGREES F. B. B.	AVERAGE RESISTANCE IN OHMS AT 68 DEGREES F. Steel
4	.238	811	$\frac{1}{4}$ mile	2433	2676	3000	5.98	7.15	8.32
6	.203	590	$\frac{1}{3}$ "	1770	1947	2183	8.14	9.83	11.44
8	.165	390	$\frac{1}{2}$ "	1170	1287	1443	12.43	14.87	17.31
9	.148	314	$\frac{1}{2}$ "	942	1036	1162	15.44	18.47	21.62
10	.134	258	$\frac{1}{2}$ "	774	851	955	18.80	22.48	26.16
11	.120	206	$\frac{1}{2}$ "	618	680	762	23.54	28.15	32.76
12	.109	170	$\frac{1}{2}$ "	510	561	629	28.53	34.12	39.70
14	.083	99	$\frac{1}{2}$ "	297	327	366	49.00	58.58	68.18

Frequent reference will be made to the different wire gauges B. & S., B. W. G., N. B. S., Stub's and A. W. G. These are abbreviations for Brown & Sharp, Birmingham Wire Gauge, New British Standard, Stub's and American Wire Gauge, respectively.

The A. W. G. is the same as B. & S.; the B. W. G. is the same as Stub's; the British Imperial Standard is the same as the New British Standard or British Legal Standard.

The B. & S. Gauge originated in this country. The sizes in this system range in diameter from No. 0000, having diameter of .460 inches, to No. 40, having a diameter of .003144 inches. This gauge is so arranged that successive numbers vary in diameter in the ratio 1.123 and the diameters double almost exactly every sixth increase in size. The areas of the cross sections double almost exactly every third increase in size. The No. 10 B. & S. has a diameter nearly one-tenth of an inch and a resistance of one ohm per thousand feet at ordinary temperature. This information is many times valuable when the size or resistance of a given copper wire is wanted, and a wire table is not at hand. For instance: No. 10 has an area of 10381 circular mils with resistance 1 ohm per thousand feet; No. 13, 5178 circular mils and resistance 2 ohms; No. 16, 2582 circular mils and resistance 4 ohms; No. 7, 20816 circular mils and resistance .5 ohms.

Circular Mil.

The word mil is an abbreviation for one-thousandth of an inch, as shown in table of prefixes. The circular mil is the area of a circle having a diameter of one-thousandth of an inch, and is used as a unit of area for circular conductors. This equals:

$$\frac{.001^2 \times 3.1416}{4} = .000,000,7854 \text{ square inches.}$$

The area of a conductor in circular mils is found by squaring the diameter of the conductor in mils. For example No. 12 B. & S. has a diameter of 80.808 mils or .080808 inches. The square of 80.808 is found by multiplying 80.808 by 80.808 which is 6529.95, as shown in the wire table.

Square Mil.

This is used as a unit of area for conductors having rectangular cross section. This equals $.001^2 = .000,001$ square inches.

The micrometer gauge shown in Fig. 5 is commonly used for measuring the thickness or diameter of various substances, including wire, when an accurate dimension is required. With this gauge it is possible to measure directly in thousandths of an inch. There are several modifications of the above, but the method of reading all of them is the same. A ratchet stop, not shown in the figure, is a small knurled thumb nut for the purpose of turning the spindle down upon the body to be measured and is to prevent undue pressure being exerted on the screw, which would cause the body to be flattened. It causes uniform pressure on all samples measured. Some types are provided with a lock nut or set screw which holds the spindle firmly in one position. This is especially convenient if several samples of the same size of material are to be gauged.

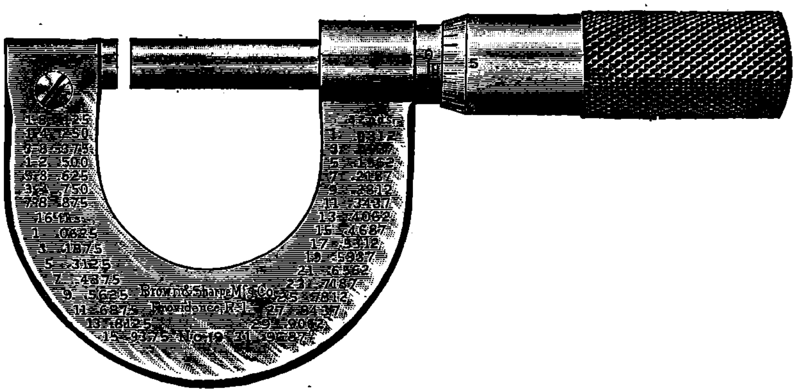


Fig. 5.
MICROMETER GAUGE.

Construction of the Micrometer.—The U-shaped frame is of heavy hardened steel, which is very rigid. Attached to this is a hollow spindle, which is fitted with an accurately machined thread inside and a gauge with reference line outside. This gauge runs from 0 up and each of these divisions has four small divisions. The pitch of the thread inside this spindle is such that one complete turn of the thumb nut connected to the spindle inside the hollow spindle advances the movable point inside the U-shaped frame just one of these four small divisions mentioned. The movable sleeve, which is a part of the knurled thumb nut, fits closely over the hollow spindle mentioned. This is divided into 25 equal divisions and is marked 0, 5, 10, 15 and 20. By making the thread 40 to the inch, then four complete turns would be 0.1 in., which is the meaning of the mark 1 on the hollow spindle. One of the four divisions of this would then be $\frac{1}{4}$ of .1 or .025 in., which agrees with the number of divisions on the movable sleeve.

Method of Reading.—Suppose that after a careful adjustment of the screw the micrometer stood as shown in Fig. 5. From the above information it can be read direct as .055 in. If this had been set so that three of the first divisions on the stationary spindle were exposed and the movable sleeve stood with the seventeenth division over the reference line, then the reading would be found as follows: Each of these three divisions is .025 in. or a total of .075 in. and that portion indicated by the movable sleeve .017 in., then the total would be .075 plus .017, or .092 in.

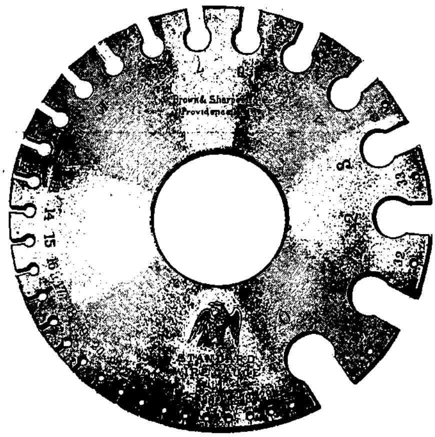


Fig. 6.
WIRE GAUGE.

When measuring No. 9 B. & S. copper wire, which is shown in the wire table to be 114.434 mils, it would be impossible to measure closer with a micrometer than the fourth place, which would then be estimated, unless the micrometer is provided with a vernier which enables one to read directly in tenths of a mil or in ten-thousandths of an inch. The scales of the micrometer when set for No. 9 B. & S. would show the figure 1, but would not show the first of the next four divisions. The movable sleeve would stand with reference line about midway between 14 and 15. A little practice will enable one to become very proficient in using the micrometer.

Adjustment of the Micrometer.—The thumb nut should turn easily, but not be loose. When from wear of the thread it becomes too loose it can be tightened by means of a split thread at the end of the hollow spindle. When the thumb nut is turned down just tight the movable sleeve should stand with the reference line on 0. If not, this may be adjusted by means of the set screw on the side of the frame opposite the spindle and against which the spindle rests when turned down tight.

A common form of wire gauge is shown in Fig. 6. The size of wire is found by trying the different slots until one just fits tightly over the wire. The next one smaller should not go over it without undue pressure. The slot in the edge of the gauge should be used, not the hole at the base of it.

TABLE NO. 6.—SPECIFIC RESISTANCE OF METALLIC WIRES.

MATERIAL	Resistance in ohms at 0° C. of Wire 1 foot long .001″ Diameter.	Increase of Resistance for 1° C. increase of temperature at 20° C. "a".
Silver, annealed	8.781	.00377
Silver, hard drawn	9.538	.0
Copper, annealed	9.529	.00388
Copper, hard drawn	9.741	....
Gold, annealed	12.56	.00365
Gold, annealed	12.78	....
Aluminum, annealed	17.48	.0039
Zinc, pressed	33.76	.00365
Platinum, annealed	54.35	....
Iron, annealed	58.31	....
Nickel, annealed	74.78	....
Tin, pressed	79.29	.00365
Lead "	115.1	.00387
Antimony, pressed	213.1	.00389
Bismuth "	787.5	.00354
Mercury "	565.9	.00072
German Silver	125.7	.00044
Gold-Silver (2 parts gold, 1 part Silver by weight)	65.21	.00065

The temperature coefficient "a" in the above table will make it possible to determine the resistance of a given wire at a given temperature when the resistance is known at 0° C.

$$r_t = r_o\ (1 + at). \qquad \text{eq. (14).}$$

In this, r_t is the resistance in ohms of the conductor at any temperature, t° Centigrade, r_o is the resistance in ohms of the conductor at 0° C.

"a" is the temperature coefficient, "t" is the difference in degrees centigrade.

If it is required to know the resistance per foot of No. 14 B. & S. annealed copper wire at 20° C. which is same as 68° F., it is first necessary to determine the area of cross section of the wire. From the wire table, this is 4107 circular mils. As the resistance of conductors of the same material is inversely proportional to the area of cross section, and as the resistance in the table is for a circular wire having a diameter of 1/1000 in. which has an area of *1 circular mil,* it would be necessary to divide the quantity 9.529 ohms (from table) by 4107, to obtain resistance of No. 14 B. & S. at 0° C. Then by substitution in equation 14

$$R_{20} = \frac{9.529}{4107}(1 + .00388 \times 20)$$
$$= .00232\ (1 + .0776)$$
$$= .00232\ (1.0776)$$
$$= .0025 \text{ ohms resistance 14 B. \& S. at } 20^\circ \text{ C or } 68^\circ \text{ F.}$$

This will be seen to correspond very closely with the resistance given in the wire table. This formula is sufficiently accurate to determine the resistance at any ordinary temperature from any other temperature.

Prefixes commonly used in connection with electrical quantities are derived from the Greek and Latin languages, as follows:

TABLE NO. 7.—AMOUNT OF MULTIPLICATION.

PREFIX	EXPRESSED IN WORDS	EXPRESSED IN FIGURES
deka	ten times	10
hecto	one hundred times	100 or 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}

For example, 1 megohm is 1,000,000 ohms. This is a quantity used in specifying the resistance of the insulation of wire and cable conductors. One kilowatt is 1,000 watts.

TABLE NO. 8.—AMOUNT OF DIVISION.

Prefix	Expressed in Words	Expressed in Figures	
deci	one tenth	1 ÷ 10	or 10^{-1}
centi	one hundredth	1 ÷ 100	" 10^{-2}
milli	one thousandth	1 ÷ 1,000	" 10^{-3}
micro	one millionth	1 ÷ 1,000,000	" 10^{-6}
bicro	one billionth	1 ÷ 1,000,000,000	" 10^{-9}
tricro	one trillionth	1 ÷ 1,000,000,000,000	" 10^{-12}

For example, 1 milliampere is one thousandth of an ampere; 1 micro-farad (unit of capacity) is one millionth of a farad.

INSULATORS.

Substances which have sufficiently high resistance to prevent any appreciable flow of current in electrical transmission are called non-conductors, insulators or dielectrics. As a general thing, all the metals and solutions of their chemical salts are classed as conductors, while the other substances or compounds then come under the head of insulators. In the ordinary construction, these insulators are applied to the conductors of the circuit to direct the flow of current along the path of the conductor. Strictly speaking, there are no known substances which are absolutely perfect insulators, as even the air is now used through which to transmit wireless telegraph signals for thousands of miles, and wireless power transmission has been considered.

The value of any substance as an insulator depends upon the conditions under which it is to operate. The first and most important condition which it must meet is the resistance to puncture or break down under the highest voltage and the worst service conditions to which it will be subjected in actual service. These conditions, such as high temperature, moisture, mechanical stress in the form of tension or compression, chemical vapors, or injurious gases from furnaces or coke ovens, excessive vibration, etc., are the worst, and should be considered in deciding upon the type of insulator to be used.

The insulating material may be applied to the circuit in two general ways. One is to support the conductor from point to point in such a manner that it does not come in contact with any other bodies. The substances with which we are most familiar for this purpose are wood, glass, fibre, hard rubber and porcelain. These are formed or moulded into different shapes, such as knobs, tubes, insulators, etc., to meet the particular requirements.

Another method is to insulate the conductor its entire length by means of a continuous covering, which is applied on each conductor to prevent its coming in contact with other conductors. The approved composition of this insulating covering depends entirely upon the conditions to be met. For example, in some lead-covered telephone or telegraph cables, dry paper is recommended, as it has good insulating qualities, and does not take up much space. This makes it possible to place a large number of conductors or wires in a comparatively small sheath or outer covering. The subject of cables will be taken up more in detail in a later paper. The most common insulator for wire is some form of rubber or its compounds, and this is usually covered with an outer braiding of one or more layers of cotton or hemp to prevent mechanical injury and oxidation of the rubber. This outer covering is usually saturated with some moisture proof insulating compound.

The Relative Values of Some of the Insulating Materials.

To Withstand High Temperatures.

Adit,	Armalac,	Hornfiber,	Mineralite,
Aetna,	Berrite,	Lava,	Mica,
Ambroin,	Celluloid,	Leatheroid,	Sterling Varnish.
Asbestos,	Electro-enamel,		

When moisture collects on the insulator, it increases very appreciably the surface leakage, and when it is absorbed by the insulator, it greatly diminishes the resistance of the insulator. This moisture not only reduces the efficiency of the insulator, but it may also act injuriously upon the quality of the insulator itself.

For Moist Places.

Adit,	Celluloid,	Electro-enamel	Leatheroid,
Aetna,	Asphalt,	Gutta-percha,	Presspahn(treated),
Ambroin,	Ebonite,	Hornfibre,	Rubber.
Armalac,			

To Withstand Large Tension or Compression Stresses.

Adit,	Ebonite,	Leatheroid,	Mineralite,
Aetna,	Fullerboard,	Megomit,	Presspahn,
Ambroin,	Hornfibre,	Megotalc,	Psychiloid,
Celluloid,	Lava,	Micanite,	Vulcanized fibre.

Adit, according to the makers, is tough; can be moulded into any shape; does not shrink so that it can be made to exact dimensions. It is not affected by moisture, and will work satisfactorily at temperatures up to 60° or 120° C., depending upon the quality. Will withstand compression up to 1800 pounds per square inch and from 500 to 800 volts per millimeter (mm) thickness, depending upon the thickness.

Aetna material is used for strain insulators. A strain insulator of this material was found to have the following properties: It punctured at 1,000 volts; insulation resistance, 20,000 megohms; tensile strength, 2.46 tons; immersed in water at 49° C. it absorbed .0317 of its own weight in 1.5 hours. This material will withstand great heat, but is inclined to be brittle. At ordinary temperatures, it has withstood as high as 1400 pounds per square inch and a compressive strength of 728 pounds per square inch.

Ambroin, according to the makers, is not affected by moisture; it will stand very high temperature; it can be moulded into any form; it does not shrink and it can be machined. Its specific gravity varies from 1.4 to 1.8, depending upon quality. Its specific resistance is about 160,000 megohms per cubic centimeter. The tensile strength is greater at from 50° to 70° than at ordinary temperatures. At ordinary temperatures this has shown on test a tensile strength of 2140 pounds per square inch and a compressive strength of 2,680 pounds per square inch.

Armalac is an insulating varnish, which has many good points claimed for it. Its melting point is over 300° C., yet it never becomes brittle. It is claimed to be a black paraffine in a solution of petroleum naphtha, the melting point of the paraffine having been raised by a secret process. It will absorb oil and be benefited by it. It contains no acids which can be liberated to attack the conductors. Its insulating value is not high, but is claimed to be very constant. It penetrates to the conductors and effectually prevents oxidation. It can be applied by dipping the object into it or it may be applied with brush same as any other varnish. Armalac putty may be made by mixing it with whiting. This is a very good conductor of heat.

Asbestos is used in insulating work on account of its heat-resisting qualities. It is made in the form of board, paper, tape, etc. Tests have shown asbestos paper to withstand 4,500 volts per mm, for a specimen 0.6 mm. thick.

Asphalt is used chiefly in conduit work, is not affected by water, is very ductile and may be easily and cheaply repaired.

Berrite is an impregnating gum. It is brittle, but withstands about 5,000 volts per mm. It runs freely at low temperatures, but its insulating qualities are not affected by great heat. Is good for impregnating cloth or paper, but paper so treated must be handled carefully to prevent cracking.

Bitumen is an excellent insulator at ordinary temperatures. It flows freely at a little above 100° C. Its dielectric strength is very high, being 12,000 volts per mm. for a thickness of 2.5 mm. Its resistance is high and is chemically inactive.

Celluloid is a very good insulating material, will work in temperatures up to 100° C., absorbs moisture only to a very slight degree, can be moulded into any form by soaking in boiling water. The safe working pressure is about 14,000 volts per mm. at 20°C., and 6,000 volts per mm. at 100° C. Colored celluloid seems to have a higher dielectric strength than the clear. When soaked 27 hours in water the increased weight was only 0.183 per cent. Its specific gravity is 1.44.

Celluloid lacquer is a most excellent material for insulating laminations. If the iron is warm when immersed in the lacquer, it will dry quickly, giving a very thin, uniform coating of very high resistance. This coating is not affected by heat, moisture or acids.

Ebonite is a kind of hard rubber. It contains sulphur, and is therefore affected by the air, which oxidizes the sulphur at the surface. This action is very rapid and destructive where ozone is present (around electric generators). It is attacked by oils and should never be used when it will come in contact with oil. It is brittle, but quite strong. At ordinary temperatures it has tensile strength of about 1,100 pounds per square inch and about twice this for compression. Its strength is greatly diminished by higher temperatures. Its dielectric strength is comparatively high, being about 35,000 volts per mm., with specific resistance of 28,000 megohms per cubic centimeter.

Vulcanite is practically same as ebonite.

Glass has a high dielectric strength, about 12,000 volts per mm. and for continuous voltage of about 83,000 volts per mm. Common window glass has specific resistance of 6,600,000 to 8,200,000 megohms per cubic centimeter, the higher resistance being obtained from the lower voltage. Water readily condenses on the surface, and rain water dissolves enough of the glass to slightly roughen the surface so that dirt, soot, smoke, etc., accumulate. When this becomes moist, the line leakage is very appreciable. Experiment has shown that glass in which potash was used in the manufacture has higher resistance than the glass using soda. The resistance is also increased by annealing. It is suitable for line insulators on low or medium voltage circuits, but not adapted for high-tension work. It can be easily inspected for cracks, dirt or other imperfections. On account of the varying composition, it is easily broken by only slight blows or stresses. In many places it is being replaced by porcelain on the low voltage telephone and telegraph circuits.

Gutta-percha is very valuable as an insulation if it can be protected from air and light, both of which act to oxidize it. If submerged in water or protected by lead sheath, this oxidation is hardly perceptible. Experiment has shown it to have a specific resistance of 450,000,000 megohms per cubic centimeter. It weighs less than water, as its specific gravity is 0.969 to 0.981. A negative temperature coefficient is shown as its resistance decreases very appreciably with increases in temperature. At 46° C it softens, is plastic at 50° and melts at 100°. The dielectric strength of untreated gutta-percha varies from 10,000 to 25,000 volts per mm., the higher values being for the thinner specimens.

Hornfibre outranks other fibrous materials, although more expensive. Its mechanical strength and insulating properties are both relatively high. This has dielectric strength of 1,000 volts per mm. untreated, but this can be approximately doubled by treating with oil or varnish.

Lava is a mineral talc and is becoming a very important insulating substance. It is not attacked by any of the acids or alkalies, except hydrochloric and then only slightly. It can be machined, and does not shrink nor expand from the effects of moisture and but slightly from heat. After having been machined, it is baked to 1,100° C., making it extremely hard.

Marble is used largely for switchboards. It should be carefully examined to make sure that it is free from all traces of metallic veins.

Mica, which is used very extensively, is one of the most valuable insulating materials. In nature, it is of a rock formation and is a silicate of aluminum and potassium or sodium. Different proportions of the elements forming it fix the colors of it, whether light or dark. This is used largely in the construction of very delicate electrical apparatus as well as the heavier and more rugged construction. This may be split down as fine as .006 mm. The dielectric strength varies from

17,500 to 28,500 volts per mm., depending upon the composition of the specimen. Its specific resistance varies from 2,300,000 to 40,000,000 megohms per cubic centimeter. It is the principal constituent in the compounds micanite, megomit, megotalc, etc.

Paraffine is used largely to impregnate insulating cloths, papers, etc., and in lead-covered cable work to exclude moisture from splices and taps. It melts at about 65° C. and has a dielectric strength of about 8,000 volts per mm. Its specific resistance is from 240,000,000 to 3,900,000,000 megohms per cubic centimeter.

Porcelain is largely used for line insulators, knobs, fittings, switch bases, etc. The specific gravity is about 2.42; tensile strength per sq. in. 1800 lbs.; compression strength per sq. in. 15,000 lbs.; dielectric strength 16,000 volts per mm. At very high temperatures it loses its properties, becoming a fair conductor.

Rubber. The various compounds of rubber are very extensively used for insulated wires and cables. Several different gums are used, but the one giving most satisfactory results is known as Para. This is usually specified for high grades of wire, but it is extremely difficult to make tests to determine the exact composition of rubber compounds. It is vulcanized by heating to 120° to 150° C. and mixing the proper amount of sulphur. Higher temperatures produce hard rubber compounds known as ebonite and vulcanite. Good authorities show the following for good 30 per cent. Para rubber insulations: Tensile strength, 800 lbs. per sq. in.; set not greater than 18.75 per cent. after stated time; specific resistance, 1,770,000,000 megohms per cubic centimeter; the temperature coefficient of resistance should not exceed 4.7 per cent. per degree C.

There are many other substances used to a greater or less extent, and each will be adapted to some particular class of work, but it is impossible to treat them all in this work. The following table gives a number of the more important insulators:

TABLE NO. 9.—RESISTANCE OF INSULATORS.

INSULATOR	Megohms per Centimeter Cube.
Mica	4×10^6 to 84×10^6
Gutta-percha	449×10^6
Shellac	1500×10^6 to 9000×10^6
Ebonite	4000×10^6 to 28000×10^6
Paraffine	240×10^6 to 34000×10^6
Paraffine oil	8×10^6 to 110×10^6
Glass, flint	9×10^6 to 20×10^6

As there are no materials which are perfect insulators that would prevent absolutely the flow of current, no matter what the voltage, neither are there any materials which are perfect conductors, having no resistance. There are all gradations between the best conductors and the best insulators, so that in speaking of a good conductor or a good insulator, the term is merely relative the same as the terms hot and cold.

LINE INSULATORS.

The insulating qualities of new glass or new porcelain insulators are very much higher than that of similar insulators after having been in use where they are subjected to the various weather and service

Fig. 7.
PONY INSULATOR.

Fig. 8.
DEEP GROOVE GLASS INSULATOR.

conditions. This lowering of the insulating qualities is caused by a deposit of soot or dirt on the surface of the insulator. This deposit seems to act more injuriously upon the surface of glass than on the porcelain insulators, as there is a certain chemical action which takes place between the glass and this deposit which eventually roughens the surface, causing dirt to adhere to it more readily.

A heavy rain will wash off the dirt from new glass insulators, but when they become roughened by this chemical action, they will not clean themselves in this manner. A well-glazed porcelain insulator is not attacked by this chemical action and for this reason maintains a more uniform insulation than the ordinary glass.

The line leakage in wet weather is not through the insulators, but over their surface to the other wires and to the ground. This is overcome very largely by so designing the insulator that there are deep grooves underneath and between the outer surface and the supporting pin or bracket. The portions of the insulator formed by these grooves underneath are called petticoats and are illustrated in the cuts of the telephone insulators known as "Deep Groove Double Petticoats" Fig. 10, and are also in the high voltage insulator having a number of very marked flanges or petticoats. Fig. 9.

Glass has been used very extensively for telephone, telegraph and low voltage transmission systems, but there is quite a tendency at the present time to use porcelain instead. Porcelain is used almost exclusively for the high voltage systems.

There are arguments in favor of each type, but there are more points in favor of a good grade of porcelain than for glass.

Fig. 9.
THREE-PIECE PORCELAIN INSULATOR
FOR HIGH TENSION LINES.

Fig. 10.
DEEP GROOVE, DOUBLE PETTICOAT
GLASS INSULATOR.
Section removed to show inside petticoat.

One great menace to the insulating properties of any open or aerial line construction, especially in wooded or country sections, is the formation of cocoons in the grooves underneath the insulator. When these become moist in damp or foggy weather, a short path to ground is formed, greatly reducing the line insulation. Spider webs between the wire and arm are also bad in wet weather.

Glass has some disadvantages, among them being its brittleness, many times being entirely shattered by a slight shock. Moisture condenses on its surface in damp weather much more readily than on porcelain. Molded glass, although more generally used than blown glass, is inferior to the latter. The cost of the blown insulator makes its use almost prohibitive. The formation of cocoons on the under surface is more readily detected with the glass than with porcelain.

Porcelain is strong; does not have its surface roughened by the action of the ordinary deposit, which facilitates the cleansing process during a rain storm; is not so readily shattered or broken by a blow or shock as glass.

Different types and sizes of insulators should be used for different classes of line construction and too great care cannot be taken in studying this feature of the line. An insulator that would give excellent service for a telephone or telegraph line would fail if used for a high voltage power transmission line. The high voltage insulator could be used for the lower voltage lines, but their cost would be prohibitive. Thus, not only the electrical efficiency, but also the cost must be taken into consideration in planning any new line work, as it would be a needless expenditure to use the large power insulators for low voltage circuits when the smaller types serve well under the worst working conditions ordinarily met in practice. The insulators for any class of construction should be so designed and installed that service will be maintained under the worse operating conditions and so that the minimum loss due to leakage will be experienced. This many times involves a careful study of all operating conditions, and if the line is very long or if the service is heavy and also important, then the expense involved in securing the correct design and material to begin with is a wise one, for the reason that the losses extend over a period limited only by the life of the line.

One feature in line construction and other installations, which is prevalent to a greater or less extent under many foremen, is the temporary work which is put in with the intention of removing it in a short time to be replaced by permanent construction. This is allowed to pass for a considerable length of time until it is forgotten and is then responsible for trouble which may develop sufficiently to cripple the whole system. It is more economical, as well as more satisfactory, to do good, permanent work to begin with than to install a makeshift to be replaced in a short time, for the reason that what has been done must necessarily be removed and replaced and possibly the material thrown away which was in the temporary installation.

Electrolysis of Underground Cables.

This is a very serious trouble which is met especially in towns having underground cable systems and an electric trolley system using a ground return. Even though the track may be carefully bonded with copper conductors, there is sure to be a certain leakage which will find its way back to the power house through the earth.

Although these cables are usually laid in non-conducting conduits, yet there is always more or less moisture on their inner surfaces which serve as a path for current to and from the cable.

If there are any lead-covered cables, gas or water mains, or metallic conduits in contact with the earth and which parallel the track or which extend through sections having a difference in potential of but a few volts, there will be very appreciable currents flowing through them, as they have a low resistance. The action upon the sheath of the cable seems to be greatest nearer the power house where the current leaves the main or sheath, providing the negative side of the generator is connected to ground, and is noticeable from the fact that the sheath or pipe is usually pitted at that point very appreciably.

The difference in potential in different parts of some cities runs as high as fifteen to twenty volts, and even a hundredth of a volt could be considered dangerous for the sheath.

Whenever a direct current passes through water the latter is decomposed into the two gases of which it is composed—oxygen and hydrogen. The hydrogen collects at the point where the electricity leaves the water when it enters the cable, while the oxygen appears where the current enters the water; that is, where it leaves the cable. Hydrogen is harmless to the metal sheath and even prevents corrosion, but oxygen, when just liberated, attacks the lead or other metal and is responsible for the pitting of the surface. This pitting eventually goes through the metal and is responsible for the trouble.

The earth always consists of certain salts and compounds which, when moist, act as an electrolyte, considering the cable sheath as one pole of a battery. The passage of the current promotes the chemical action. Some metals are attacked more than others in this process, lead being the most sensative, wrought iron less, while cast iron—especially the hard white cast iron—is very free from these attacks. Many cities have adopted a system of wood water mains which eliminate this trouble for this system.

A slight pin hole in the sheath of a lead-covered cable is sufficient to admit moisture, causing an entire section of cable to go in trouble, as the conductors are ordinarily insulated with dry paper. As these cables in many cases have as many as one hundred to four hundred pairs of wires, and when the moisture once enters it, that section is no longer fit to use, but must be junked, the seriousness of this trouble can be appreciated. This electrolytic action is no respecter of cables and is just as apt to attack the busiest trunk line cables over which thousands of messages are handled daily as the one used occasionally. This fact only emphasizes the very great importance of making the installation in every case in such a manner that the cable will be as nearly as possible proof against this action.

Means of Preventing Electrolysis.

Using two wires or metallic trolley circuits.

Using alternating current for trolley circuit.

If a single wire trolley system using ground return is employed by the traction companies, and this has been upheld by court decisions, then the prevention of the damages must be taken care of by applying devices to the cable itself. If it were possible to make a practical covering for the cable which would be a non-conductor, or if the current could be made to leave the cable where the ground was dry and no chance for electrolytic action, or if the conduit could be kept dry and made of insulating material, then this trouble could be considered as cleared in a very practical way. As yet, however, these are not on a practical basis. Some companies use an insulated joint in the cable sheath with fairly good success, but this also has its faults, as the joint itself is very liable to have or to develop holes which would admit moisture.

No matter how carefully the rail joints and rail bonds may be made there is sure to be some leakage to earth, which would mean that there are chances for this current entering the cable.

The practice with many telephone companies is to bond together the sheaths of all the cables in a manhole and connect this to a permanently moist earth, or to the rail of the railway system. A better practice is to connect to a return feeder, if these are used by the trolley company. In some cases where this trouble is too serious, copper conductors of sufficient size to carry the current are run direct from the telephone manholes to the generating plant and connected to the feeder bus bars.

The pipe used in the air lines laid in the ground along the tracks of electric railways are often attacked by electrolysis unless special precautions are taken to prevent. These air lines are used for the operation of the electro-pneumatic signals, and it is absolutely necessary that they operate correctly for the movement of trains. Leaks in this air line caused by the action of electrolysis would, therefore, cause serious difficulty.

This trouble may be eliminated by careful bonding to the track or by the use return feeders. The particular type of bond best adapted would be determined to a certain extent by the character of the electric circuit of the signal system with which it is used, also by the kind of pipe and the coating of it. On account of the electrolytic action which takes place at the junction of two unlike metals and the consequent corrosive action at this point, it is not advisable to use bare copper bonds on iron rails or iron pipe. The ends of the copper at least should be tinned. This also facilitates soldering or sweating the connection.

ELECTROSTATICS.

The preceding pages have referred to electro-magnetic units or terms. Another division with which it is well to be familiar is known as electrostatics. The name means electricity at rest, not current electricity.

Certain conditions in power, telephone and telegraph transmission are brought about by the presence of the so-called static charge and discharge and have a very appreciable bearing on the line construction, the design of the terminal and protective apparatus to overcome these effects. Some of the experiments used to illustrate the principles of this may seem in no way associated with the above line conditions, but their connection will be seen later.

When a glass rod or piece of amber is rubbed with silk or fur they have the property of attracting small pieces of silk, wool, feathers, paper, gold leaf, pith, etc.

If sealing wax or hard rubber are rubbed with flannel or cat's fur the opposite effect will be noticed.

The charge produced on the glass rod by rubbing it with silk is termed positive, +, while that on the sealing wax rubbed with flannel is termed negative, —. In either case the charge is not produced alone, but an equal amount of the opposite charge is produced on the substance with which the rod is rubbed; thus, the silk will have the same amount of negative charge as the glass rod has positive and the flannel will have the same amount of positive charge as the sealing wax has negative.

In order to produce the greatest charge on the bodies thus treated it is necessary to bring every portion of the surface of each into intimate contact with the other. After this is accomplished, additional rubbing or friction will not increase the charge on either body.

The following is a table by which the nature of the static charge can be determined when the substances are rubbed together. Any of the substances receives a *positive* charge when rubbed with any substance following it and a *negative* charge when rubbed with any that precede it:

TABLE NO. 10.—ELECTROSTATIC SERIES.

1. Fur.	6. Cotton.	11. Sealing Wax.
2. Flannel.	7. Silk.	12. Resins.
3. Ivory.	8. The body.	13. Sulphur.
4. Crystals.	9. Wood.	14. Gutta-percha.
5. Glass.	10. Metals.	15. Gun Cotton.

To illustrate: Glass rubbed with flannel has negative charge and the flannel is positively charged, but when the glass is rubbed with cotton or silk the glass becomes positively charged.

In speaking of elevation, the point of zero elevation is taken at sea level, both for water systems and for general altitude measurements. Similarly the earth is considered as possessing zero electrical potential or pressure and to be one large reservoir of electricity having a limitless quantity.

It is on this account that it is necessary to insulate all lines from the earth connections to prevent the current or charge from going to earth, as electricity always flows toward a point of lower potential or head. In this manner again the electric circuit behaves much the same as the water system.

It is because there is a better path to ground in wet weather, caused by the leakage over the insulators and down the wet poles, that there are greater line losses then than in dry or fair weather. This emphasizes the importance of maintaining a very high degree of insulation, especially in long circuits where the almost inappreciable leaks that occur on each insulator are multiplied as many times as there are insulators on the lines, which makes a very bad condition taken in the aggregate.

One body charged with positive electricity attracts another body negatively charged and opposes one positively charged. Thus, bodies with like charges repel each other while those with unlike charges attract each other.

A body said to be positively charged possesses a higher potential than the earth, while one negatively charged has potential lower than the earth. It has been assumed for clearness that a charge flows from a positively charged body to one negatively charged when brought into contact with it; that is, that the positively charged body has higher potential or pressure than the one negatively charged.

This current flow takes place until an equalization is reached and the flow is called a current of electricity. If the quantity of electrification is limited, as in the case of the Leyden Jar, which will be explained later, then the current is temporary, but if this potential is maintained then the current is continuous, as is the case with the primary cells. In the former case this transferal of charge often manifests itself in the shape of a spark, jumping from one body to another through the air, which equalizes their potential.

The doctrine of the Law of Conservation of Electrical Energy is that the total amount of positive electricity in the universe is exactly equal to the total amount of negative electricity. In other words, for every amount of positive electricity generated there is a corresponding amount of negative electricity.

In the above it has been understood that to transfer a charge from one body to another the bodies must come into contact with each other. It may be proved by experiment that a charge may be transferred from one body to another without actually coming in contact with it. In the latter case the charge is said to be "induced" and the charge an "induced charge."

Distribution of Charge.

A static charge lies wholly upon the outer surface of the body charged, is densest where the curvature of the body is greatest and is independent of the substance of the conductor. The charge on a sphere is therefore uniform, but on an egg-shaped body it is greatest at the small end. From these statements it will be seen that the charge will be greatest at projecting points where the curvature is sharpest and discharge takes place most readily there. For this reason points and sharp edges are avoided in the design of apparatus to be used with static electricity, unless it is desired that a charge or discharge should take place there, in which case they are purposely provided.

The region surrounding a charged body is called an electrical field.

If pith balls are suspended by small threads and brought into the field of a charged body they will be attracted or repelled by the presence of this charged body. When several pairs of these pith balls are suspended at intervals along a conductor and a charged body brought near the conductor a charge is induced in the conductor, as is shown by the behavior of the pith balls. If the charging body has a positive charge then the nearest end of the conductor suspending the pith balls will have a negative charge induced and the opposite end an equal positive charge.

Although electricity does not ordinarily flow through glass yet it acts across it by induction. When two pieces of tin foil are pasted to opposite sides of a sheet of glass and charged, one with positive and the other with negative, the charges will attract each other; that is, they are held or bound. *Electrostatic capacity* is that property which the two conductors on opposite sides of the glass, dielectric, possess when they can hold and accumulate these static charges.

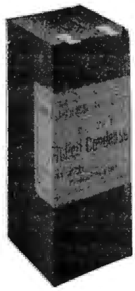


Fig. 11.
COMMON TELEPHONE CONDENSER.

The ordinary *Condenser* in Fig. 11, used extensively in signal, telegraph and telephone work, possesses this property of holding and accumulating a quantity of static electricity on surfaces of tin foil insulated from each other usually by wax paper as the dielectric.

A common form of condenser used in laboratory work is known as the Leyden jar, and consists of a glass jar coated outside and inside with tin foil for about two-thirds its height. A metal rod extending two or three inches through the stopper, which must be dry and an insulator, and down into the jar, the lower end of the rod being provided with a short metal chain which will touch the bottom of the jar, is used for charging and discharging the jar.

The jar is charged by bringing the end of the center rod, which is usually provided with a ball or disc, into contact with a charged body, the outer coating being connected to earth either through the hand or otherwise. A greater charge may be imparted if this outer coating is connected to ground than if there is no chance for the repelled charge to pass to earth. The capacity of a Leyden Jar or condenser depends directly upon the area of the plates, the larger area having correspondingly larger capacities. The jar is discharged by connecting between the outer coating and the knob. This may be done by bending a wire or other conductor into a V shape, supporting it with some insulating material for a handle, touching the outer coating with one end of the wire and the knob with the other. It will be found that a second and third spark may be obtained from one charge, but the subsequent sparks are not as large as the first. This is known as the *Residual Charge,* which was seemingly absorbed by the glass or dielectric.

The capacity of a condenser is not determined in any way by the thickness of the conducting plates, but is fixed by their area.

The capacity is also dependent upon the thickness of the insulating plate or dielectric separating the conducting plates, it being inversely proportional to this dimension; that is, the thicker the dielectric the less the capacity. Any substance which will admit of electrostatic induction through it is called a dielectric and as different substances possess this quality in varying degrees, the capacity of the condenser is determined largely by the material.

When the same area of plates and the same thickness of dielectric are used the capacity is then dependent upon the material in the dielectric, or, in other words, upon the "Inductive Capacity" of the dielectric. The "Specific Inductive Capacity" of a dielectric is the ratio of the inductive capacity of the substance to that of air.

For example, paraffine paper used as a dielectric in a condenser will admit twice the charge on the plates as could be obtained if the plates were separated the same distance by a layer of air.

The unit of quantity of electricity in known as the "Coulomb," and is that amount which would pass through a circuit in one second if the current is one ampere.

The unit of capacity is known as the "Farad," and is that capacity which requires one coulomb to charge it to a potential of one volt. That is, a conductor or condenser capable of holding one coulomb at a pressure of one volt has a capacity of one farad.

The unit most commonly used in practice is the Microfarad (M.F.), which is one millionth of a farad.

From the foregoing, then, the capacity of a condenser depends upon the area of the conducting plates, the material used as dielectric and the thickness of the dielectric.

The rating of condensers is based upon the charge they will hold at a potential of one volt, but the amount of the charge which they can hold varies directly with the voltage impressed upon the terminals of the condenser. With the 2 M.F. condenser there would be only 0.000002 coulombs in the charge if 1 volt was impressed across its terminals. This would be increased to .000048 coulombs if the voltage was increased to 24.

The capacities of two condensers may be readily compared by discharging them through a high resistance voltmeter, if they have been charged to the same voltage or potential. The volume of the charge is proportional to the capacities of the two condensers. The capacities of the two condensers are proportional to the throw of the needle, so that if the capacity of one condenser is known the other can readily be determined by this experiment. An instrument with a comparatively heavy, slow-moving needle is better for this purpose. The throw of the needle is caused by the instantaneous impulse from the condenser and is called the "condenser kick" of the needle.

While the charge is held on the condenser plates the dielectric is under a strain. If the impressed voltage is raised sufficiently the strain increases until the dielectric reaches its break-down limit, and the condenser discharges itself through this ruptured surface. Lightning striking a line is responsible for trouble in condensers many times if the apparatus is not properly protected with arresters at the substations or points where the condensers are installed.

The specific inductive capacity or inductivity of a number of dielectrics is given in the following table. Air, as previously stated, is considered as 1.

TABLE No. 11.—SPECIFIC INDUCTIVE CAPACITY OF DIELECTRICS.

Glass	3 to 10	Shellac	2.95 to 3.60
Sulphur	2.24 to 3.84	Mica	4 to 8
Vulcanite	2.50	Quartz	4.5
Paraffine	1.68 to 2.30	Turpentine	2.15 to 2.45
Rosin	1.77	Petroleum	2.04 to 2.42
Beeswax	1.88	Water	73 to 90

The formula for determining the capacity of a plate condenser is as follows:

$$C = 885 \times 10^{-16} \times \frac{KA}{X} \qquad \text{eq. (15)}$$

C is in farads.

K is inductivity of dielectric.

A is area in square centimeters of all layers of the dielectric between the plates.

X is the thickness of the dielectric in centimeters.

Example: What is the capacity of the condenser made up of tin foil and paraffine paper if there are 100 layers of the wax paper 15 by 30 cm. and the dielectric is of paraffine sheets, .01 cm. thick?

Solution: From the table the average inductivity of paraffine is $2 = K$. The area of the plates is $15 \times 30 \times 100 = 45{,}000$ sq. cm. $= A$. $X = .01$. Then by substitution in equation 15

$$C = \frac{885 \times 2 \times 45{,}000}{10^{16} \times .01}$$

$$= \frac{1{,}770 \times 4{,}500{,}000}{10^{16}}$$

$$= \frac{7{,}965{,}000{,}000}{10^{16}}$$

$$= .7965 \times 10^{-6} \text{ Farads.}$$

As the quantity 10^{-6} is another way of expressing one-millionth and as the microfarad is one-millionth of a farad then this can better be expressed as .7965 M. F., which is practically .8 M. F.

By this formula it is easily possible to determine what shall be the thickness of the dielectric if the other dimensions and capacity are known or if the number of sheets and their thickness are known together with the desired capacity their size can very readily be determined.

If an electrolytic cell is connected to the terminals of a condenser, momentary charging current will flow from the cell to the condenser. The value of this current falls off very rapidly from the first current rush or impulse to zero in the small fraction of a second. As soon as the condenser becomes charged to the potential of the battery to which it is connected no further current will flow, and it has the same effect upon the direct current as would be obtained by breaking the circuit.

The counter electro-motive force (E. M. F.) or opposing force developed in the condenser by charging it prevents a further flow of current through it.

This charge remains in the condenser after the battery supply has been removed and will be held there until there is some connection between the condenser terminals. The condenser kick mentioned is obtained when a voltmeter is connected in the discharge circuit. This discharge current is similar in form to the charging current, being greater when the circuit is first closed and rapidly falling off to zero.

The name of a condenser is usually determined by the nature of the dielectric used as air condenser, paraffine condenser, mica condenser, etc.

The two wires of a transmission line and the air space separating them may be considered as the two plates and the dielectric, respectively, of a condenser; similarly the paper and air separating the two conductors of a paper insulated cable. This subject will be taken up more in detail in a later paper.

The ordinary commercial condenser is made from sheets of tin foil separated by mica or paraffined paper. Some manufacturers now have a process of placing a thin layer of tin foil upon one side of the paraffined paper forming a part of the paper itself. The condenser is then built up by placing several sheets of tin foil and waxed paper or the special paper mentioned upon each other and rolling or folding them into the commercial shapes. Alternate layers of the tin foil are connected and brought out of the terminals as shown in Fig. 11.

Condenser Connections.

By remembering how resistances connected in series and in parallel affect the total resistance and then applying just the opposite to condensers to obtain the total capacity there will be no trouble in remembering the rules of the condenser connections.

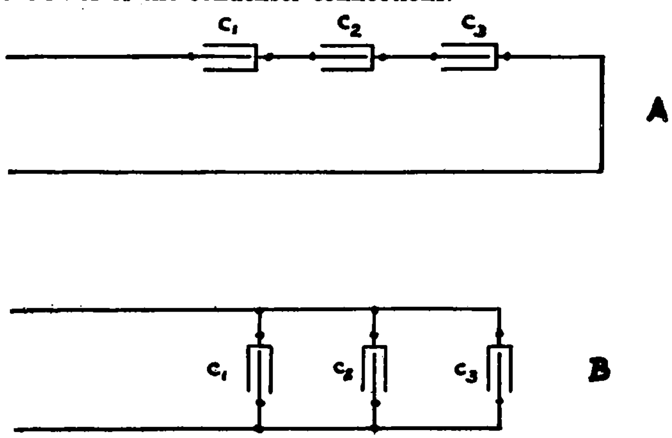


Fig. 12.
CONDENSER CONNECTIONS.

The capacity of condensers connected in series as shown in Fig. 12–A is

$$C=\frac{1}{\frac{1}{c_1}+\frac{1}{c_2}+\frac{1}{c_3}+\ldots} \qquad \text{eq. (16)}$$

When connected in parallel or multiple as in Fig. 12–B the capacity is

$$C=c_1+c_2+c_3+\ldots \qquad \text{eq. (17)}$$

in which C is the total capacity and c_1, c_2, c_3, etc., are the capacities of the individual condensers connected.

For example, two 2 M. F. and one 4 M. F. condensers are connected in series. What is the combined capacity?

Solution: From eq. (16)

$c_1=2$, $c_2=2$ and $c_3=4$.

Then by substituting their values in equation 16

$$C=\frac{1}{\frac{1}{2}+\frac{1}{2}+\frac{1}{4}}=\frac{1}{5/4}=\frac{4}{5}=.8 \text{ M. F.}$$

If these same condensers had been connected in multiple, then from eq. (17) $C=2+2+4=8$ M. F.

Problems.

Note.—These should be answered one or more complete lessons at a time.

First Lesson.

1.—If a 25-watt tungsten lamp is operating on a 110-volt circuit, what current is passing through the lamp?

2.—When the power costs twelve cents per Kilowatt hour, what will it cost to burn the 25-watt lamp 10 hours?

3.—If 25-watt, 120-volt lamps were to be burned on 120-volt circuit for same length of time, what would be difference in the cost of this service and that in problem 2?

4.—When the lighting current in a building was 220 volts and only lamps with 110-volt rating were available, how would they be connected?

5.—What is the resistance in ohms of 25 and 40-watt lamps operating on 110-volt circuit?

SECOND LESSON.

6.—What is the loss in power in watts due to the transmission line copper loss if 10 horse-power is being furnished a customer, assuming it was delivered at 110 volts 1000 feet from the power house and the line was of two wires, No. 4 B. & S. hard-drawn copper?

7.—What would the loss have been if the voltage was 220?

8.—How is this an argument in favor of high voltages for the transmission line when the line is long or when large amounts of power must be transmitted?

9.—This loss is manifested by the drop in voltage between the power house and the customer's end of the circuit, called line drop. This is required to overcome the resistance of the line. (a) What would be the voltage at the power house in the sixth problem above? (b) What in the seventh problem above?

10.—The commercial efficiency of any part of a plant is considered as the ratio of the output to the input at that load. What is the efficiency of the transmission line at the load mentioned in problem 6?

THIRD LESSON.

11.—What size wire with (a) rubber insulation and with (b) other insulation should be used, disregarding the voltage drop, for 20 incandescent lamps, each rated at 40 watts on 110 volts?

12.—What size for 10 lamps otherwise as above?

13.—What current carrying capacity must the wire have which is used in the winding of four relays connected in series and operating on 350 volts if two of them have a resistance of 100 ohms each, one 150 ohms and one 50 ohms, with line resistance of 25 ohms?

14.—If 25-watt lamps are operated on a 30-volt circuit, how does the current through them compare with that through 110-volt lamps rated at 25 watts?

15.—Assuming that the filaments in the two lamps in problem 14 are of the same material and length, how do their cross sections compare, taking into consideration their voltages and resistances?

16.—If the ordinary carbon lamps require about $3\frac{1}{4}$ watts per candle-power and the tungsten lamps $1\frac{1}{2}$ watts per candle-power, how does the cost of current compare for the same intensity of illumination?

Fourth Lesson.

17.—What is the copper loss in a two-wire transmission line between points 4 miles distant if the size wire is No. 4 B. & S. hard-drawn copper carrying 100 amperes at 68° F.?

18.—What would this loss amount to in one year if the average current was 25 per cent. of the above, and with the power costing $0.06 per K. W. hr. to produce?

19.—What is the diameter of a wire in mils which measures 3/64 inch in diameter?

20.—What are some of the advantages in using paper insulated, lead covered cables for telephone and telegraph purposes?

21.—What is its great disadvantage in case it is installed out of doors and a crack develops in the lead sheath?

22.—What is the total conductivity of a multiple 110-volt circuit on which there are 10 forty watt and 1 twenty watt lamps, disregarding the resistance of the wiring and fixtures?

23.—What is the total current flowing in the circuit in problem 22?

24.—What is the combined resistance of the 11 lamps connected as in problem 22?

25.—If these same lamps were to be connected in series, what voltage would be required, omitting the 20-watt lamp?

26.—What would be the total current in the circuit when the lamps are connected in series as in 25?

Fifth Lesson.

27.—If one of the lamps connected as in problem 25 proved defective on account of a broken filament, how would this affect the series circuit?

28.—The temperature of a conductor is found by measurement to be 90° F. What is its temperature C.? Show steps.

29.—What should the C. scale show when the F. scale reads 10° below zero or —10° F.?

30.—What important advantage is gained by using hard-drawn line wire instead of annealed? In what respect is annealed superior to hard-drawn?

31.—From the wire table find or determine the following for No. 10 B. & S. hard-drawn copper wire:

(*a*) Diameter in inches.
(*b*) Diameter in mils.
(*c*) Area in circular mils.
(*d*) Area in square inches.

(*e*) Weight per hundred feet (C′).
(*f*) Weight per mile of metallic circuit.
(*g*) Resistance per 1000 feet (M′).
(*h*) Approximate breaking strength.
(*i*) Per cent. elongation in one foot.

32.—(a) What size in N. B. S. gauge is nearest to No. 10 B. & S.? (b) What is their difference in area?

33.—How would the micrometer gauge be set for No. 8 B. W. G. copper wire?

Sixth Lesson.

34.—What is the unit of electrical pressure?

35.—What is the relation between the pressure and the current in a circuit?

36.—How does the current depend upon the resistance or does the resistance depend upon the current?

37.—State Ohm's law as you understand it.

38.—What is the cause of the loss of pressure in a pipe carrying a fluid such as water?

39.—How does the current leaving a generator compare with that returning to it?

40.—What is known as "line drop"?

41.—How does the "copper loss" vary in lines having the same resistance, but different current values?

42.—What current is flowing in a conductor having a resistance 0.15 ohms if it has a drop of 2 volts?

Seventh Lesson.

43.—Of what does the return conductor or feeder usually consist in a street railway system?

44.—Why is this objectionable from the standpoint of the company having underground conduit and cable systems in the neighborhood?

45.—What methods have been suggested to overcome this trouble in a practical way?

46.—What is the action taking place which causes the trouble in the underground system?

47.—If conductors having a resistance equivalent to 30 mi. of 19 B. & S. gauge cable are considered the limit of good telephone transmission, what length of No. 8 B. W. G. hard-drawn copper would be its equivalent from the resistance standpoint?

EIGHTH LESSON.

48.—If the voltmeter kick of a condenser having a capacity of 1 M. F. charged to 10 volts was 12.5 scale divisions when discharged, what is the capacity of another condenser charged by same battery and giving a throw of the needle or "kick" of 20 scale divisions?

49.—How do you account for the subsequent discharges from a condenser?

50.—(a) What amount of electricity would be required to charge a 2 M. F. condenser to a pressure of 1 volt? (b) To 5 volts?

51.—What is the total capacity obtained by connecting in series two–5 M. F., one–1 M. F., and one–6 M. F. condensers?

52.—If these same condensers were to be connected in multiple, what will be the capacity?

53.—The rating of condensers is based upon their capacity when charged to a potential of 1 volt. What is the amount of electricity required to charge the condensers connected as in problem 52, if charged to a potential of 10 volts?