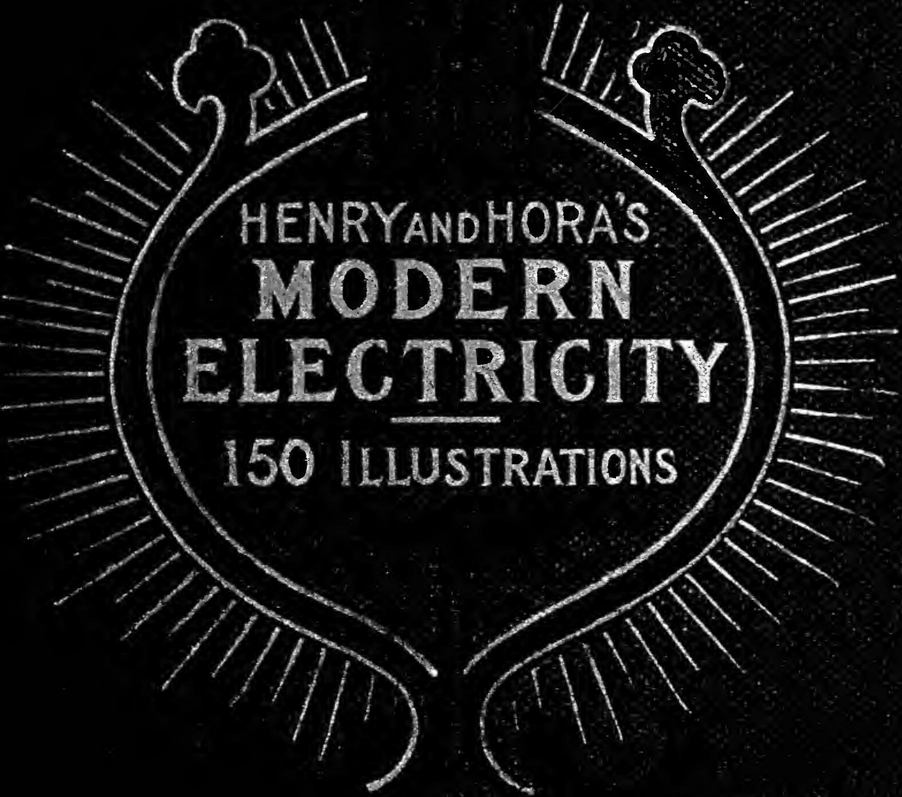

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MODERN ELECTRICITY

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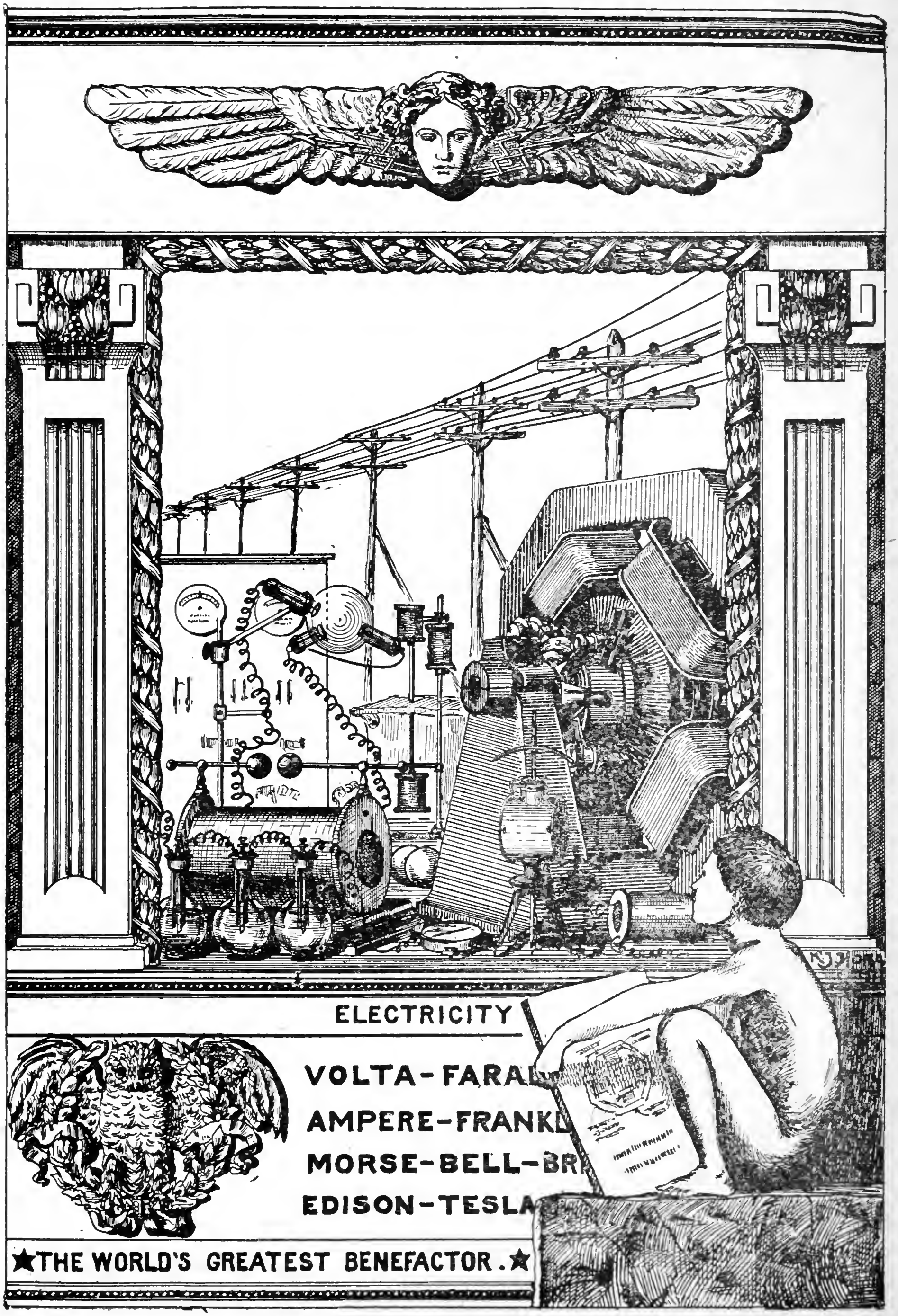
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MODERN ELECTRICITY

A PRACTICAL WORKING ENCYCLOPEDIA
A MANUAL OF
THEORIES, PRINCIPLES AND APPLICATIONS

BY

JAMES HENRY, M. E.
PROFESSOR OF ELECTRICAL ENGINEERING

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EXPERT ELECTRICAL ENGINEER

A Text-book for Students, Apprentices, Artisians, Engineers

Static and Current Electricity — Batteries — Measuring Instruments — Direct
and Alternate Current Machinery—Transformers—Converters — Power
Stations—Electric Railways—Telegraph—Electric Light—Tele-
phone — Wireless Telegraphy — Electroplating — X-Rays
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INTRODUCTION

PROBABLY no one branch of modern science has accomplished so much for the development of a higher civilization as electricity. Less than a century ago, this mysterious force was practically unknown. At present there is scarcely a country or a town of any size where it is not utilized in some form, and yet its possibilities are still but dreams. The next quarter-century no doubt will revolutionize the present method of generating and transforming electricity into motive force.

No field of industry offers the young man as many or as great opportunities as that of electrical engineering. Men of technical education, men of practical experience in the various branches of electrical engineering are in constant demand.

Many of the works relating to the subject, seem to lack the practical knowledge necessary for everyday use. Theoretically correct, they lack the practical instruction essential to a thorough knowledge of electrical science.

HENRY AND HORA'S **Modern Electricity** has been prepared with a view of meeting every emergency that might confront the electrical engineer and inventor. In this volume every effort has been made to simplify the information, without sacrificing its clearness or accuracy, so that every apprentice and artisan will be able to gain a complete knowledge of the fundamental principles and applications of electricity.

Each formula is explained in the clearest manner possible, and the processes of arriving at results have been mathematically demonstrated.

The work will be found eminently practical, scientific and accurate.

The illustrations have been prepared especially for this work, and represent the most modern forms of electrical devices and appliances.

That **Modern Electricity** will answer the requirements of those for whom it is intended, and that it will meet the unqualified approval of every student, apprentice and artisan is the earnest desire of

THE AUTHORS.

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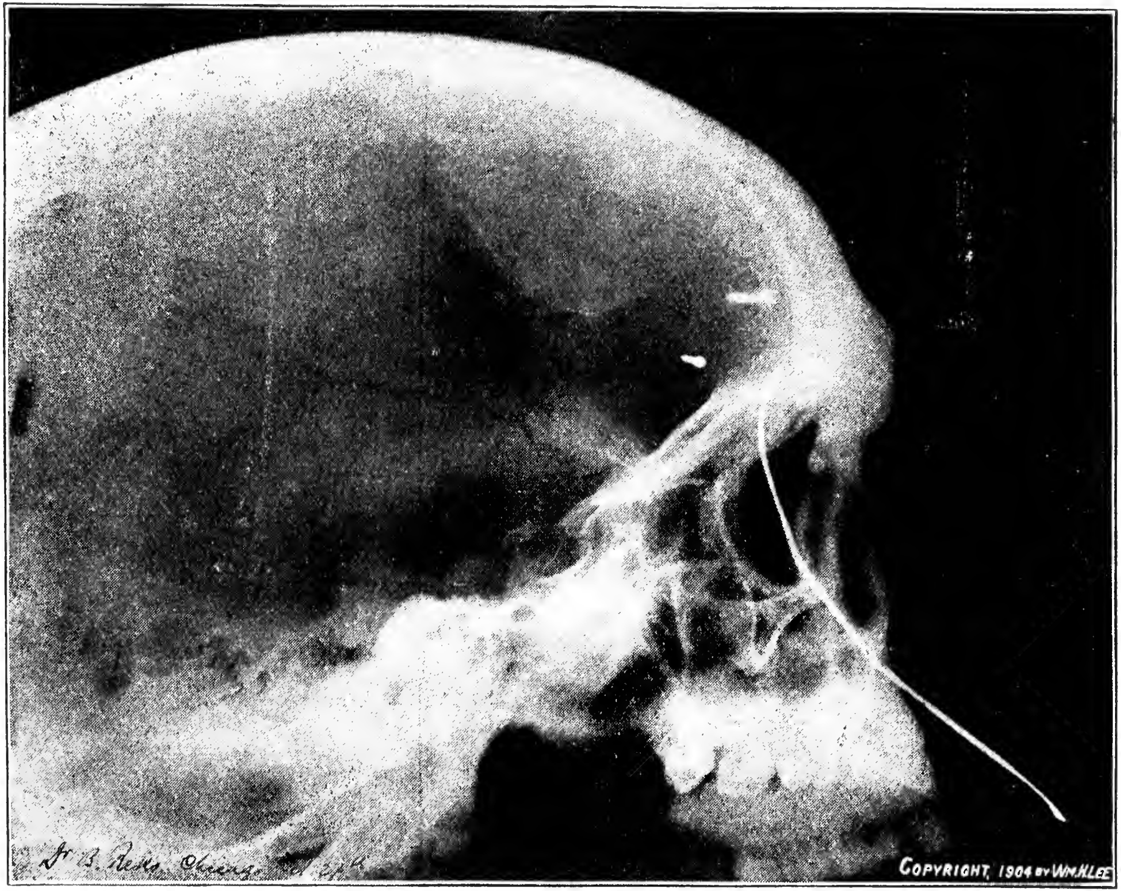
THOMAS A. EDISON
THE WORLD'S GREATEST ELECTRICIAN



RADIOGRAPH OF HUMAN SKULL

MODERN ELECTRICITY

CHAPTER I. — INTRODUCTION

Electricity

1. The true nature of electricity has not yet been discovered. Many think it a quality, inherent in nearly all the substances, and accompanied by a peculiar movement or arrangement of the molecules. Some assume that the phenomena of electricity are due to a peculiar state of strain or tension in the ether which is present everywhere, even in and between the atoms of the most solid bodies. If the latter theory should be the true one, and if the atmosphere of the earth is surrounded by the same ether, it may be possible to establish these assumptions as facts. The most modern supposition regarding this matter, by Maxwell*, is that light itself is founded on electricity, and that *light waves* are merely *electro-magnetic waves*. The theory "that electricity is related to, or identical with, the luminiferous ether," has been accepted by the most prominent scientists.

But while electricity is still a mystery, much is known about the laws governing its phenomena. Man has mastered this mighty force and made it his powerful servant; he can produce it and use it.

---

*James Clerk-Maxwell, a celebrated Scotch physicist (1831-1879), first called attention to the fact, that the velocity of light waves (185,000 miles per second) and of electricity seem identical. Experiments made since, chiefly by Hertz, have demonstrated that electric waves have all the properties of light waves. They can be reflected, refracted, polarized, brought to a focus, etc.

2. Its simplest effects were observed by the ancient Greeks. Thales of Miletus, who flourished about 600 B. C., noticed that amber, when rubbed with silk, attracted light bodies, as bits of bran or cork. The name "electricity" is derived from *elektron*, the Greek for amber. The word was first used in 1600, by Dr. Gilbert, a famous English scientist, who proved before a large assembly in Colchester, that diamonds, crystals of minerals, glass, and sealing wax, had the same peculiarity as amber. He also mentioned the fact that moist air prevented good results in his experiments. The phenomena of electricity are *attraction and repulsion, heat, light, mechanical destruction,* and *chemical decomposition.* They have been known in part for considerable periods, but all their practical applications are of recent origin.

Production of electricity

3. Electricity is generated by mechanical or chemical action

(a) *Friction.* (See § 5.)

(b) *Percussion.* A blow by one substance on another produces opposite electrification on the two surfaces that come in contact.

(c) *Vibration.* Vibration produced in a rod of iron coated with an insulating substance produces opposite electricities (in the rod and the coating). Experiments made by Volpicelli.

(d) *Disruption.* If a playing card is torn in two pieces, both pieces prove to be electrical.

(e) *Cleavage.* Quick cleavage of mica produces sparks in a dark room.

(f) *Crystallization.* Sulphur melted by heat and then left to cool and crystallize, becomes electrified when in process of crystallization.

(g) *Evaporation.* When water evaporates, the liquid possesses the opposite electrification of the vapor.

(h) *Combustion.* Burning charcoal proves to be electrified.

(i) *Pressure.* Cork when pressed with guttapercha or metals proves to be + (plus) electrified, while the guttapercha or metals are — (minus) electrified.

(j) *Heating of crystals.* Tourmaline and other crystals, when heated or cooled, become electrified. (Such crystals are called pyro-electric.)

(k) *Atmosphere.* The atmosphere is always charged with more or less electricity.

(l) Some *animals* are provided with an electric organ which they bring into action when touched by an enemy. Torpedo, gymnotus, and malapterurus are fish possesing powerful electric organs.

(m) The roots and juice of *plants* are —, the leaves +.

(n) *Dissimilar metals* when brought into *contact* produce opposite electrification.

(o) *Heating* the junctions of two *dissimilar metal rods* produces opposite electrification in them, and electricity flows from one metal rod across the junction to the other.

(p) *Contact of two dissimilar liquids.*

(q) *Contact of a liquid and a metal.*

(r) *Chemical action* of a liquid on two dissimilar metals.

(s) *Movement* of a conductor in a magnetic field (*magneto-electricity.*)

Static and current electricity

4. There are two states of electricity, *static* and *current.* The first is electricity at rest, the second is electricity in motion. The difference between them is not well defined, and the laws governing the two kinds are about the same. Static electricity includes the facts known to the ancients. There is, however, one important difference: Current electricity seems to flow through the substance of the conductor; Static electricity remains always on the surface of the charged body, as, for instance, in a hollow cylinder it is found on the outside or convex surface. The reason for this difference is unknown, but it is probably closely connected with the nature of the two kinds of electricity.

Positive and negative electricity

5. A glass rod rubbed with silk in dry air, becomes charged with an electricity called *positive*, while a rod of sealing-wax or other resinous substance, rubbed with wool or fur produces an electricity called *negative*. These terms were first employed by Benj. Franklin, instead of the old names *vitreous* and *resinous* electricity. That this distinction is not made without a difference, can be proved in the following manner:

Two balls of light material, as pith, are attracted to a charged glass rod, adhere to it, become charged themselves and then are repelled and fly off. They also repel each other, when charged and suspended in close proximity, but are attracted by a charged rod of sealing-wax.

From these facts the following general law is deduced:

RULE 1.—A body charged with one kind of electricity repels one charged with the same kind, and attracts one charged with the opposite kind.

6. The silk and wool, with which the rods were rubbed, are affected in the reversed sense; the silk used to rub the glass is found to be negatively electrified, and the wool with which the sealing-wax was rubbed is found to be positively excited. From this fact we deduce another general rule:

RULE 2.—Whenever a positive charge is developed, an equal negative charge is also developed and vice versa.

7. But silk does not produce positive electricity in all other substances; sulphur, for instance, becomes negatively charged if rubbed with silk. In the following series, materials are enumerated in such an order that by rubbing together any two materials named, the one mentioned first will *generally* become positively charged: fur, wool, certain resinous substances, glass, cotton, silk, wood, metals, sulphur, certain other resinous substances, India-rubber, hard rubber.

Conductors and non-conductors

8. Metals become electrified by mere rubbing, but if the piece of metal is held in the hand while rubbing it, the electricity flows into the human body as fast as it is produced. This can be avoided by fastening the metal in a frame or handle of dry wood or hard rubber. Materials which allow electricity to flow through them, or in other words, which *conduct* electricity, are called CONDUCTORS; materials that conduct electricity only slightly or not at all, are termed NON-CONDUCTORS or INSULATORS.

TABLE OF CONDUCTORS.

GOOD.	PARTIAL.	NON-CONDUCTORS.	
1. silver (best)	8. animal bodies	14. oil	20. sulphur
2. metals	9. plants	15. porcelain	21. ebonite
3. charcoal	10. cotton	16. silk	22. paraffine
4. graphite	11. dry wood	17. wool	23. glass
5. acids	12. marble	18. resin	24. dry gases
6. salty solutions	13. paper	19. shellac	25. air
7. water			

Dry air is a perfect or absolute insulator or isolator.

9. A conductor is said to be insulated, when it is supported on insulators in such a way that electricity cannot flow or escape from it,— as by placing it on a plate of glass, or on feet of glass or other insulating material.

Induction

10. If two bodies, as brass balls, both insulated, and one electrified, the other not, are placed near together, the other will also be found to become electrically charged, by INDUCTION. The side near the first ball will hold the opposite kind, and the other side will show the same kind of electricity as the first ball holds. If a finger is held close to the further side of the second ball, the electricity on that side passes into the body of the person, leaving the ball charged with the opposite kind of electricity. This charge will spread over the whole ball, if it is removed from the neighborhood of the first ball. If, however, the two balls are brought into contact, the two charges will join, balancing, and thereby destroying, each other. This proves that the two charges, the inducing one and the induced one, are *equal to each other.*

11. It can be proved, furthermore, that the attraction of light bodies, as pith balls, by charged bodies, is caused by induction. The glass rod or sealing-wax first charges the pith ball by induction, half positively, half negatively. One half is attracted, the other half is repelled. The attracted half is *nearer* the inducing body than the repelled half, and, therefore, the force of attraction is greater than that of repulsion.

12. The unit of quantity of electricity is the COULOMB, named after a French physicist who lived 1736-1806. Each coulomb in one charged body attracts or repels each coulomb in the other. Therefore:

RULE 3.—The total attraction or repulsion is equal to the number of coulombs in one multiplied by the number in the other.

The *intensity* of attraction or repulsion between two charged bodies, then, is determined, *first,* by the product of the quantities of electricity in the two bodies; *second*, by the material between them; and *third*, by the distance between them.

The electrostatic unit of quantity is the quantity which, when placed at a distance of one centimeter in air from an equal quantity, repels it with a force of one DYNE.

EXAMPLE 1.

Two spheres charged with 4 and 6 units respectively are placed 2 centimeters apart. What force will they exert on each other?

Solution:

Any result equals the force divided by the resistance. The force is 4 *multiplied* by 6; therefore the resistance must be 2 *multiplied* by itself.

$$\frac{4 \times 6}{2 \times 2} = 6 \text{ dynes.} \quad \text{Ans}$$

Electroscope

13. An *electroscope* is used to discover the presence of a charge; an *electrometer* measures the quantity of electricity in a charge. An electroscope is necessarily a very sensitive instrument. The one shown in fig. 1 consists of a glass jar, through the stopper of which a brass rod extends into the interior of the jar. At the lower end of the brass rod two narrow strips of gold leaf are attached.

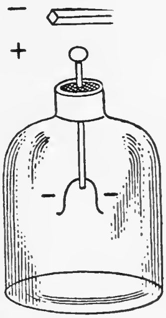


FIG. 1.

hanging straight down. As soon as any body, as a stick of sealing-wax, charged in the slightest way, is brought near the upper end of the brass rod, the two strips of gold leaf will fly apart, and if the charge is strong they will tear. This is caused by *induction:* the upper end of the brass rod becomes charged positively at the approach of the negatively charged sealing-wax, and consequently the two pieces of gold leaf are charged negatively and repel each other.

Questions and Answers

Q. Name a few common manifestations of electricity?

A. When the air is dry and hair is combed with a rubber or metal comb, the hairs rise toward the comb and are repelled by each other. A faint crackling noise is heard, and if it is dark, minute sparks may be seen. Dragging the feet quickly over a woolen carpet and then approaching a conducting body with a finger, a spark will show, which in some instances has been utilized to light the gas. The lightning in the clouds is such a spark of enormous size and length.

Q. How do like charges of electricity affect each other?

A. They repel each other.

Q. What effect have unlike charges of electricity upon each other?

A. They attract each other.

Q. If metal is rubbed with silk, with what kind of electricity will it be charged?

A. The metal negative, and the silk positive.

Q. If metal is rubbed with India-rubber, with what kind of electricity will it be charged?

A. The metal positive, and the India-rubber negative.

CHAPTER II.— ELECTRICAL MACHINES

Potential

14. When two electrically charged bodies are connected by a wire, electricity will flow from one to the other, until they are charged alike. The body *from* which the electricity flows is said to have a higher electrical POTENTIAL. This fact may be illustrated by a comparison. If we connect two vessels of water with different levels by a pipe, water will flow into the vessel with the lower level, until the two levels are the same.

The body from which the electricity flows is said to be POSITIVELY charged, the other NEGATIVELY. "Positive" means here: above the common level or average, and "negative" means below; just as + and — mean above zero and below zero on a thermometer scale. Of course, the two charges are positive and negative, of higher and lower pressure, only in *relation to each other* (relative potential). They may both be higher or lower than a charge in some other body, just as two bodies of water of different level may both be higher or lower than the sea level. The electrical level (zero) corresponding to the sea level in physics, is assumed to be the average electrical pressure of the earth's surface, and the electrical pressure of a conductor is reckoned to be the difference between its potential and zero.

Electrical energy

15. In general, the amount of electricity actually utilized in the form of mechanical power or work done, is small as compared with the energy spent, but it is economical nevertheless, because it allows mechanical power to be transmitted over long distances, and through its several effects accomplishes results not to be achieved in any other way, except at a much greater expense of labor.

Electrical energy is not used in the same quantity for all purposes. For some purposes it is used in the form of a small quantity falling through a great difference of potential while for other purposes we must have a large quantity of electrical energy falling through a small difference of potenial. Lightning consists in the passage through the air of a current of electricity under enormous pressure. Thunder is the noise made by the electric spark called lightning which heats the air in its path, causing sudden expansion and compression followed by as sudden a rush of air into the partial vacuum thus produced.

16. *Kinetic* energy does not enter into the question of electricity, because kinetic energy is the result of a substance in motion. *Potential* energy is stored up and ready to be brought into play, as the elasticity in a bent bow, or the weight of a pendulum at the turning-points at the extremities of the oscillation. It is *tendency to motion*, Kinetic energy is the result of *actual motion.*

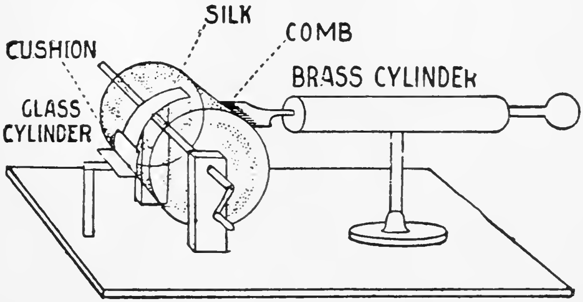


Fig. 2.

Friction machine

17. The oldest type of these machines is the cylinder electric machine. A glass cylinder revolves around its axis which is turned by means of one or two wooden handles. On one side there is a leather cushion covered with amalgam of zinc or tin pressing against it, and a piece of silk extending from this cushion covers the upper part of the cylinder. On the other side there stands a brass cylinder, with a rod extending toward the glass cylinder and provided with sharp points (like a comb), See fig. 2.

Turning the handle we produce friction between the glass and the cushion, and thus a + charge on the glass cylinder and a — charge on the cushion. The + electricity is collected by means of the comb as follows:

The + (plus, positive) charge of the upper surface of the glass cylinder, revolving toward the comb repels the + charge of the comb, which keeps passing into the brass cylinder, leaving the comb — (minus, negative) charged. The + electricity of the glass cylinder is thus neutralized by the —electricity of the comb, and the lower half of the cylinder remains uncharged, until it returns to the cushion, by the friction of which it is charged again with + electricity. The cushion is usually connected with the "earth" by means of a chain.

The earliest form of this machine was designed by Otto von Guericke of Magdeburg, who used a sulphur ball instead of the glass cylinder, and his own hand instead of the cushion. Sir Isaac Newton, Von Bose, Winkler of Leipzig, Gordon of Erfurt, De la Fond, Planta, Ramsden, Cuthbertson, Toepler and Holtz aided in the development of this machine.

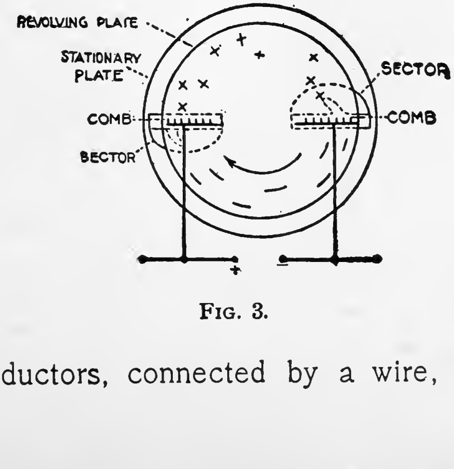


FIG. 3.

A combination of two disks, one stationary and one revolving, and two conductors, connected by a wire, (a so-called *Holtz Machine*, see fig. 3), will produce a steady flow of electricity. Such a machine generates a small *quantity* of electricity, but the *pressure* is very great.

Hydraulic analogy

18. The flow of electricity may be explained by comparing the electric machine to a pump for circulating water through a system of two tanks with two connecting pipes. Electricity is not a fluid, of course, and the comparison is only made for the purpose of illustrating the manner of working, not to explain the *nature* of electricity. We can substitute the pipe for the wire, flow of water for current, pressure or head for voltage, friction for resistance, gallons delivered for amperes, valves for switches, safety valve for fuse, pipe fittings for contacts (joints), pressure gauge for volt meter and the water meter for watt meter. In velocity electricity can be compared only to that of sunlight, traveling 186,000 miles per second, and being nearly instantaneous.

It will be helpful to the student to familarize himself with the following parallel:

Water	**Electricity**
Pressure	
If the water in two tanks of any diameters stands at the same level, there will be no flow through a connecting pipe. But if the level in one tank is higher, water will flow to the other until the two levels are at the same height. The flow is caused by press-	If any two conductors, electrically connected, hold electricity at the same potential, there will be no current. But if the potential is higher in one conductor, an electric current will flow toward the other, until the two potentials are equal. The flow is caused

ure due to *difference of level.* The quantity of water in each tank is immaterial.

The pressure of one pound per sq. inch is taken as the unit of pressure.

by pressure due to *difference of potential.* The quantity of electricity in each conductor is immaterial.

One *volt* is used as the unit of difference of potential.

Resistance

The current of water in the pipe is *resisted* by friction against the interior surfaces of the pipe, couplings, valves, etc. This resistance is the higher, the longer the pipe and the smaller its cross-section.

The electric current in a circuit has to overcome the *resistance* of the material (low conductance meaning high resistance). The longer the wire and the smaller its cross-section, the higher the resistance. One *ohm* is the unit of electric resistance.

Intensity

The *strength of the current* is equal to the pressure divided by the resistance. The unit of flow of water is either one cubic foot or one gallon of water per second.

The *intensity of the current* is equal to the difference of potential, divided by the resistance. The unit of intensity is one *ampere,* produced by the pressure of one volt against one ohm.

If the two tanks are *connected by two pipes* of equal dimensions, the pressure and resistance will be divided between them, that is, the totals will remain the same. The

If two similar electric cells are *connected in parallel* (see §47), the pressure and resistance will be divided between them, and will, therefore, remain the same. The intensflow of water will be doubled.

If several tanks are connected in a line, so that their water levels descend in steps, the pressure equals the sum of all the pressures, and the resistance will equal the sum of all the resistances. The flow per second will remain the same.

ity will be the sum of the two intensities.

If several electric cells are *connected in series* (see § 47), the pressure of the battery equals the sum of the pressures of all the cells, and the total resistance equals the sum of all the resistances. The current equals that of one cell,

Condenser. Electrical capacity

19. A condenser is a device, consisting of two conductors with large surfaces separated by an insulator. The conductors are called the *plates* or *coatings*, and the insulating material is called the *dielectric*. A simple condenser consists of two sheets of tinfoil pasted upon the two surfaces of a piece of mica. The mica insulates the two sheets of tinfoil from each other. If the two *plates* are given opposite charges, one positive and the other negative, each of the charges, by induction, *increases the capacity of the other plate,* by raising their *relative potentials,* that is their difference in electrical pressure, as to each other, as explained in § 14. (This may be compared to increasing the capacity of a water tank by adding to its height.) A condenser is charged by charging one plate positively, and by putting the same quantity of negative on the other plate. This is done very simply by connecting each plate with one pole of an electric machine, *or* by connecting one plate with the "earth" (ground), and charging the other.

This subject of condensers is highly important, because every insulated wire may be considered to be one plate and the earth the other, while the rubber covering of the wire, or the surrounding dry air, is the dielectric.

20. *RULE 4.— The capacity of a condenser equals the combined capacity of the two plates.*

The capacity of condensers is the greater,

(a) the larger the metal plates or coatings,

(b) the thinner the dielectric between them,

(c) the higher the dielectric capacity of the dielectric.

The unit of electrical capacity is the FARAD. A conductor is said to have a capacity of *one farad,* if the pressure in it is raised to a potential of one volt by *one coulomb,* that is, if the transfer of one coulomb from one plate to the other, changes the difference of relative potential by one volt. But such a capacity (of one farad) is enormous. It never really occurs in the electrical industries. As the practical unit of capacity, therefore, the *micro-farad* (from the Greek *mikros,*small) is used, being the one millionth part of a farad. The farad was named after Michael Faraday, the eminent English scientist (1791–1867), who discovered the fact that pressure is induced by moving a conductor across a magnetic field, and who may, therefore, be considered the primary inventor of the dynamo.

The *quantity* of electricity in a charged condenser equals the capacity of the condenser (in farads), multiplied by the difference of potential between the plates (in volts).

21. A Leyden jar is a condenser, the glass jar forming the dielectric, and the inside and outside tinfoil coatings, on about two thirds of its height, forming the plates. A brass rod terminating in a knob connects below with the inner coating, usually by means of a loose chain. The glass surface above the coatings is usually varnished, for better insulation. See fig. 4. A number of such jars having all the inner coatings connected, and also all the outer coatings, so that they may be charged and discharged together, is called a *battery.* See fig. 5.

FIG. 4.

Questions and Answers

Q. Does 'positive' and 'negative' mean the same in this chapter as in Chapter I?

A. It does not. In the first chapter the terms are used to distinguish between vitreous (positive) and resinous (negative) electricity. In this chapter, and in general, "positive" means "of the higher potential" and "negative" signifies "of the lower potential," expressing merely a difference in electrical pressure.

Q. Which is the positive pole of a cell?

A. That from which the current flows through the connecting wire to the other pole.

Q. Does the current *in* the cell flow from the negative plate to the positive?

A. It does, to complete the circuit. In a zinc-copper cell the copper plate is always called the positive plate, as it would be only confusing to call it positive *above* the liquid, and negative *in* the liquid.

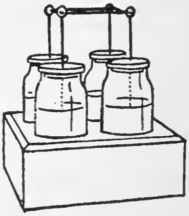


FIG. 5.

Q. Describe a Holtz machine? See fig. 3.

A. The Holtz induction machine has two disks of glass mounted close together, one of which rotates. The stationary disk has two openings pasted over with paper. These papers, or *sectors,* are charged, one positive, the other negative, with the aid of rods of glass and sealing-wax, or in some other way. In front of the revolving plate, opposite each sector there is a row of points (comb), each comb being connected with a conductor provided with an adjustable knob. The electricity in the sectors excites the combs and conductors; from the combs the electricity flows into the revolving disk, which carries the charges from one comb to the other, acting inductively on the combs, and the charges are in turn neutralized by them. If the knobs of the conductors touch, a flow of electricity continues, as long as the disk revolves. If they are separated, a spark will fly from knob to knob, completing the circuit.

Q. How long does a lightning stroke last?

A. An infinitely short time. The impression it makes on the eyes lasts very much longer, and is, therefore, deceiving.

Q. Can you give an instance which proves this?

A. The spokes in a wheel revolving so fast, that the human eye cannot recognize the spokes in ordinary light, are plainly seen in a dark night by the flash of lightning.

Q. What is the principle of a condenser?

A. It seems that the close proximity of the plates enables them to hold a larger quantity of electricity.

Q. Does this mean an increase in the voltage?

A. No. A water tank of a larger diameter will hold a larger quantity of water than another, other things being equal, but if the bottoms and water surfaces in the two tanks are at the same level, they will have exactly the same pressure.

Q. After whom was the ampere named?

A. After Ampere, a French scientist, who lived 1775-1836.

CHAPTER III.—BATTERIES.

Voltaic cell and Voltaic pile.

22. An electric cell is an apparatus by means of which heat generated by chemical action is converted into an electric current. This heat is generated in a way similar to the heat of burning wood. The carbon in burning combines with oxygen from the air and this chemical combination is accompained with the generation of heat. In a cell a metal combines with an acid, also giving off heat.

A simple cell is constructed in this way: A glass vessel containing an acid or a salt solution, and two plates, one of zinc, one of copper are placed in the liquid at a distance from each other and connected outside the vessel by a wire. This is called a VOLTAIC CELL, in honor of its inventor, Volta, an Italian scientist, 1745-1827. Several such cells, connected *in series,* (the zinc of one cell connected with the copper of the next, and the zinc of the last connected with the copper of the first,) constitute a battery. See fig. 7.

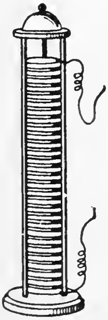


FIG. 6.

23. A VOLTAIC PILE is a battery consisting of a pile of disks of zinc, disks of cloth moistened with acid, and disks of copper, stacked up alternately in the order named. Each set of 3 disks constitutes a battery cell, and when the top copper disk is connected by a wire with the bottom zinc disk, a current flows through the wire. The pressure equals the sum of all the differences of potential in the several cells; the more cells, the more pressure. See fig. 6.

The uppermost copper plate is called the positive pole, because the current flows from it through the connecting wire to the lowest zinc plate.

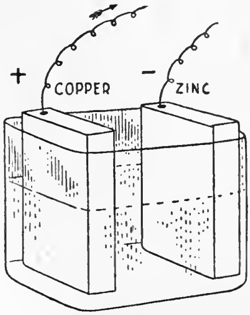


Fig. 7.

The electrical pressure, or electromotive force (*E. M. F.*), developed by one Voltaic cell has been chosen for the unit of measure of electrical pressure, and is called a VOLT. Strictly speaking, the *volt* is about one ninth less than the pressure in a Voltaic cell with zinc and copper plates in diluted sulphuric acid.

24. The acid attacks and eats into the zinc, undergoing a chemical combination with it. This chemcal process goes on with a giving off of heat, the heat is converted into another kind of energy, an electric current, and the electricity then flows as long as the chemical action continues. — The zinc plate is called the negative plate, and the copper plate the positive. Similarly, in cells having plates of other metals, the plate most readily attacked by the acid is always termed *negative*, Usually the negative plate is of zinc, while the positive plate is of copper, carbon or platinum. The liquids commonly used are various acids, solutions of salammonia, caustic potash or other compounds in water.

Another name for the poles is ELECTRODES; the liquid is called ELECTROLYTE (*lytos*, from the Greek, meaning *"dissolving."*)

25. A pump lifts water *against a difference of pressure;* in the same way, the chemical action in the cell drives the current from the negative zinc plate through the liquids to the positive copper plate, *against the difference of potential.*

A large cell does not give a higher pressure than a small one, the pressure depending exclusively on the nature of the liquid and the plates. This can easily be proved: If two cells of unequal size are made up from the same materials, and the copper plates connected, and also the zinc plates,— there will be no current, a proof that the two electrical pressures in the two cells, working in opposite directions, neutralize each other, that is, are equal.

Polarization

26. The hydrogen gas contained in the sulphuric acid is liberated by the chemical action (see § 48) and settles on the copper plate in bubbles. These bubbles, intervening between the liquid and the copper, reduce the chemical action and also present a high resistance to the flow of the current, thus doubly interfering with the working of the cell. When they stop the current entirely, the cell is said to be POLARIZED.

27. A cell may be DEPOLARIZED by *mechanical* action: causing the bubbles to rise to the surface; or by adding a *chemical* that absorbs the hydrogen gas; or *electro-chemically:* coating the zinc plate with a metal that will take the place of hydrogen and deposit on the positive plate.—An OPEN CIRCUIT cell is one in which depolarization is very slow: so the cell must be given time to rest between two periods of activity. They are used for door bells, telephones, etc., where a small current suffices and is in use at intervals only.— A CLOSED CIRCUIT cell is one in which provision is made for constant depolarizing. It gives a continuous flow of current, and is used for plating, lighting, running small motors, and in telegraphy.

Mechanical depolarization

28. Mechanical depolarization could be done by constant stirring. In some cells the copper plate is made very rough, so that the bubbles will not stick to it so easily, or the positive plate, mostly made of carbon, is very large, the liquid consisting of sal-ammoniac.

Chemical Depolarization

29. Chemical depolarization is effected by adding to the liquid some substance that will combine with the free hydrogen as quickly as it forms. Such substances are nitric acid, bichromate of soda or of potash, chloride of lime, dioxide of manganese; the materials mostly used for the plates are zinc and carbon.

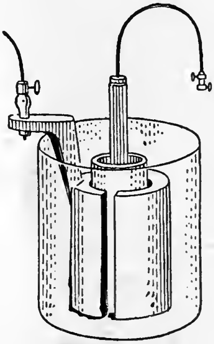


FIG. 8.

30. A BUNSEN CELL consists of a glass vessel containing sulphuric acid, in which stands a zinc cylinder, and in this a cup of porous earthenware containing nitric acid and hard carbon. The nitric acid and the sulphuric acid unite sufficiently through the porous cup to produce an electric current. The nitric acid is used as a depolarizer, but would consume the zinc very rapidly, if it touched it. The Bunsen cell's E. M. F. is 1·9 volts, intern. resist, = 0·25 ohm. It is not used much, being very expensive, and because of the poisonous gases it produces.—The GROVE CELL (fig. 8) is the same as the Bunsen, substituting platinum for carbon. E. M. F. = 1·95 volts, intern. resist. = 0·15 ohm.

Depolarization is effected in these cells as follows: The hydrogen liberated at the zinc plate, is oxidized in passing through the nitric acid, producing water and red fumes of peroxide of nitrogen gas.

31. In the EDISON-LALANDE CELL the plates are made of zinc and compressed copper oxide. The liquid is caustic soda or caustic potash dissolved in water. To protect the liquid from the carbonic acid in the air, it is covered with paraffine oil. The oxygen in the copper oxide readily combines with the hydrogen gas, thus efficiently preventing polarization. This cell is very useful for medical purposes.

32. In a LECLANCHE CELL a porous cup containing the positive plate or rod of carbon and small lumps of dioxide of manganese, is placed, together with a rod of zinc, in a glass vessel almost filled with sal-ammoniac dissolved in water. The top of the carbon and the inside rim of the jar are coated with paraffine to prevent the salts from "creeping up," and the porous cup is sealed with a resinous substance, leaving only two small holes which allow the liquid to enter the cup. This cell is very good for intermittent use, as for door bells and telephones. E. M. F. = 1·48 volts, intern. resist. = 0·4 ohm.

33. A PLUNGE BATTERY consists of a set of cells made of zinc, carbon and a bichromate dissolved in sulphuric acid. It is so arranged that the plates may be lifted out of the liquid when not used,—because the liquid destroys the zinc very rapidly. The liquid is prepared by dissolving the crushed bichromate (6 parts) in boiling water (90 parts). cooling it and adding sulphuric acid (12 parts). This battery is used to run small motors, ignite the gas in gas engines, etc. It gives a large current.

Electro-chemical depolarization

34. Where continuous service is required, Daniell's cells and Gravity cells are generally used. DANIELL'S CELL has a zinc plate immersed in dilute sulphuric acid, and, in a porous cup, a copper plate immersed in a depolarizing solution of blue vitriol (copper sulphate). The acid eats into the zinc forming *sulphate of zinc* and liberating hydrogen, which combines with the copper sulphate, taking from it copper and depositing it on the copper plate, which is in this way kept bright and in good condition. It is necessary to keep up the full strength of the copper sulphate by adding crystals of blue vitriol from time to time. The E. M. F. of this cell is 1·08 volts, intern. resist. = 0·61 ohm.

35. A GRAVITY CELL (see fig. 9) is made of the same materials as the Daniell's cell, but the arrangement is different. The blue vitriol, being much heavier than the well diluted sulphuric acid, is put in the bottom of the jar with the copper plate and the crystals. Then water is poured on very gently, so it will float on top, and the zinc is suspended in it. By pouring a few drops of sulphuric acid into the water, the cell will at once work. The two liquids mix gradually by diffusion, unless there is a constant current. If the copper sulphate reaches the zinc, it deposits on it oxide of copper, making it unfit for service, until cleaned. It is very good in a closed circuit battery, there being absolutely no polarization but not for intermittent work. The E. M. F. is 1·07 volts.

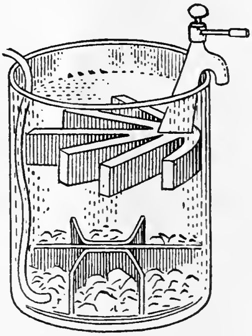


FIG. 9.

36. A DRY BATTERY CELL, or dry cell, has zinc and carbon electrodes of various shapes, separated by a sal-ammoniac or acid paste. Generally a zinc cup is used for the outer shell, the carbon being in the cup, surrounded by the paste, and the whole sealed with a resinous substance. The E. M. F. of different types differs, the average being 1·5 volts.

CONSTANTS OF CELLS.

NAME OF CELL.	Exciting solution.	Manner of depolarization	Depolarizer.	Approxim. E. M. F. Volts.	Approx. int. resistance. Ohms.
Bunsen . . . . Zinc (Zn) Carbon (C)	sulphuric acid $+H_2O$	chemical	Nitric acid	1·9	0·05–0·25
Clark (Standard) . . . . *A.*, zinc (Zn) *K.*, mercury (Hg)	$Zn\,SO_4$	electrochemical	Hg_2SO_4	1·43	various
Daniell (Meidinger, etc.) *A.*, zinc (Zn) *K.*, copper (Cu)	$Zn\,SO_4$	electrochemical	$Cu\,SO_4$	1·079	0·61
Grove . . . . *A.*, zinc (Zn) *K.*, Platinum (Pt)	$H_2\,SO_4$	chemical	$H\,NO_3$	1·95	0·15
Dry cells . . . . *A.*, zinc (Zn) *K.*, carbon (C)	various	chem. or electrochemical	various	1·46 various	0·2
Leclanché . . . . *A.*, zinc (Zn) *K.*, carbon (C)	$N\,H_4\,Cl$	chemical	$Mn\,O_2$	1·48	0·3–0·5
Smee. . . . . *A.*, zinc (Zn) *K.* platinized silver (Ag)	$H_2\,SO_4$	mechanical.	none	1·0–0·59	0·1

Zinc and its consumption

37. Electrical energy is furnished in all these different batteries at the expense of a consumption of zinc. But zinc is too expensive to use a battery for furnishing current of great magnitude, as in electric lighting. It is much cheaper to produce electricity by running a dynamo with a steam engine.

Pure zinc is hard to get, and the impurities contained in the common commercial article cause the so-called LOCAL ACTION, which is an eating away of the zinc in the impure spots, which form small LOCAL CELLS with the surrounding pure zinc. To prevent this local action, the surface of the zinc plate may be AMALGAMATED with mercury. After cleaning the surface of the zinc by dipping it in a weak acid solution, a little mercury is rubbed onto it. The mercury makes a pasty, shining AMALGAM with the pure zinc, covering up the impurities, with which the mercury does not mix. The pure zinc in the amalgam is consumed by the acid, but the mercury keeps forming an amalgam with the pure zinc below, and thus the plate is kept in working order. The mercury may be added when the zinc is being cast, with results equally good.

The quantity of zinc consumed in a cell depends on the amount of electricity that passes through it. The quantity consumed, when one coulomb of electricity passes through a cell, is called the *electrochemical equivalent* of zinc. (See § 49).

Secondary Battery or Accumulator

38. A "Secondary Battery" or "Accumulator" is an apparatus by which energy can be accumulated and stored in form of chemical work. The secondary battery does not develop any energy, but it converts the electric energy supplied to it by a dynamo or by primary batteries into chemical work, which may be stored up in this state, and then used at convenience, by again converting the stored up chemical work into electrical energy. The Leyden jar, which can be charged and discharged, is a simple accumulator.

When the liquid of a cell is saturated with the dissolved zinc (zinc sulphate), the zinc may be deposited again on the zinc plate by sending an electric current, generated by another cell or a dynamo, *from the copper plate through the liquid to the zinc plate.* The zinc thus re-deposited is then, of course, ready to be dissolved again by the electro-chemical action of its own cell. The process of re-depositing the dissolved zinc by means of an electric current is called CHARGING the STORAGE BATTERY, and the using of the stored up energy is called DISCHARGING. Of course, it is not possible to expend the same amount of energy in discharging, as was used in charging; there is considerable loss.

39. The common STORAGE CELL (see fig. 10) is made up of two lead plates, or two sets of lead plates, corrugated or perforated (GRIDS), each set fastened together so that the plates of one set fit in between those of the other, but do not touch them. They are immersed in dilute sulphuric acid. Such a cell does not generate any electric current of its own, it simply delivers the current received and stored. When this cell enters into the circuit of an electric current, there is at once a very lively chemical action. The plates through which the current enters the cell, (anode) receive a coating of lead oxide, (peroxide of lead), while the surface of the other set of plates (cathode) turns gray and spongy. As soon as the anode plates are completely covered with the red peroxide of lead, the cell is *charged* to its capacity, and it must be taken out of the circuit of the battery or dynamo, or the plates may bend, which would spoil the cell.

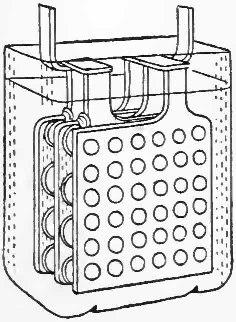


FIG. 10.

When the poles of such a charged cell are connected, a current flows immediately from the gray plates through the liquid toward the reddish ones, that is in the direction opposite to that during the charging process; and the chemical action is also the opposite, undoing the work of the charging process; the oxide of lead changes to sulphate of lead, and the spongy lead on the other plates also changes to sulphate of lead. The current continues until the surface on all the plates is well changed to sulphate of lead, then the action ceases, as two *different* metals are always required to generate an electric current. The discharge is then complete, and the cell is ready to be charged again, and so on. Storage batteries are called SECONDARY BATTERIES, as distinguished from the PRIMARY BATTERIES, by means of which they may be charged.

40. It is safe to say that, on account of the loss of energy incident to imperfect material and imperfect chemical action, a storage battery *in actual service* will yield only one half of the voltage with which it was charged. The pressure obtainable is about 2·2 volts at the start, and gradually drops to 1·8 volts, below which point it should not be allowed to go. It must never be allowed to become completely discharged, as this would result in serious damage to the plates. Nor should it remain in the discharged state for any length of time, as the positive plates would sulphate; it is best to charge the cell until the positive plates assume a deep brownish red color and the liquid effervesces violently; in this state the battery may stand idle without sulphating for about two months, adding water enough occasionally to keep the plates covered about one half of one inch above the tops.

41. The method described above is called the CORRODING or FORMING or PLANTÉ METHOD, being rather slow. A quicker way is by the PASTING or FAURE process, in which a paste of red oxide (minium) moistened with sulphuric acid is filled into the perforations of the positive plates, and a paste of yellow oxide of lead (litharge) is put on the negative plate. During the charging process, the minium changes to peroxide of lead, and the litharge to lead. Or both plates may be pasted with sulphate of lead moistened with sulphuric acid.

Making a storage battery

42. A storage battery that would supply 40 incandescent lamps of 16 candle power (c. p.) for 5 hours, or 5 lamps for 40 hours, etc., can be made as follows:

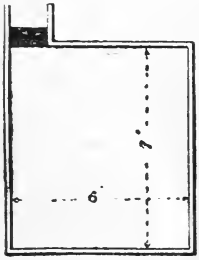


FIG. 11.

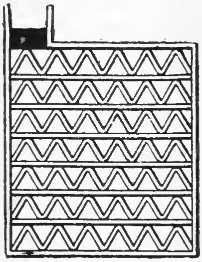


FIG. 12.

Assuming that it takes $\frac{1}{2}$ ampere per lamp, there will be required $40 \times \frac{1}{2} \times 5 = 100$ ampere hours. Procure a quantity of lead tape one-64th inch thick by $\frac{3}{8}$ inch wide, known to the trade as torpedo lead, and a quantity of $\frac{3}{8} \times \frac{1}{4}$ inch strip lead called chemical or desilverized lead. If the strips cannot be obtained, get about 10 pounds of sheet lead, $\frac{1}{4}$ inch thick and cut into strips $\frac{3}{8}$ inch wide. With these $\frac{3}{8} \times \frac{1}{4}$ inch strips proceed to make seven frames; size inside 7×6 inches, molding them around a 7×6 block of wood, so as to have them all alike. (See fig. 11.) Insert a $\frac{3}{8}$ strip between the projecting ends (lugs), and solder firmly together with a blowpipe and rosin.

Now cut off a number of torpedo lead strips 6 inches long, and as many of 8 inches; corrugate the 8 inch strips and fit them all into the seven frames the 6 inch way, as in fig. 12.

Fuse the ends, so the strips will not fall out. Then *paste* four of the frames with a mixture of $3\frac{1}{2}$ pounds of yellow lead and 1 part sulphuric acid and 10 parts water. These are the negative plates. Then fill the other three frames with a composition of $2\frac{1}{2}$ pounds of red lead mixed with 1 part sulphuric acid and 10 parts water. These are the positive plates.

Now take sheets of card board about three-16ths of an inch in thickness, soak well in silicate of soda, and let thoroughly dry. When ready, lay a negative plate on its side; place on top a sheet of prepared cardboard, then a positive plate with the lug opposite to the negative lug, then a sheet, then a negative, and so on until all are laid, then tie up tightly with string. Fuse a heavy strip of lead, (see fig. 13), called binding or head strips, across the 3 positive plates, and another across the 4 negative plates (see fig. 14). Put them in a glass jar or asphalt coated, tight box, that will hold acid. The liquid and the manner of preparing it, has been described. It is well to add about two ounces of bicarbonate of soda. Connect the positive bar with wire to the positive wire of dynamo, and the negative bar with the negative wire of dynamo, and pass a current of 10 amperes into the storage battery for 48 hours until the solution in battery gasses or boils well. This battery when charged will deliver 100 ampere hours at 2 volts pressure.

FIG. 13.

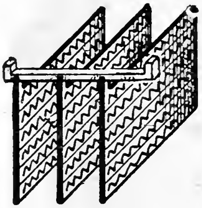


FIG. 14.

43. The MODERN EDISON BATTERY has a shell of sheet steel; the plates are firmly set in between hard rubber, and consist of thin sheet steel frames with slits in which iron oxide (positive) and of nickel hydrate (negative) have been pressed hydraulically, and covered with perforated steel lids. Each cell has twenty-four plates, $9\frac{3}{8} \times 4\frac{3}{4}$ inches, 0·1 inch thick. The electrolyte is caustic potash. All the attention it needs is replacing the water that may have evaporated. It can be discharged at the rate of 200 amperes without damage. It may be run down to 0 without harm. It gives out one H. P. for each 53·3 pounds of weight. The chemical charge consists in the transference of oxygen to the nickel side when charging, and to the iron side when discharging.

Charging a secondary battery

44. By a battery. The primary current causes an opposing E. M. F. in the secondary cells, therefore the source furnishing the primary current must have a higher E. M. F. than the secondary cell. In order to charge an accumulator of 12 cells of 2·2 volts each, joined in series, the E. M. F. of the source must be more than 12 × 2·2. However, if the source possesses only 3 volts, the secondary cells might be joined in parallel, so as to represent one large cell. But it is best to use currents of moderate strength, and one large cell works better than several small ones joined up in parallel, because it is impossible to have the cells exactly alike, and those subjected to the stronger currents are likely to be damaged.

By a dynamo. The secondary cells are best arranged in series, The process of charging should be slow. Dynamos with permanent steel magnets are used, as they do not change their poles. The machine should be shunt-wound, because if the whole circuit were in series, it might happen that the E. M. F. of the secondary battery became stronger than that of the source, and the current would be reversed, injuring the machine. In using a shunt-wound dynamo two circuits are connected with the brushes of the commutator: one circuit has the sec. battery, the other the field coils and a rheostat.

The two currents are inversely proportional to their resistances, therefore, the resistance can be regulated by means of the rheostat. Great care, however, is needed, to avoid a heavier E. M. F. in the secondary battery than in the generator. *Hospitalier's* charger breaks the circuit as soon as the machine current decreases beyond a certain point, and connect again, when the machine current has regained the required strength. Accumulator switch-boards are used for the same purpose.

Arrangement of cells in batteries

44. A broad stream of water might run a number of mill-wheels at the same point, the wheels being erected abreast on a straight line across the current. If the same number of mill-wheels are to be turned by a small stream of water, they must be placed along the current, one below the other. In the first case we have a large quantity of water and a small fall; in the second case a small quantity of water and a large fall.

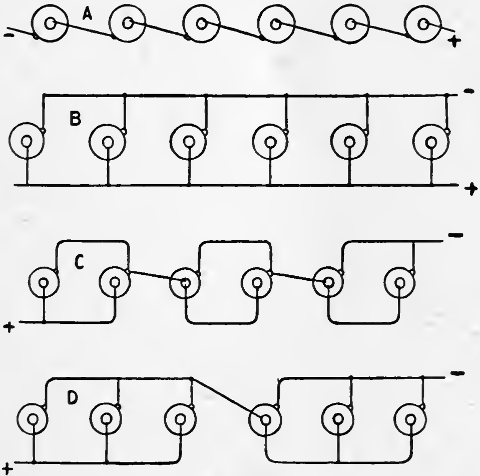


FIG. 15.

In the same way, the cells of a battery may be connected so as to generate a large current at low pressure, or a small current at high pressure. If the positive pole of one cell is always connected with the negative pole of the next (see fig. 15 A) the cells are said to be connected *in series* (as in a Voltaic pile), and the more cells there are, the greater will be the E. M. F. Six cells of 1·5 volts and 4 amperes each would give 9 volts and 4 amperes. The current would not be stronger than that of a single cell.

EXAMPLE 2.

The E. M. F. of a single cell is 1 volt; its internal resistance is 2·4 ohms, and the external 3 ohms. What is the strength of the current? (See foot note.*)

$$1 \div (2{\cdot}4 + 3) = 1 \div 5{\cdot}4 = 0{\cdot}185 \text{ ampere. Ans.}$$

EXAMPLE 3.

The E. M. F. of each of 6 cells connected in series is 1·5 volts; the internal resistance of each is 2 ohms; the external resistance 4 ohms. What is the strength of the current?

$$1{\cdot}5 \times 6 \div [(2 \times 6) + 4] = \frac{9}{16} = 0{\cdot}56 \text{ ampere. Ans.}$$

On the other hand, if all the positive poles of the cells are connected together, and the negatives together, *in parallel* or *for quantity,* (Fig. 15 B) the voltage is the same as in the single cell, but the strength of the current equals the sum of all the amperes delivered by each cell, because the internal resistance is reduced in direct proportion to the number of cells, owing to the increased number of paths. It is exactly as if the cells had been replaced by one large cell, the area of whose plate equaled the sum of the areas of the several small plates. This is why the lead plates in a storage battery are connected in parallel.

If 2 cells are connected, each of 1·5 volts and 4 amperes, in parallel, and three of such groups in series (Fig. 15 C), then the E M. F. of one group $=1{\cdot}5$ volts, and the intensity of the current, $I=2\times4=8$ amperes, and the E.M.F. of the whole

---

* Current = E. M. F. divided by resistance. See § 51.

battery, E = 1·5 × 3 = 4·5 volts and I = 8 amperes. If these these cells are joined in 2 groups in series, each group of 3 cells in parallel, (Fig. 15 D), then the E. M. F. of one group E = 1·5 volts, and I = 3 × 4 = 12 amperes, and the E of the whole battery, E = 2 × 1·5 = 3 volts and I = 12 amperes.

EXAMPLE 4.

6 cells are joined in parallel; E. M. F. of each cell 1·5 volts, internal resistance 2 ohms, external ·5. What is the strength of the current?

It is equal to the E. M. F. of a single cell (1·5) divided by the sum of the external resistance (·5) plus the internal resistance (2) divided by the number of cells (6).

$$\frac{1\cdot5}{\frac{2}{6}+\cdot5}=\frac{1\cdot5}{\cdot83}=1.8 \text{ amperes. Ans.}$$

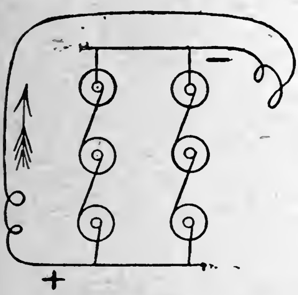


FIG. 16.

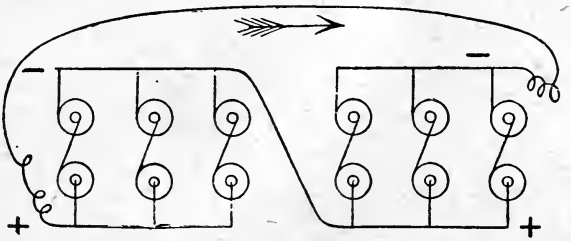


FIG. 17.

Fig. 16 represents the cells connected in series multiple. Fig. 17 represents cells connected in series multiple in series. Any such combination (of both *series* and *parallel*) as in fig. 15 *C, D*, and figs. 16 and 17 is said to be *connected in series multiple.*

By the arrangement of fig. 16, the internal resistance of the battery is reduced directly in proportion to the number of series; the E. M. F. of the battery and the internal resistance of each series are both increased in proportion to the number of cells in each series. In consequence, the current will equal the E. M. F. of a single cell multiplied by the number of cells in each series, divided by the internal resistance of a cell times the number of cells in series, divided by (the number of series plus the external resistance of the circuit).

EXAMPLE 5.

A battery of 6 cells is arranged 3 in series and 2 in parallel. The E. M. F. of one cell is 1·5 volts, and its internal resistance 0 5 ohms; external resistance is 2 ohms. What is the strength of the current?

$$\frac{3\times 1\cdot5}{\frac{3\times \cdot5}{2}+2}=\frac{4\cdot5}{2\cdot75}=1\cdot6 \text{ amperes.}\quad \text{Ans.}$$

EXAMPLE 6.

Find the current of a battery of 24 cells arranged 8 in series and 3 in parallel. The E. M. F. of one cell is 1.5 volts, and its internal resistance ·5 ohm; external resist. is 6 ohms.

$$\frac{8\times 1\cdot5}{\frac{8\times 0\cdot5}{3}+6}=\frac{12}{7\frac{1}{3}}=\frac{36}{22}=1\cdot64 \text{ amp. (approx.)}$$

EXAMPLE 7.

A battery arranged *in series* with the E. M. F. of each cell 2·5 volts, and an internal resistance of ·5 ohm, drives a current of 3 amperes through a circuit of 9 ohm resistance. How many cells are there?

We assume x to be the number of cells.

$$I=\frac{x\times E}{x\times r+R};\ 3=\frac{2\cdot5\,x}{\cdot5\,x+9};\ 3\,(\cdot5\,x+9)=2\cdot5\,x$$

$$1\cdot5\,x+27=2\cdot5\,x;\quad x=27 \text{ cells.}\quad \text{Ans.}$$

EXAMPLE 8.

A battery arranged *in parallel*, with E. M. F. of each cell 4 volts, internal resistance 5 ohms, external resistance 1 ohm, drives a current of 2 amperes. How many cells?

$2 = \frac{4}{\frac{5}{x} + 1}$; $\frac{4}{2} = \frac{5}{x} + 1$; multiplying by x, we get $2\,x = 5 + x$;

$x = 5$ cells. Ans.

In order to have a *steady* current of the greatest serviceableness, the cells should be so arranged that the internal resistance will equal the external.

EXAMPLE 9.

125 cells, with a resistance of 1 ohm per cell, are to be so arranged as to send the maximum current through an external resistance of 5 ohms.

To find the inner resistance, we multiply 1 (ohm) by the number of cells in series (x), divided by the number in parallel (y), and make this quotient = 5.

$$\frac{x \times 1}{y} = 5 \text{ and } \quad x \times y = 125$$

$$x = 5\,y \text{ and } 5\,y \times y = 125$$

$$5\,y^2 = 125 \qquad x\,\frac{125}{y} = 25$$

$$y = \quad 5 \text{ in parallel.} \qquad = 25 \text{ in series. Ans.}$$

RULE 5.—The efficiency of a battery, in percentage, *equals the external resistance, multiplied by 100, and divided by the sum of the external and internal resistances.*

EXAMPLE 10.

A battery of 40 cells; external resistance 16 ohms; internal resistance of each cell ·5 ohm. What is the efficiency?

$$\frac{16 \times 100}{16 + (40 \times\ 5)} = \frac{1600}{36} = 44{\cdot}4 \text{ per cent. Ans.}$$

Electrolysis

45. ELECTROLYTES, as explained in § 25, are solutions of acids or salts of the metals, in which ELECTROLYSIS, electrochemical decomposition, takes place when a current flows through them. The plate at which the current enters the cell, is called the POSITIVE ELECTRODE, or ANODE; the other plate is termed the NEGATIVE ELECTRODE, or CATHODE. The products of electrolysis are called IONS (anions and kations). A SALT OF A METAL (as sulphate, chloride, nitrate, or carbonate of copper) is the product of the action of an acid on the metal; carbonic acid acting on copper produces carbonate of copper; *sulphuric acid acting on copper produces sulphate of copper.* Now, sulphuric acid consists of its ACID RADICAL (*sulphur* and *oxygen*), combined with *hydrogen.* But the acid radical has a greater affinity for copper than for hydrogen, especially when heated,* and as soon as a piece of copper is placed in the acid, the acid radical enters into a chemical combination with it, forming sulphate of copper, while the hydrogen is liberated. The sulphate of copper stays in the liquid, unless it is crystallized out in the form of blue crystal-like lumps. But if this liquid containing sulphate of copper is used as the electrolyte for two copper plates connected with a battery, the electric current at once *decomposes the sulphate* into its two parts, the acid radical and metallic copper, and *deposits the copper on the cathode.* The acid radical liberated returns to the work of attacking the copper of the anode, and so on. The anode will gradually be dissolved, while the cathode will increase in size. (See more about this in the chapter on Plating.)

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* Sulphuric acid has a great affinity for water, and unites with it readily in any proportion, evolving at the same time great heat.

46. On the same principle it is possible to ELECTROLYZE the *salts of other metals*, and even *liquids that hold no salts in solution.* If, for instance, two platinum plates connected with a battery are placed in an electrolyte containing sulphate of copper, the copper is deposited on the cathode, but — the acid radical having no affinity for platinum, does not attack it. It attacks, therefore, that within its reach for which it has the greatest affinity, which in this case is the water in the solution. It combines chemically with the hydrogen in the water, forming again sulphuric acid, and liberating the oxygen, which collects in bubbles on the anode and escapes. After all the copper dissolved in the electrolyte has been deposited on the cathode, the chemical action will be limited to the decomposition of the water, the hydrogen bubbles appearing at the cathode and the oxygen bubbles on the anode. The GENERAL PRINCIPLE, of vast industrial importance, of chemical action in an electrolytic cell is:

RULE 6.— The acid radical, or its equivalent in oxygen, flows against the direction of the electric current toward the anode; the metal part, or its equivalent in hydrogen, flows with the electric current towards the cathode.

Chemical equivalents

47. It is characteristic of all *primary* cells, that oxidation takes places on one plate, and that there is no action whatever on the other plate, the hydrogen remaining in its gaseous state. *The hydrogen, easily measured, is therefore taken as the unit.* Hydrogen is released in a definite, invariable ratio to the amount of zinc dissolved: for every atom of zinc converted into sulphate of zinc, two atoms of hydrogen are liberated; but an atom of zinc weighs 65 times as much as an atom of hydrogen, so that the weight of zinc dissolved will be 32·5 times as much as that of the hydrogen. This is meant by the expression: "the chemical equivalent of zinc is 32·5," taking that of hydrogen as the unit (1). A quantity of acid that will just dissolve 32·5 grammes of zinc, will also just dissolve 29·3 grammes of nickel. These values, given in the table below, are at the same time the rates *at which the metals enter into chemical combinations.* This is easily understood by the action of the voltameter (§ 50), in which water is dissolved into oxygen and hydrogen: the two elements will certainly combine again into water in the same proportions. It is, furthermore, true that the power expended in making a given amount of chemical change, is equal to the power necessary to undo this change (see § 83), making due allowance for unavoidable losses.

Electro-chemical equivalents

48. After the *chemical* equivalents in weight have been determined for the several metals, etc., used in electrolysis, by experiments, it is easy to find the ELECTRO-CHEMICAL equivalents by multiplying together the weight of the hydrogen liberated by one coulomb of electricity and the chemical equivalent of each of the other elements or substances. For instance, to find the electro-chemical equivalent of nickel, we multiply $\cdot 010384 \times 29\cdot 3 = \cdot 30425$. On the other hand, the electro-chemical equivalent in milligrammes per coulomb, of any metal, divided by the electro-chemical equivalent of hydrogen (·010384) gives the chemical equivalent of the metal.

The INTERNATIONAL AMPERE adopted by the Electrical Congress in Chicago, 1893, is a steady current which deposits silver at the rate of ·001118 grammes (or 1·118 milligrammes) per second (or 4·025 gr. per hour) from a solution of silver nitrate in water, of a fixed strength. The following table gives the rates for other metals and substances:

TABLE OF ELECTRO-CHEMICAL EQUIVALENTS.

IONS.	Symbol and Valency.	Atomic Weight.	Chemical Equivalent in weight.	Electro-chemical Equival'nts mg. p. c.†	Deposits in grammes per Ampere hour.
+Aluminum..........	Al_3	27·3	9·01	0.0936	0·3370
+Copper (cupric)*....	Cu_2	63·18	31·59	0.3290	1·1819
+Copper (cuprous)....	Cu_1	63·18	63·18	0.6588	
+Gold.............	Au_3	196·2	65·4	0.6818	2·4458
+Hydrogen..........	H_1	1	1	0.1039	0·0374
+Iron (ferrous).......	Fe_2	55·9	18·6	0.1932	0·6955
+Iron (ferric)........	Fe_3	55·9	27·9	0.2898	1·0433
+Lead..............	Pb_2	206·4	103·2	1.0731	3·8595
+Mercury (mercuric)..	Hg_2	199·8	99·9	1.0363	3·7362
+Mercury (mercurous)	Hg_1	199·8	199·8	2.0727	7·4725
+Nickel............	Ni_2	58·6	29·3	0.3044	1·0958
—Nitrogen..........	N_3	14·01	4·67	0.0488	0·1758
—Oxygen............	O_2	15·96	7·98	0.0831	0·2992
+Potassium..........	K_1	39·03	39·03	0.4051	1·4584
+Silver.............	Ag_1	107·67	107·67	1.1183	4·026
+Tin (stannic).......	Sn_4	117·8	29·45	0.3083	1·0958
+Tin (stannous).......	Sn_2	117·8	58·9	0.6166	2·1953
+Zinc..............	Zn_2	64·9	32·45	0.3385	1·2118

+ means electro-positive, — electro-negative.

* Some metals have two chemical equivalents, for two classes of compounds one being a multiple of the other (½ or ⅔).

† Milligrammes per coulomb. Note that the electro-chemical equivalents are given in *milligrammes*, not grammes. (= in grammes p. c. × 1000).

Faraday's Laws

49. On the basis of the above named general principle (§ 46) and facts (§ § 47, 48), Faraday succeeded in establishing, by his experiments, the following two laws:

RULE 7.—The quantity of the electrolyte decomposed by an electric current depends on the number of coulombs that pass through it. The size of the electrodes and the voltage are of no consequence.

RULE 8.—Equal quantities of electricity passing through different electrolytes, decompose equivalent quantities of the electrolytes, that is to say, the chemical change worked by the passing of one coulomb, depends on the *equivalent weights* of the elements in the electrolyte.

Water voltameter

50. Perfectly pure water is a non-conductor and is, therefore, not decomposed by electrolysis, but by the addition of some sulphuric acid this condition is changed, and after the current has decomposed the acid, the *acid ions* in turn become the means of decomposing the water into its two elements, hydrogen and oxygen. The above table shows that one coulomb of electricity liberates almost 8 times more oxygen than hydrogen (in weight). In the diagram (fig. 18) of a *water voltameter,* the three connecting tubes are filled with slightly acidulated water and A and B emptied of air through the stop-cocks. When the platinum plates in A and B are connected with the battery D, there appears very soon hydrogen in tube B and oxygen in tube A, in the proportion of 1 to 8 by weight. But a given weight of oxygen is of so much smaller *volume* than the same weight of hydrogen, that the water in the oxygen tube will be pressed down only about half as far as that in the hydrogen tube. From the amount of

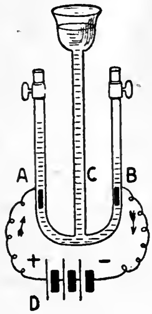

FIG. 18.

gases collected and their electro-chemical equivalents the strength of the current can be calculated: *The number of coulombs flowing per second equals the amperes of current.*

Questions and Answers.

Q. How many kinds of depolarization are there?

A. Three: mechanical, chemical, and electro-chemical.

Q. Which kind is used in the bichromate cell?

A. The chemical.

Q. Describe a bichromate cell and its working?

A. Zinc and carbon plates in dilute sulphuric acid and bichromate of potash. The zinc should be taken out, when the cell is not used. It gives a large electro-motive force (1·95 volts), is used as a closed circuit cell, but is not constant.

Q. How is the liquid mixed?

A. Add 5 ounces of sulphuric acid slowly to 3 pints of cold water; when cooled, add 6 ounces of pulverized bichromate of potash or soda, mixing well.

Q. What is a silver chloride cell?

A. It consists of a zinc plate and a silver plate upon which silver chloride has been cast, in sal ammoniac or ammonium chloride, the silver chloride acting as depolarizer.

Q. What is a crowfoot?

A. The zinc in a gravity cell is so named from its shape.

Q. Does a large cell give a higher pressure and a larger current than a small one?

A. It gives a larger current but not a higher pressure.

Q. Does a plunge battery give a large current?

A. Yes, as many as 30 amperes have been obtained from a single cell.

Q. How could a powerful single cell plunge battery be made for experimental purposes and obtain from 25 to 28 amperes, and the glass jar not to be over five inches square?

A. Fasten a number of carbon plates close to the sides of zinc plates, and plunge into tank containing a solution of one-half pint sulphuric acid, one quart water, and one-fourth pound bichromate of potash. Arrange the plates so that they can all be raised up out of the solution at once when not in use,

Q How is evaporation in a storage battery prevented?

A. If the cell is covered up with a glass plate, the vapor will condense on it and fall back in drops.

Q. What points are to be observed about storage batteries?

A They must be kept clean, and the connections should be tight, as any dirt would increase resistance, reducing the efficiency of the battery.

Q. What is the rule for finding the EFFICIENCY OF A BATTERY?

A. Divide the resistance of the external circuit, by the resistance of the external circuit *plus* the internal resistance, and multiply by 100. This gives the percentage of efficiency

Q. Give an example.

A. In a battery of 12 cells, the external resistance being 20 ohms, and the internal resistance of each cell ·2 ohms, we have

$$\frac{20}{20 + (12 \times \cdot 2)} \times 100 = \frac{20 \times 100}{22 \cdot 4} = 89 \text{ per cent.}$$

Q. What is meant by short-circuiting a cell.

A. It means connecting the two terminals or external poles by a short wire, instead of connecting it with a system of wires, bells or other devices.

Q. If we have several voltameters of different sizes connected in series, will the chemical action in them vary in quantity?

A. No, it will be the same in each cell, because the same amount of current flows through them all.

Q. If ten cells, each with a pressure of 9-10ths of a volt, are connected in series, what will be the total pressure?

A. Nine volts.

Q. How do you calculate the amount of any metal separated from the electrolyte, when the amount of silver separated under the same circumstances is known?

A. Multiply the weight of the silver by the ratio of the equivalent weight of the other metal to that of silver.

Q. Give an example.

A. Assuming that 12 ounces of silver have been separated, then the amount of nickel separated under the same circumstances would be $12 \times \frac{29.3}{107.7} = 3{\cdot}26$ ounces. (See table on page 53.)

Q. Is it known how the chemical decomposition in an electrolytic cell takes place?

A. Not with certainty. The *theory* is that the molecules break up into their atoms, and that one class of these atoms have a strong affinity for one of the electrodes, and flow toward it, repelling the other kind towards the other electrode.

Q. What is the meaning of P. D.?

A. Potential difference.

Q. What is the meaning of C. G. S.?

A. It means the centimeter-gramme-second system of electrical units, almost universally employed by electricians.

CHAPTER IV.—INTENSITY OF ELECTRIC CURRENTS

Ohm's law

51. In the same way in which two pipes of equal size, and under the same pressure, may not deliver the same quantity of water, owing to greater roughness of the inner surface in one of them, so the electric current's flow depends on the material and size of the conductor. But while in the case of a water pipe the *friction* is only on the surface of the water column, in the case of the electric conductor the *resistance* is in the whole cross-section, and, besides the length, the temperature is of consequence. The law for measuring is the same in the two cases.

RULE 9.— The flow equals the pressure divided by the resistance.

The German scientist Ohm was the first to make this application of the general law: The result equals the effort divided by the resistance, and the rule is, therefore, properly named after him. In the formula $I=\frac{E}{R}$, expressive of Ohm's Law. I, E, R, mean intensity (current), electromotive force (pressure), resistance. From this formula we derive also: $R=\frac{E}{I}$ and $E=I\times R$, which is easily understood by substituting proper figures: $7=42\div6$; $6\times42\div7$; $42=6\times7$.

EXAMPLE 10A.

a. Through a wire of 20 ohms resistance, at a pressure of 100 volts, a current of 5 amperes will flow.

b. A conductor using 3 amperes at 60 volts pressure, has a resistance of 20 ohms.

c. A lamp filament using 4 amperes at a resistance of 100 ohms requires 400 volts to make it properly incandescent.

52. The term "total resistance" means, in the case of a battery, the sum of the internal resistances in each cell added to that of the conductor. If there are 6 cells, each with a pressure of 1·5 volts and an internal resistance of 2 ohms, connected in series with an external circuit of 3 ohms resistance , then the total resistance equals $(6\times 2)+3=15$, and the pressure is $6\times 1{\cdot}5$ volts. Therefore the current is

$$I=\frac{E}{R}=\frac{6\times 1{\cdot}5}{(6\times 2)+3}=\frac{9}{15}=\frac{3}{5}=0{\cdot}6 \text{ ampere.}$$

Conductance

53. As stated in § 8, the metals vary greatly in CONDUCTANCE.* Pure silver and copper, showing the least resistance to the electric current, have been taken as the standards for conductance, being marked 100, and the other metals in percentage. (For exact values see p. 62.)

Pure silver,	100	Platinum,	17	Lead,	8
Pure copper,	100	Wrought iron,	16	German silver,	7
Gold,	76	Nickel,	12	Cast iron,	3
Aluminum,	54	Tin,	12	Mercury,	1.6
Zinc,	28				

These figures refer to wires of equal lengths and cross sections. They are subject to changes, dependent on the quality of the metal, due to its origin or the process of manufacturing, or other conditions.

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* Conductance is the reverse of resistance. Conductance $= \frac{1}{\text{resistance}}$.

Conductivity or Specific Conductance is the conductance of a prism 1 cm. long and 1 sq. cm. in cross-section.

Resistivity or Specific Resistance is the resistance of a prism 1 cm. long and 1 sq. cm. in cross-section.

Standard of resistance

54. *The conductance of a conductor increases with its cross section; its resistance increases with its length.* Applied to cylindrical wires *of equal length,* this means that their conducting power is directly proportional to the squares of their diameters, and their *resistance is inversely proportional to the squares of their diameters.* A wire of one centimeter thickness has only $\frac{1}{4}$ of the resistance of a wire $\frac{1}{2}$ centimeter thick. At the Electrical Congress held in Chicago during the world's fair, 1893, the INTERNATIONAL OHM was established as the unit of resistance. It is the resistance of a column of pure mercury, 106·3 centimeters long, of a uniform cross section of one square millimeter at the temperature of melting ice. Such a column contains 14·4521 grammes of mercury. As such mercury columns are inconvenient to handle, so-called RESISTANCE COILS, of German silver or other high resistance wire, adjusted, by means of the mercury column, to any desired number of ohms, are used for measuring resistance in practical service. (See Rheostat, Chap. VII.)

Temperature coefficient

55. In § 51 it was said that the temperature had great effect on resistance. In *most metals* it increases with the rising temperature, while in bad conductors it decreases greatly with increasing heat. Glass is a conductor when at red heat, and the carbon in the incandescent lamp has only about half the resistance when incandescent, that it has when cold. In general, it may be said that pure metals change 1 per cent in resistance for every 4·5 degrees Fahrenheit, up or down the scale, or for every 2·5 degrees centigrade, or, in other words, *four tenths of one per cent for every degree centigrade,* or 22 hundredths for every degree Fahrenheit. This is called the TEMPERATURE COEFFICIENT of pure metals. For German silver the value is about one tenth as much. Other alloys vary from the value given for German silver to 0.

Resistance of a wire

56. Scientists generally use a wire one centimeter long and of a cross section of one square centimeter in determining its resistance, but in practice wires *one foot* long and of a cross section of one CIRCULAR MIL are used. Such a wire is called a *mil foot*. A circular mil is the area of a circle the diameter of which is one mil, which is *one-thousandth of an inch.* A *microhm* is *one-millionth* of an ohm.

EXAMPLE 11.

A wire $\frac{1}{4}$ inch thick has a diameter of 250 mils. Area of cross section equals $250 \times 250 = 62.500$ circular mils; or, the square of the diameter in mils equals the area in circular mils.

The specific resistances of ordinary wires are known; that of a mil foot of copper is about 10·5 ohms at a temperature of 75° F. The resistance in ohms of a wire of any length is, therefore, *the resistance of one mil foot of the wire, multiplied by its length in feet, and divided by the cross section in circular mils.*

EXAMPLE 12.

A copper wire 5000 ft. long and 49,000 c. m. in cross section has a resistance $= 10{\cdot}5 \times 5000 \div 49{,}000 = 1{\cdot}07$ ohms.

TABLE OF RESISTANCES.

MATERIAL.	Specific Resistance		Relative Conductance.	Conductivity compared with Mercury at 0° C
	(of 1 cm. cube) (in microhms)	of wire 1 metre long, 1 sq. mm. cross section (in ohms)		
Metals and alloys at 0° C				
Silver, pure..........	1.492	0·01492	105	63·8
Copper, pure.........	1·570	0·01570	100	55·86
Gold................	2·077	0·02077	76	44·06
Aluminum...........	2·889	0·02889	54	30·86
Zinc................			28	16·64
Platinum............	8·982	0·08982	17	6.073
Iron, pure...........	9·638	0·0964	16	9·685
Nickel..............			12	7·374
Tin.................			12	9·874
Lead................	19·63	0·1963	8·3	5·111
German Silver........	20·76	0·2076	7·6	3·603
Mercury.	94·34	0·9434	1·6	1·000
Liquids at 18° C.				
Water, pure..........	2,650,000,000		0·000,000,92	
5% solution of $H_2 SO_4$	4,860,000		0·000,000,83	
30% " "	1,370,000			

1 cm. cub. glass at 20° C has a sp. res. of 91,000,000,000,000,000,000 and a rel. conductance of 0·000,000,000,082.

Simple and compound circuits

57. When a circuit consists of various parts, all of different resistance, but connected *in series,* forming a single path, the total resistance is the sum of all the resistances. When a circuit is compounded or branched, that is connected *in parallel,* each of the parallel paths must be calculated separately.

EXAMPLE 13.

If there are two branches A and B, with resistances of 5 and 4 ohms respectively, between two common terminals, and the pressure is 40 volts, then the current flowing through A will be $40 \div 5 = 8$ amperes, and that through B $40 \div 4 = 10$ amperes, according to Ohm's law. The two currents stand in the proportion $\frac{1}{5}$ and $\frac{1}{4}$ (meaning that $\frac{1}{4}$, resp. $\frac{1}{5}$, of the number of volts [40] will give the amperes [8, resp. 10].) The total current being $8 + 10 = 18$ amperes, and the pressure being 40, the *joint resistance* (of the two branches) must be $\frac{40}{18} = 2\frac{2}{9}$ ohms. The joint resistance can also be figured as follows: The joint conducting power is $\frac{1}{5} + \frac{1}{4} = \frac{9}{20}$; the inverse * of this is $\frac{20}{9} = 2\frac{2}{9}$.

RULE 10. — In a circuit consisting of parts connected *in parallel, the total resistance equals the inverse of the total conductance. The total conductivity equals the sum of the conductances of the parts.*

EXAMPLE 14

Three wires of 6, 8, and 12 ohms resistance respectively, are connected in parallel. Their several conductances are $\frac{1}{6}$. $\frac{1}{8}$, and $\frac{1}{12}$ or $\frac{4}{24}$, $\frac{3}{24}$, $\frac{2}{24}$. These added give the total conductances;$= \frac{9}{24} = \frac{3}{8}$. The inverse of $\frac{3}{8}$ is $\frac{8}{3} = 2\frac{2}{3}$. The total resistance of the group of three wires is $2\frac{2}{3}$ ohms. Ans.

In a case of two *similar* wires in parallel the conducting power is exactly doubled, while the resistance is reduced to one half.

RULE 11. — *The joint conducting power of two wires in parallel equals the sum of the individual resistances, divided by their product.*

The inverse of this ratio gives the joint resistance. In a compound circuit, where some parts are in parallel, their resistance must be regarded, in calculation of the whole resistance, equal to the resistance of a single conductor which might replace them without a change in the total resistance.

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* The inverse or reciprocal of 3/4 is 4/3; of 3 it is 1/3; of 1½ it is 2/3.

EXAMPLE 15.

How shall 6 Daniel cells, of 1·08 volts and 0·6 ohm resistance each, be connected to drive the greatest current through a circuit of 3 ohms resistance?

The current of one cell $= \dfrac{1{\cdot}08}{3+0\ 6} = \dfrac{1{\cdot}08}{3{\cdot}6} = 0{\cdot}3$ amp.

Therefore, if we arrange the cells

a. 6 in series. $I = \dfrac{6 \times 1{\cdot}08}{3+(6\times 0{\cdot}6)} = \dfrac{6{\cdot}48}{6{\cdot}6} = 0{\cdot}98$ amp.

b. 2 parallel sets of 3 cells in series, $I = \dfrac{3\times 1{\cdot}08}{3+\dfrac{3\times 0{\cdot}6}{2}} = \dfrac{3{\cdot}24}{3{\cdot}9} = 0{\cdot}83$ amp.

c. 3 parallel sets of 2 cells in series, $I = \dfrac{2\times 1{\cdot}08}{3+\dfrac{2\times 0{\cdot}6}{3}} = \dfrac{2{\cdot}16}{3{\cdot}4} = 0{\cdot}63$ amp.

d. 6 in parallel, $I = \dfrac{1{\cdot}08}{3+(0\ 6\div 6)} = \dfrac{1{\cdot}08}{3.1} = 0\ 35$ amp. (approximately)

The arrangement 6 in series gives the greatest current Ans.

A more direct way of figuring out similar problems is made possible by

CADIOT AND DUBOST'S FORMULA:

a. *Total number of cells* (n) equals the product of four times external resistance (R), times internal resistance of one cell (r), times square of *the required current* (I)

divided by the square of the E. M. F. of one cell (E).

$$n = \frac{4\times R\times r\times I^2}{E^2}$$

b. *Number of cells in series* (x) equals the product of twice *the required current* (I) times external resistance (R), divided by the E. M. F. of one cell (E).

$$x = \frac{2 \times I \times R}{E}$$

c. *Number of groups in parallel* (y) equals the product of twice *the required current* (I) times internal resistance of one cell (r), divided by the E. M. F. of one cell (E).

$$y = \frac{2 \times I \times r}{E}$$

EXAMPLE 16.

12 electric fire alarm bells, each of nine ohms resistance are connected in parallel on a wire of 0·25 ohm resistance. What is the least number of 2-volt cells of $1\frac{2}{3}$ ohms resistance (r) each, required to send a current of 0.25 amp. through each bell?

Each bell requires 0·25 amp.; $12 \times 0{\cdot}25 = 3$. Each bell has 9 ohms resistance; $\frac{9}{12} = 0{\cdot}75$ ohms. Therefore:

$R = 0{\cdot}75 + 0{\cdot}25 = 1$ ohm; $r = 1\frac{2}{3}$ ohm;
E of each cell $= 2$ volts; $I = 3$ amp.

According to Cadiot and Dubost's formula *b*,

$$x = \frac{2IR}{E} = \frac{2 \times 3 \times 1}{2} = 3$$

and formula *c*,

$$y = \frac{2Ir}{E} = \frac{2 \times 3 \times 1\frac{2}{3}}{2} = 5$$

5 groups in parallel, each of 3 cells in series. Ans.

EXAMPLE 17.

8 cells of 2 volts E. M, F. and 2 ohms internal resistance each are arranged in two parallel sets, each of 4 cells in

series. What current will flow through an external resistance of 1 ohm?

E of each series $4 \times 2 = 8$ volts
int. resistance $4 \times 2 = 8$ ohms
E of battery 8 volts
total resistance $(8 \div 2) + 1 = 4 + 1 = 5$ ohms.

$$I = \frac{E}{R} = \frac{8}{5} = 1{\cdot}6 \text{ amp.}$$

EXAMPLE 18.

18 electrolytic vats, each of which requires 100 amperes at a pressure or 6 volts, are supplied by a dynamo with a current of 400 amperes at a pressure of 12 volts. How are the vats connected up?

The conditions are the same as where 18 cells drive a motor under the same circumstances. Therefore,

$$r = \frac{6}{100} = 0{\cdot}06 \text{ ohm}; \quad R = \frac{12}{400} = \frac{3}{100} = 0{\cdot}03 \text{ ohm.}$$

The total number of the cells (N) multiplied by $\frac{R}{r}$, equals the square of the number *in series* (n_s).

The total number of the cells (N), multiplied by $\frac{r}{R}$, equals the square of the number of groups *in parallel* (n_p).

$$n_s^2 = \frac{N \times R}{r} \qquad n_p^2 = \frac{N \times r}{R}$$

$$n_s = \sqrt{\frac{N \times R}{r}} = \sqrt{\frac{18 \times 0{\cdot}03}{0{\cdot}06}}$$

$$n_p = \sqrt{\frac{N \times r}{R}} = \sqrt{\frac{18 \times 0{\cdot}06}{0{\cdot}03}}$$

Multiplying both dividends and divisors by 100, the square of 10, which operation does not change the ratio, we get

$$\sqrt{\frac{18 \times 0{\cdot}03}{0{\cdot}06}} = \sqrt{\frac{18 \times 3}{6}} = \sqrt{9} = 3$$

$$\sqrt{\frac{18 \times 0{\cdot}06}{0{\cdot}03}} = \sqrt{\frac{18 \times 6}{3}} = \sqrt{36} = 6$$

6 groups in parallel of 3 vats in series. Ans.

EXAMPLE 19.

A battery of 15 cells in series, of 1·8 volts pressure on open circuit and 0·2 ohm internal resistance each, supplies a magnet coil of 1·5 ohm resistance, through a wire of 0·5 ohm res. What pressure is in the coil?

The E. M. F. of the battery, $E, = 15 \times 1{\cdot}8 = 27$ volts;
battery resistance, $r, = 15 \times 0{\cdot}2 = 3$ ohms
external. resistance, $R, = 1{\cdot}5 + 0{\cdot}5 = 2$ ohms
total resistance $= 3 + 2 = 5$ ohms
coil resistance $= 1{\cdot}5$ ohms. Therefore, the coil, offering only $\frac{1{\cdot}5}{5}$ of the resistance, requires only $\frac{1{\cdot}5}{5}$ of the E. M. F.

$$\frac{1.5}{5} \times 27 = \frac{40{\cdot}5}{5} = 8{\cdot}1 \text{ volts.} \quad \text{Ans.}$$

Fall of Potential

58. If it requires 16 pounds pressure to make 400 gallons of water per minute flow through a pipe 200 ft. long, 8 pounds pressure will make the same quantity of water flow through 100 feet of the same pipe, 4 pounds for 50 feet, 2 for 25, 1 for 12½. If pressure gauges were placed at each interval of 12½ feet, each following gauge would show one pound pressure less. The same is true of an electric current. If a wire 20 feet long is connected at one end (A) to the positive pole of a battery furnishing a current of 1 volt pressure, the negative pole of which is grounded, and the other end (B) to the ground, then the pressure at A will be 1 volt and at B it will be 0. At the middle of the wire (C) it will be $\frac{1}{2}$-volt, half-way between A and C $\frac{3}{4}$-volt, between C an B $\frac{1}{4}$-volt.

RULE 12.—The pressure falls directly as the resistance passed over.

Units of work and power

59. The work done by a pump is measured by FOOT POUNDS. A *foot pound* is the quantity of work done by a force, equivalent to *one pound* in weight, moving a body through a distance of *one foot.* A gallon of water weighs about $8\frac{1}{3}$ pounds; if therefore 120 gallons (=1000 pounds) of water per minute are forced through a pipe by a pressure equivalent to 33 feet of *head,* the amount of work done equals 33,000 foot pounds per minute. This rate has been adopted as the unit in measuring mechanical work, and is called one HORSE POWER. A *horse power hour* is 60 times this amount. If a pump lifts 600 gallons of water (= 5000 pounds) per minute 20 feet, the pumps works at a rate of a little more than 3 horse power. ($20 \times 5000 = 100{,}000$, while 3 horse power = 99,000.) (Metric H P = 75 kilogram meters per second.)

Similarly, when the quantity of electricity conveyed by one ampere in one second, or one coulomb, is passed through a wire under a pressure of one volt, the quantity of work done is called a JOULE (after the English scientist Joule). The amount of power required to do work at this rate, is called *volt-ampere* or WATT, after James Watt, the inventor of the condensing steam engine. *One horse power equals 746 watts.* The KILOWATT (= 1000 watts) is a little over $1\frac{1}{3}$ horse power (746 + 249 = 995).

RULE 13.— The power required to keep a steady current flowing through a wire, is calculated by multiplying the amperes of the current by the volts of pressure.

$$P = I \times E. \quad \left\{ I = \frac{P}{E}; \quad E = \frac{P}{I} \right\}$$

EXAMPLE 20.

a. If a current of 30 amperes is to flow through a circuit under a pressure of 90 volts, the power required is = 2700 watts. $P = I \times E$.

b. A dynamo which gives out 80 per cent of the power supplied by a 30 horse power engine, develops 17,904 watts.

c. If a dynamo develops 600 kilowatts and the pressure is 30 volts, a current of 20 amperes will result. $I = \frac{P}{E}$.

d. If a current of 8 amperes requires 440 watts, the pressure will be 55 volts. $E = \frac{P}{I}$.

e. If 3000 coulombs pass through a circuit each second, under a pressure of 9 volts, 97,200,000 joules will be expended in an hour. [3000 (coulombs) × 9 (volts) × 3600 (seconds).]

EXAMPLE 21.

What current is used by each of 80 incandescent lamps requiring 100 volts each, and connected in 40 parallel sets of 2 lamps in series, when the power used amounts to 4 kilowatts?

	Pressure.	Resistance.	Current.
For one lamp .	$E = 100$	R	$\frac{E}{R}$
For two lamps in series, ...	$2\,E = 200$	$2\,R$	$\frac{2\,E}{2\,R} = \frac{E}{R}$
For 40 parallel sets of 2 lamps in series, . . .	$2\,E = 200$	$\frac{2\,R}{40}$	$\frac{2\,E}{\frac{2\,R}{40}} = \frac{80\,E}{2\,R} = \frac{40\,E}{R}$

Now, current = watts divided by volts, therefore

$$I = \frac{4000}{200} = 20 \text{ amperes, and } 20 = \frac{40\,E}{R} = \frac{40 \times 100}{R}$$

$$20 = \frac{4000}{R} \qquad R = \frac{4000}{20} = 200 \text{ ohms.}$$

$$I \text{ of one lamp} = \frac{100 \text{ (volts)}}{200 \text{ (ohms)}} = 0{\cdot}5 \text{ ampere. Ans.}$$

EXAMPLE 22.

How much silver will be deposited in two hours, when one horse-power is applied to an electrolytic vat at a pressure of 1·86 volts?

$$1 \text{ H-P} = 746 \text{ watts}; \quad I = \frac{P}{E} = \frac{746}{1{\cdot}86} = 400 \text{ amperes.}$$

Amount of silver deposited by 1 ampere in 1 hour: 4·026 gr. (see § 48.)

$$2 \times 400 \times 4{\cdot}026 = 3220{\cdot}8 \text{ grammes. Ans.}$$

Electrical energy converted into heat

60. In example 20*b* a dynamo is supposed to develop 80 per cent of the power supplied by the engine. The other 20 per cent cannot be utilized, and is lost, in one sense of the word. But *no energy is ever destroyed.* In this case it is *converted into heat,* in overcoming the friction of the dynamo bearings, the resistance in the wire, etc.; a dynamo in operation is always warmer than the surrounding air. A gimlet used in boring a hole through wood gets hot, which means that a part of the energy applied to it is converted into heat by the friction that must be overcome. A nail driven into hard wood by hammer blows gets warm, which means that not all the power applied is actually used in driving. In the same way, a wire becomes heated when electricity passes through it.

RULE 14.—The amount of heat so produced is proportional to the number of watts expended in passing the current through the resistance.

If no work is done by the current, that is to say, if all the power is converted into heat, then the amount of heat is equal to the number of watts.

The formula for this law is again derived from Ohm's law: $E = I \times R$. Multiplying both sides of this equation by I, we have $I \times E = I \times I \times R$, or $E\,I = I^2\,R$.

$P = I \times E$ (see § 59); $P = I^2\,R$ or, in words,

RULE 15.—The power required to overcome the resistance of a wire equals the square of the current in amperes multiplied by the resistance in ohms.

This amount of power, not utilized in the actual work to be done, is called the *I square R loss*

From Ohm's law another formula for the loss may be derived: $I = \frac{E}{R}$ $P = I\,E$, and by substituting $\frac{E}{R}$ for I. $P = \frac{E^2}{R}$ or, in words,

RULE 16.—The I square R loss equals the pressure squared divided by the resistance.

EXAMPLE 23.

If a current of 75 amperes passes through a resistance of 6 ohms, 33,750 watts are expended in heating the wire.

$$(P = I^2 R;\ 75 \times 75 \times 6 = 33{,}750.)$$

EXAMPLE 24.

If power is delivered to a circuit at a pressure of 450 volts and the resistance of the wire is 5 ohms, the power expended amounts to 40·50 kilowatts. $(450 \times 450 \div 5.)$

Joule's law

61. The amount of heat generated in a wire by the electric current can be measured by a CALORIMETER. This is a device consisting of a jar nearly filled with water, in which a centigrade thermometer is immersed, and through which a wire runs in loops. The amount of heat needed to raise the temperature of a gramme of water one degree centigrade (as from 0° to 1°) is called a CALORIE. A certain percentage of the heat is lost, of course, through radiation.

RULE 17.— Heat amounting to 0·24 of a calorie equals the work represented by one joule,

(which also means: 1 calorie = 4·2 joules), and the sum of calories produced in one second in the calorimeter is, therefore, 0·24 times the power expended: $0{\cdot}24\ I^2\ R$. This value is multiplied by the number of seconds. The formula is

$$H = {\cdot}24\ I^2\ R\ T \quad (\mathrm{H} = \text{heat};\ \mathrm{T} = \text{time.})$$

EXAMPLE 25.

An incandescent lamp of 150 ohms resistance uses 1 ampere. How much heat does it give off every half-hour?

$$H = 24\ I^2 R\ T = {\cdot}24 \times 1 \times 150 \times 1800$$
$$= 64{,}800 \text{ calories.} \quad \text{Ans.}$$

In a circuit having a resistance of 6 ohms, through which a current of 20 amperes flows for one-half hour there will be developed 1,036,800 calories of heat. $(\cdot 24 \times 400 \times 6 \times 1800.)$

From the formula $H = \cdot 24\ I^2 R\ T$ another formula is derived:

$$I^2 = H \div \cdot 24\ R\ T$$

or, in words, the square of the current in amperes equals the calories divided by ·24 times the resistance multiplied by the time in seconds.

Heat amounting to ·24 of a calorie equals one joule; a joule (watt-second) per second equals one watt; a watt means the flowing of one ampere under the pressure of one volt, therefore, a watt produces ·24 of a calorie every second.

EXAMPLE 27.

How much greater is the heating effect of a current of 32 amperes than that of one of 8 amperes, in a wire of 10 ohm resistance? No time is mentioned.

$$32 \times 32 \times 10 = 10{,}240$$
$$8 \times 8 \times 10 = 640$$
$$10{,}240 \div 640 = 16 \text{ times as great. Ans.}$$

EXAMPLE 28.

What part of the total power supplied to 50 incandescent lamps, connected in parallel, with a resistance of 180 ohms each, is lost in a wire having a resistance of 0.6 ohm?

$$\text{Lamp resistance} = \frac{180}{50} = \frac{360}{100} = 3{\cdot}6$$
$$\text{Wire resistance} = 0{\cdot}6$$

Total resistance $= 3{\cdot}6 + 0{\cdot}6 = 4.2$

0·6 is one-seventh of 4·2. $\frac{1}{7}$ or 14·28 per cent. Ans.

EXAMPLE 29.

How much heat per minute is generated in an electrical heating apparatus using 6 H. P.?

1 H. P. = 746 joules per second.
6 H. P. = 6 × 746 = 4476 j. p. s.
60 × 4,476 = 268,560 joules per minute.
0.24 × 268,560 = 64,454 cal. Ans.

EXAMPLE 30.

A battery raises the temperature of 1,000 grammes of water in a calorimeter 6° C. in ten minutes. If one-seventh of the total heat generated is lost by radiation, how much power is supplied to the coil by the battery?

Raising the temperature of one gramme of water 1° C. in one second requires 4·2 joules. Therefore, to raise the temperature

of 1,000 gr. 1° C. in 1 second, requires 1,000 × 4·2 joules
" 1,000 gr. 6° C. " 1 " " 6 × 1,000 × 4·2 "
" 1,000 gr. 6° C. " 10 minutes " $\frac{6 \times 1{,}000 \times 4\cdot 2}{600}$ "

$$\frac{6 \times 1{,}000 \times 4\cdot 2}{600} = 10 \times 4\cdot 2 = 42 \text{ joules per second.}$$

One seventh being lost, $42 = \frac{6}{7}$; total heat = 49.
49 joules per second = 49 watts. Ans.

62. A wire through which a current flows, gives out a part of the heat developed in it. When it gives out as much as is developed, it remains at a fixed temperature. An insulated wire gives out more heat than one not insulated, because the insulation being quite thick as compared with the wire itself, offers a much larger surface than the wire, and the increased radiation more than balances the increased difficulty of the heat in reaching the surface.

Thermo-electric current

63. When a rod of bismuth is soldered, end to end, to a rod of antimony, and the two free ends are connected by a wire, and the junction is heated, a current flows through the whole circuit in the direction from bismuth to antimony. If the junction is cooled, the current flows from antimony to bismuth. On the other hand, if a current is sent through such a rod in the direction from bismuth to antimony, the junction becomes cooled; when from antimony to bismuth, the junction is heated. This is true of all combinations of metals which are THERMO-ELECTRICALLY affected. It is also true, in a minor degree, of two different kinds of the same metal, of two liquids, and of a liquid and a metal.

In the following *contact series of metals in air* each metal named is electro-positive in regard to all that follow it and electro-negative to all that precede it: Bismuth, zinc, lead, copper, iron, silver, platinum, antimony. Bismuth and antimony, being farthest apart in the series, give the best results.

RULE 18. — The difference of potential, produced by the contact of any two metals, is equal to the sum of the differences of potentials between the intervening metals in the constant series. (Volta's law.)

Here follows a table of the differences of potential set up by contact of some of the metals:

Zinc Lead	·210	Iron Copper	.146
Lead Tin	·069	Copper Platinum	.238
Tin Iron	.313	Platinum Carbon	.113

According to Volta's law, the difference in potential between zinc and tin is .210 + ·069 = 279; between zinc and iron, ·210 + ·069 + ·313 = ·592, etc.

Such a pair is called a THERMO-ELECTRIC COUPLE. The power of any thermo-electric couple, as a rule, increases with the increase of difference of temperature between the junction and the other ends, up to certain limits, beyond which the current may cease altogether, or flow in the opposite direction.

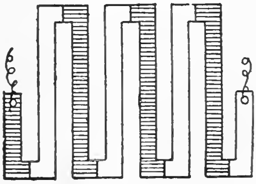

FIG. 19.

A circuit of several such couples is called a *thermopile*. (See diagram, fig. 19.) They are so arranged that one set of junctions (the first, third, fifth, etc.) can be heated, while the other set (the second, fourth, sixth, etc.) are kept cool. The E.M.F. generated by a couple is so low that it is measured in microvolts (millionths of a volt), but they are very convenient in laboratory work, especially for discovering minute differences in radial heat, because the current set up may be kept perfectly constant, as by putting the even numbered junctions in boiling water and the odd numbered ones in melting ice. Some thermopiles are so sensitive that they will indicate a difference of temperature of $\frac{1}{5000}$ of a degree.

Questions and Answers.

Q. What is the resistance in one mile of No. 1 B & S (Amer. standard wire gauge) trolley wire? (See page 208.)

A. Between 6 and 7 tenths of an ohm

Q. If a current of 6 amperes flows through a wire of 10 ohms resistance, what will be the pressure? A. 60 volts.

Q. In a battery of 4 gravity cells in series each cell has an internal resistance of 4 ohms, and gives 1·5 volts pressure. The external resistance is 8 ohms. What current will flow?

A. $\frac{1}{4}$ ampere.

Q. If a battery of 4 cells in series, of 1·5 volts each, develops a current of 6 amperes, what is the resistance in each cell, the external resistance being negligible, that is, too small for consideration?

A. $\frac{1}{4}$ ohm.

Q. What does $E = I \times R$ mean?

A. It means that the electrical pressure in volts between 2 points in a circuit can be calculated by multiplying the current flowing in that part, in amperes, with the resistance, in ohms.

Q. Through a copper wire 2000 feet long, with a cross section of 25,000 circular mils, flows a current of 60 amperes. How great is the pressure?

A. 50·4 volts. ($R = 10{\cdot}5 \times \frac{2000}{25000} = \frac{21}{25} = 0{\cdot}84$ ohms; $E = 0{\cdot}84 \times 60 = 50{\cdot}4$.)

Q. A wire has a resistance of 150 ohms. A piece of the wire 10 feet long has a resistance of 2 ohms. How long is the wire?

A. 750 feet. ($150 \div 2 = 75$; $75 \times 10 = 750$.)

Q. A dynamo of 9 ohms resistance supplies 12 eight-ampere arc lamps, each requiring 50 volts and connected in series. The copper wire has a cross section of 12,000 c. m. and is 6,000 feet long. What is the total pressure?

A. 714 volts. (The resistance of the wire $= 10{\cdot}5 \times \frac{6}{12} = 5{\cdot}25$; that of the lamps $= \frac{12 \times 50}{8} = 75$; that of dynamo $= 9$. Total 89·25 ohms. $E = 8 \times 89{\cdot}25 = 714$.)

Q. A single incandescent lamp is supplied with a current of 2 amperes. The copper wire circuit is 2000 feet long, cross section 5000 c. m. The pressure is 200 volts. What is the hot resistance of the filament?

A. 95·8 ohms. (Total resistance = 200 ÷ 2 = 100; wire resistance $= 10{\cdot}5 \times \frac{2000}{5000} = 4{\cdot}2$; $100 - 4{\cdot}2 = 95{\cdot}8$.)

Q. What is the joint resistance of 4 parts of a circuit in series, when their respective resistances are 5, 4, 2 and 1 ohms? And what is it when they are connected in parallel, with 10-volts pressure at their terminals?

A. In series, 12 ohms ($5 + 4 + 2 + 1$). In parallel, 0·5 ohm. (The currents in the parts are $\frac{10}{5} + \frac{10}{4} + \frac{10}{2} + 10 = 19{\cdot}5$ amperes; $\frac{10}{19{\cdot}5} = 0{\cdot}5$. Or: The conductances of the parts are $\frac{1}{5} + \frac{1}{4} + \frac{1}{2} + 1 = \frac{39}{20}$. The reverse of this is $\frac{20}{39} = 0{\cdot}5$.)

Q. What is the inverse of $\frac{1}{3}$, 29, $\frac{8}{3}$?

A. 3, $\frac{1}{29}$, $\frac{3}{8}$.

Q. What is the joint conductance of 2 branches receiving 12 volts, and with 6 and 18 ohms resistance respectively? And what is the joint current and joint resistance?

A. Joint conductance $\frac{4}{18}$; joint current $2\frac{2}{3}$ amperes; joint resistance 4·5 ohms. ($\frac{1}{6} + \frac{1}{18} = \frac{4}{18}$; $\frac{12}{6} + \frac{12}{18} = \frac{8}{3} = 2\frac{2}{3}$; $12 \div \frac{8}{3} = 12 \times \frac{3}{8} = \frac{36}{8} = 4{\cdot}5$.)

Q. The joint resistance of 2 wires in parallel is 3 ohms. The resistance of one branch is 5 ohms, what is that of the other?

A. 7·5 ohms. (Joint conductance $\frac{1}{3}$; conductance of 5 ohm wire $\frac{1}{5}$; $\frac{1}{3}=\frac{5}{15}$; $\frac{1}{5}=\frac{3}{15}$; the difference $\frac{2}{15}$ indicates the conductance of the other branch, and the inverse, $\frac{15}{2}=7{\cdot}5$, is its resistance.)

Q. Three incandescent lamps placed in parallel, have the following resistances: 150, 200, 300 ohms. The voltage at the terminals is 120 volts. What is the total current?

A. 1·8 amperes. $\left\{\frac{4}{5}+\frac{3}{5}+\frac{2}{5}=\frac{9}{5}=1\frac{4}{5}=1{\cdot}8.\right\}$

Q. If the current in a circuit is to be increased one half, by placing a similar wire in parallel, without causing a change in the drop of pressure, of what size should the second wire be?

A. One half the cross section of the other, in circular mils.

Q. Can water be frozen by electricity?

A. Yes, by cooling the junctions of a thermopile, as by sending a current from the bismuth rod to the antimony rod, a drop of water at the cooled junction may be frozen.

Q. How much voltage does one thermo-electric couple of German silver and an alloy of zinc and antimony generate?

A. About four-hundredths of one volt.

Q. What is Mho?

A, The unit of conductance, little used because resistance impliedly expresses conductance, being its reciprocal. "Ohm" spelled backward is "Mho".

CHAPTER V. — MAGNETISM.

Theory of magnetism

64. What MAGNETISM really is, has not been discovered. The latest theory, well supported by facts, assumes that the molecules of a magnetic substance are minute magnets by nature, each having two poles. In a bar magnet each molecule at the two ends may be supposed to have the attraction of its inward-pointing pole neutralized more strongly than that of the outward-pointing pole, which, therefore, is free to attract other bodies. A certain native oxide of iron is called MAGNETITE, because pieces of it (lodestones or leading stones) sometimes are *natural* magnets. Such a natural magnet changes a magnetic piece of soft steel or iron to an *artificial* magnet, without losing any part of its own magnetism. The steel magnet is a permanent magnet, the one of soft iron loses almost all its magnetism, as soon as the contact with the natural magnet ceases. The ancients found this stone near Magnesia in Asia Minor, hence

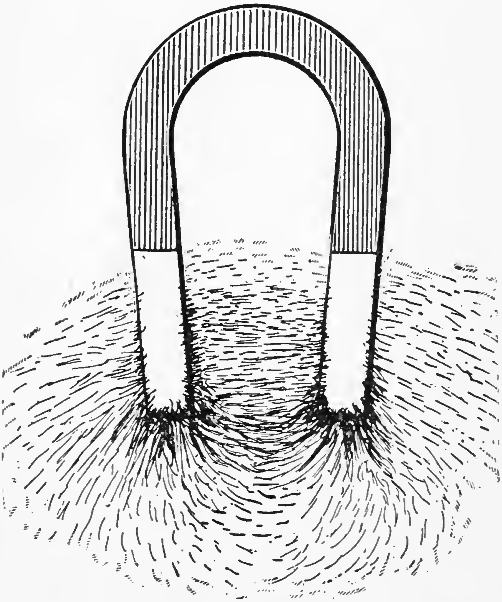

FIG. 20.

the name. It is occasionally found in Sweden, Spain, Arkansas and the Isle of Elba.

A HORSESHOE MAGNET (see fig. 20) is a steel bar magnet, the two ends of which are bent close together. The advantage of a horseshoe magnet lies in the fact that a piece of soft iron placed across its poles is a strong protection of its magnetism. The piece of soft iron is called a keeper or armature.

Terrestrial magnetism

65. A magnetic bar (needle) properly suspended on a thread, will turn so as to point almost exactly north and south, and in the northern hemisphere the *north-seeking pole of the magnetic needle dips down* (INCLINATION), and the more the closer it is to the geographical North Pole. On the southern hemisphere the *south*-seeking pole dips. All this proves that the earth is a magnet of two poles. But its geographical and magnetic poles are not identical; nor are the magnetic poles constant: they vary back and forth in the course of time, and in different longitudes (DECLINATION).

Magnetic induction

66. If two magnetic needles properly suspended are placed near each other, the two north poles or south poles repel each other, while the north pole of one needle will attract the south pole of the other. Judging from this, the north-seeking pole of a magnetic needle has not the same magnetism as the north pole of the earth.

RULE 18A.—Like poles repel, unlike poles attract each other.

(Compare Rule 1 in § 5.) If a soft iron bar is substituted for one of the magnetic needles, the result is quite different: *Either end of the bar will attract either pole of the needle.*

The magnetic needle MAGNETIZES the bar by INDUCTION; and if a steel magnet is substituted for the needle, the induction will be strong enough to cause the soft iron bar to magnetize another soft iron bar to a lesser degree, and this one will magnetize a third bar by induction to a still smaller degree, and so on. This decrease in strength is due to the fact that in each bar the attracted end is nearer to the inducing link in the chain of bars than the repelled end, and the attraction is therefore stronger than the repulsion.

Each magnetized body has two opposite poles. If a steel magnet is broken in two, each piece is at once a magnet with two poles. If a soft iron bar is touched at its two ends by two steel magnet north poles of equal strength, the two ends of the bar become south poles, and in the middle of the bar a north pole is formed; it is called a CONSEQUENT POLE.

Magnetic substance

67. Substances capable of becoming magnetized by induction are called MAGNETIC MATERIAL. Of all these, iron in all its forms stands at the head. Nickel, cobalt, platinum and a few other substances are magnetic in a far lesser degree. Magnetism acts through paper, wood, a vacuum, and, in short, through all materials that may not be magnetized. As seen in § 64, magnetic materials differ in their power of retaining magnetism; they differ also in their power of resisting magnetization. Hard steel is difficult to magnetize, but it also retains magnetism very strongly; it is said to have great COERCIVE FORCE; soft iron is easily magnetized and demagnetized. (See 72.) Sudden shocks, as by dropping on a hard ground, or great heat will deprive a magnet of its force. A steel bar may be magnetized by stroking one end from the center with one pole of a magnet, and the other end from the center with the other pole, or by laying it against an electromagnet, or by placing it within a coil of wire carrying an electric current. A very strong magnet can be made by placing several thin magnetized bars of even length one upon the other. The reason for this is that the magnetic force appears on the surface of each bar. Such a magnet is called a compound or LAMINATED magnet. When a steel bar has been magnetized to its full capacity,it is said to be SATURATED. It will lose part of this strength again, until it reaches its proper strength, which is then *permanent*. When it has reached its permanent strength it is said to be AGED. Steel magnets are aged artificially by immersion in steam for a length of time.

Magnetic field

68. In keeping with the theory set forth in § 64, the magnetic force in a steel bar magnet shows most strongly at its ends, but it extends in ever decreasing degree towards the middle. If iron filings are strewn on a paper placed on a magnet, this fact becomes at once evident from the quantity of filings gathering at different points. (See fig. 21.) It is also

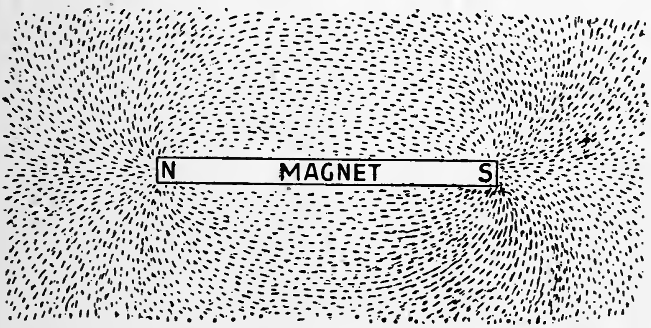

FIG. 21.

evident that the filings place themselves in a certain order represented by curves reaching from one pole to the other. These lines are called LINES OF (magnetic) FORCE, and the space in which a magnet may create such lines, is called a MAGNETIC FIELD OF FORCE. The STRENGTH of this force decreases with the increasing distance from the pole. Abnormally a magnetic bar may have one or more intermediate points of maximum attraction, which are then called CONSEQUENT (= one following upon another) poles. See § 66.

Any small, thin, needle-like piece of iron thrown on the paper will place itself in a position tangential to the curve nearest which it was dropped. If a free-swinging magnet is brought within the field of force of another magnet, it will set itself so that its own lines of force are parallel to those of the other, and in the same direction. A few light iron filings floating on a water surface organize at once into a compact body when a magnet is held near them, and assume a north and south position, when the magnet is removed. If the magnet is moved about, some of the filings swing completely around.

Measures of magnetism

69. In order to arrive at a standard of measure for magnetism, the magnetic field is *imagined* to be filled with so many lines of force per square centimeter, and a UNIT FIELD is *imagined* to have *one* line of force per square centimeter. A magnet pole is said to have UNIT STRENGTH, when it repels or attracts another similar pole, placed at the distance of one centimeter in air, with a force of one DYNE. (A dyne is the force which, acting on a body weighing one gramme in one second, imparts to it a velocity of one centimeter per second.) Of course, two such poles cannot be constructed in practice, as magnets of only one pole cannot be made. The number of lines of force in a square centimeter of cross section of the field determine the MAGNETIC DENSITY; if it is uniform, the field is called UNIFORM. The total uumber of lines in the whole field are called the MAGNETIC FLUX, or simply the MAGNETISM. As seen in § 68, the lines of force reach from one pole to the other, and, as in electricity, see § 14, the magnetic pressure is due to a DIFFERENCE OF POTENTIAL. This pressure is measured by the work necessary to move an independent north pole of a certain strength from the south to the north pole of the magnet. This amount of pressure is called a MAGNETIC UNIT.

Electromagnetism

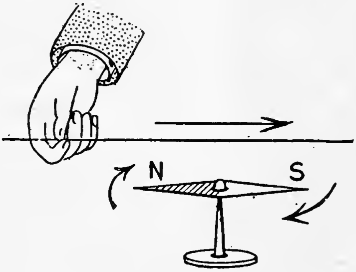

FIG. 22.

70. A close relation appears to exist between magnetism and electricity. In the scientific world this was first established in 1819, when a Danish investigator, Oersted, announced that a compass needle is disturbed by the neighborhood of an electric current. If the wire through which the current flows is held above and parallel to the needle, the needle tends to set itself at right angles to the wire. (See fig. 22.) The degree to which it does this, depends on the strength of the current in the wire and on its nearness. If the current is just strong enough and near enough to balance the magnetism of the earth, the needle will deflect 45 degrees. The explanation given for this phenomenon is that *the current creates another magnetic field* (see § 68) *the force of which affects the needle.* The reason for this fact, science has not fathomed. The lines of this ELECTROMAGNETIC force in the field about a round wire must necessarily be concentric circles around the wire, as the direction of the force on all sides is at right angles to the direction of the current. If the wire of a battery is passed vertically through a piece of cardboard placed horizontally, (see fig. 23,) on which iron filings have been strewn, the filings will arrange themselves in concentric circles as soon as the current is turned on.

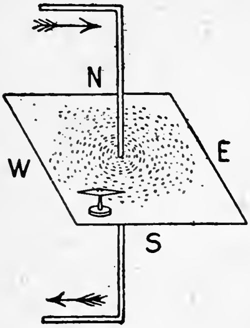

FIG. 23.

All that is stated in § 68, applies here. If we place a compass needle on the card board, with its pivot directly over a curve of filings, as shown in the figure, it will tend to place itself in a position tangential to the curve. The north pole of the needle in the figure points West; if placed East of the wire, it would point South. If, however, the current were flowing in the opposite direction to that indicated by the arrows, the needle would point East in the position shown, and if placed East of the wire, would point North. AMPERE'S RULE for determining the direction in which the needle will deflect:

RULE 19.—Suppose yourself to be in the wire, floating with the current and facing the needle; its north pole will turn toward your left hand.

The fact may also be remembered as follows: Grasping the wire with the right hand, so that the thumb points in the direction in which the current flows, and the fingers enclose the wire, the finger tips point in the direction in which the North pole of the needle will deflect. Based on the first rule is the common method of determining the direction of a current in a wire by placing a compass *under* the wire.

If two thin wires are loosely suspended near each other, and a current is sent through them so as to flow up in one and down in the other, the two will repel each other ; if the current flows in the same direction in both, they will attract each other. Wires inclined to each other tend to become parallel. A flexible charged wire will wind around a fixed magnet. All the facts mentioned in this section, are of the greatest importance, for from them is derived

RULE 20.—Magnetic lines of force tend to occupy a position in which they are parallel with each other and run in the same direction.

Apparently the lines of force cannot become parallel or point in the same direction, when the two conductors are at an angle, or too close together, or too far apart.

The Solenoid

71. If a charged wire is placed above a magnet, and another below it, at the same distance, their influence on the magnet will be twofold, according to Ampere's rule : If the currents flow in opposite directions, the influence will be doubled ; if they flow in the same direction, the two influences will balance or neutralize each other, and the needle will not deflect.

RULE 21.— If one wire is coiled into several turns around the needle, this influence of the current is determined by the strength of the current times the number of the turns.

This product is called CURRENT TURNS or AMPERE TURNS, and the set of coils is called a SOLENOID. The law stated at the end of § 70 applies also in the case of a solenoid: within the coils the lines run parallel and in the general direction of the current from one end of the coil to the other; between the single turns, and outside, the lines of force adjust themselves to each other. The lines of force emerge from one end of the solenoid (helix or coil), pass around its outside and enter the other end, thus completing the magnetic circuit. (See fig. 24.) The word "solenoid" (from the Greek) means "pipe-shaped."

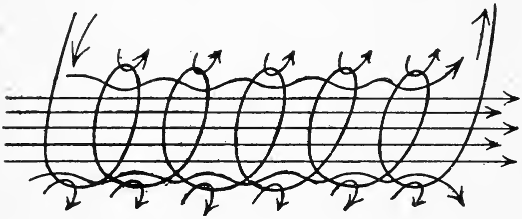

FIG. 24.

RULE 22.— The number of lines of force (called induction, per square centimeter) set up in an empty helix, equals the product of the number of turns (per centimeter in length of the coil) times the number of amperes multiplied by 1.257. When the inch is used the constant is 3·2.

EXAMPLE 31.

a. How many turns to the inch are required to set up an induction of 400 lines with a current of 5 amperes?

One ampere turn gives 3·2 lines of force; 400 ÷ 3·2 = 125 ampere turns; 125 ÷ 5 = 25. Ans.

b. A current of 5 amperes flows through a 24-inch helix of 192 turns. How many lines of force per square inch inside the coil?

192 ÷ 24 = 8 turns per inch. 8 × 5 × 3·2 = 128. Ans.

c. How many amperes will produce 1,000 lines per square inch in a coil 15 inches long with 3000 turns?

1000 ÷ 3·2 = 312·5 ampere turns per inch in length of the coil. There are 200 turns per inch (3000 ÷ 15). 312·5 ÷ 200 = 1·56. Ans.

A solenoid is in every respect exactly like a steel magnet, and all that has been said about the latter, applies to the solenoid as well. The direction in which the current flows through it, indicates the polarity:

RULE 23.— For a person standing at the south pole, the current flows in the direction in which the hands of a clock turn, from the left *over* to the right.

The Electromagnet

72. When a bar of iron or steel is placed within a solenoid, the electric current magnetizes it strongly; *the lines of force produced are enormously increased in number.* This power of iron is called its PERMEABILITY. Bodies in which the magnetizing force produces a large quantity of lines of force, are said to possess a high permeability. The more *ampere turns,* the more readily will the bar be saturated.

It was stated in § 69 that magnetism is due to a difference of magnetic potential. Therefore we may safely assume that a solenoid produces such a difference, and experiments have proved that

RULE 24.— one ampere turn sets up almost exactly one and one-quarter units of magnetic pressure.

The formula used to express this law is $M = 1{\cdot}256\ n\ i$, M representing the magnetic pressure, n the number of turns, i the current in amperes, and $n\ i$, therefore, the ampere turns.

From the above it will be readily uderstood, that a bar of soft iron wound with a large number of turns, through which a strong current flows, will become a magnet of enormous strength. Of equal importance is the fact (discovered by the English scientist Sturgeon, 1825) that while a steel bar retains its magnetism after the current is shut off, a soft iron bar instantly loses almost all its magnetism. On these two facts, furnishing a perfectly controllable force, is based the bulk of the magnificent modern electric achievements. The insignificant amount of magnetism retained by the soft iron bar, when the current is shut off, corresponds to the powerful magnetism retained in a hard steel bar; they are both called RESIDUAL MAGNETISM.

Permeability

73. *RULE 25.—The permeability of a bar of iron is figured by dividing its number of lines of force by the number which pass through the same space when the iron is not present.*

In the case of example 31*b* in § 71, with 45,000 lines of force per inch passing, the permeability would be 351. (45,000 ÷ 128 = 351.)

There is no substance, that comes near iron in *magnetic permeability.* Nickel and cobalt, next in order, have a much lower permeability. Wrought iron has the greatest, then steel, then cast iron. The purer the iron the greater is its permeability, or the smaller its RELUCTANCE, which term means the same in magnetism, as *resistance* in electricity. The reluctance of a material is the inverse of its permeability; therefore, the

$$\text{reluctance} = \frac{1}{\text{permeability}} \times \frac{\text{length in inches (or cm.}}{\text{cross section in sq in. (sq cm)}}$$

Up to the point of saturation of the electromagnet with magnetism, there is naturally a great variety of permeability (the amount of magnetism produced by currents of various strength): in a non-magnetized bar a slight current will create a large quantity of magnetism; the more magnetized the bar becomes, the smaller the effect of the increasing strength of the current; after saturation even a current of greatly increased strength will cause only a slight rise of the magnetic pressure.

The saturation curve

74. *For each kind of iron* its permeability may be indirectly established by drawing a curve corresponding with its relations between ampere turns and magnetism. In fig. 25 distances on the lines across the page (horizontal) indicate the ampere turns per inch of the length of the helix, and distances on the vertical lines indicate the number of lines of force per sq. inch or cm. in the iron. The curve C B, therefore, indicates *the average induction per square inch of soft iron which will be produced by a certain number of ampere turns per inch of its length.* Near point A will be the point of saturation, with 12,000 lines per sq. c. m, indicated at six ampere turns per sq. centimeter. A curve similar to C B may be constructed from experiments, indicative of the rate at which the magnetism leaves the iron, when the current is gradually

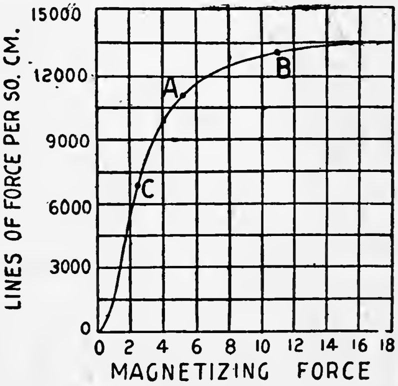

Fig. 25.

diminished and finally shut off entirely. The deviation of this curve from the path of curve C B is called HYSTERESIS, and is due to the *coercive force* of iron. (See § 67.)

By dividing the indicated number of lines of force per square centim. by the indicated magnetizing force per square centim., we arrive indirectly at the permeability of a piece of iron at any point of the saturation curve. — The magnetizing force per square cm. is found by multiplying the ampere turns per cm. in length by 1.257

75. Air, as compared with iron, has a very low permeability, and has therefore been taken as unity (1). Materials that have a greater permeability than air are called PARAMAGNETIC, those having a less permeability are called DIAMAGNETIC. But all substances, even a vacuum, have some degree of permeability, so that there is no *insulation* possible in magnetism, as there is in electricity.

RULE 26. — The permeability of any piece of material increases with the increase of cross section and decreases with the increase of length.

76. Saturation curves have been fixed for all the important kinds of iron, and they are very useful in dynamo calculations. See §74. The vertical scale gives the number of lines per sq cm. or sq inch; from where a horizontal line drawn from there intersects the curve, a vertical line drawn downward to the horizontal scale marks the number of ampere-turns required per cm. or inch in length of the magnetic circuit in the ring.

The number of ampere-turns needed to drive a given number of lines of force through an iron ring, is calculated as follows: Divide the number of lines by the number of square inches cross section of the ring. This gives the induction per square inch. Then find on the saturation curve of the iron the number of ampere turns per inch, in length corresponding to this induction per square inch, and multiply it by the medium length of the magnetic circuit in the iron ring in inches (the length of a ring of *d* inches in diameter equals $\pi \times$ d or 3·1416 times diameter). The result is the answer required.

RULE 27.—To find the permeability of a bar of iron at any point of the saturation curve:

a, if the curve is given in terms of lines per sq. cm., and ampere turns per cm. in length, *divide the number of lines of force per sq. cm. by magnetizing force per sq. cm.*

b, if the curve is given in terms of lines per sq. inch and ampere-turns per inch in length, *divide the induction per sq. inch by the magnetizing force per sq. inch, which equals the ampere-turns per inch in length times 3·2.*

RULE 28.—a. To reduce from lines of force per sq. cm. to lines of force per sq. inch, multiply by 6·45.

b. To reduce from lines of force per sq. inch to lines of force per sq. cm. divide by 6·45.

c. To reduce from magnetizing force per sq. cm. to ampere turns per inch in length, divide by 3·2 and multiply by 6·45.

d. To reduce from ampere turns per inch in length to magnetizing force per sq. cm., multiply by 3·2 and divide by 6·45.

Magnetomotive Force

77. Ohm's law is but an application of the general law that *the result of any effort is equal to that effort divided* *by the opposing force,* and this general law holds good in regard to the electromagnet:

RULE 29.—The number of lines of force in any magnetic circuit equals the magnetic pressure divided by the reluctance. (Formula: $N=\frac{M}{P}$; —N representing the number of lines of force, M the magnetomotive force or magnetic pressure, P the reluctance.) The formula for M has been stated in §72.

Of course, from the above formula we also derive: $M=N\times P$; and $P=\frac{M}{N}$.

EXAMPLE 32.

a. What is the permeability of iron at 75,000 lines per sq. inch, when the ampere-turns per inch in length are 18?

$18\times 3{\cdot}2=57{\cdot}6$; $75{,}000\div 57{\cdot}6=1{,}302$. Ans.

b. What is the permeability of cast steel at an induction of 75,000, with 24 ampere turns per inch in length?

$24\times 3{\cdot}2=76{\cdot}8$; $75{,}000\div 76{\cdot}8=976+$. Ans.

c. What is the permeability of cast iron at an induction of 38,000 lines, with 80 ampere-turns per inch in length.

$80\times 3{\cdot}2=256$; $38{,}000\div 256=148$. Ans.

EXAMPLE 33.

How many units of magnetic pressure are set up in a copper wire coil of an electromagnet, when the wire has 1200 turns 2 feet long each and 1100 circul. mils cross section, by a current of 50 volts pressure? According to § 56,

$$\text{resistance of 1 turn}=\frac{2\times 10{\cdot}5}{1100}=\frac{21}{1100}=0{\cdot}019 \text{ ohm.}$$

$$\text{res. of 1,200 turns}=1200\times 0{\cdot}019=22{\cdot}8 \text{ ohms.}$$

According to § 72, $Mmf = 1{\cdot}257\ n\,c$

$$C = \frac{50}{22.8} \text{ therefore } Mmf = 1.257 \times 1200 \times \frac{50}{22.8}$$

$$= \frac{1{\cdot}257 \times 60000}{22{\cdot}8} \qquad = \frac{75420}{22{\cdot}8}$$

$$= 3307 \text{ units of } Mmf. \quad \text{Ans.}$$

EXAMPLE 34.

6 Daniel cells, arranged in 3 sets in parallel of 2 cells in series, and of a pressure of 1·1 volts, and an internal resistance of 3 ohms each, are connected to a solenoid of 1000 turns and 4 ohms resistance. What is the magnetic pressure set up?

E of one set of 2 cells $= 2 \times 1{\cdot}1 = 2{\cdot}2$ volts
r " " 2 " $= 2 \times 3 = 6$ ohms
E of three sets $= 2{\cdot}2$ volts
r " " $= \frac{6}{3} = 2$ ohms
$R = 4$ ohms; total res. $= 4 + 2 = 6$ ohms

$$C \text{ of three sets} = \frac{2.2}{6} = 0{\cdot}366 \text{ amperes}$$

$$Mmf = 1{\cdot}257 \times 0{\cdot}366 \times 1000$$

$$= 1{\cdot}257 \times 366 \qquad = 460 \text{ units of } Mmf. \quad \text{Ans.}$$

EXAMPLE 35.

What is the magnetic pressure set up, if the 6 cells in the preceding example are arranged in series?

$E = 6 \times 1{\cdot}1 = 6{\cdot}6$ volts
$r = 6 \times 3 = 18$ ohms
$R = 4$ ohms
total res. $= 18 + 4 = 22$ ohms

$$\text{Current } C = \frac{E}{r+R} = \frac{6.6}{22} = 0{\cdot}3 \text{ ampere}$$

$$Mmf = 1{\cdot}257 \times 0{\cdot}3 \times 1000$$

$$= 1{\cdot}257 \times 300 \qquad = 377{\cdot}1 \text{ units of } Mmf. \quad \text{Ans.}$$

EXAMPLE 36.

A ring of iron 200 cm. long, with a cross section of 30 sq. cm., and a permeability of 700 when 50.000 lines of force pass through it, has wound upon it a coil of 400 turns. How much current is required to set up this magnetization?

Number of lines (§ 77) = magn. pressure ÷ reluctance.

$$\text{Reluctance (§ 73)} = \frac{1}{700} \times \frac{200}{30} = \frac{200}{21000} = \frac{2}{210}$$

$$\begin{aligned}\text{Number of lines: } 50{,}000 &= 1{\cdot}257 \times 400 \times C \div \frac{2}{210} \\ &= \frac{210 \times 1{\cdot}257 \times 400 \times C}{2} \\ &= 105 \times 1.257 \times 400 \times C \\ &= 42000 \times 1{\cdot}257 \times C \\ &= 52794 \times C \\ C &= 50{,}000 \div 52{,}794 \\ C &= 0{\cdot}95 \text{ ampere. Ans.}\end{aligned}$$

If a magnetic circuit consists partly of iron and partly of air gaps, as in dynamos, the ampere-turns must be figured for each part separately, and the results added up, to arrive at the number of ampere turns required to drive a desired number of lines through the circuit. The number of lines of force per sq. inch in a gap must be multiplied by ·3133 (the reciprocal of 3·2) *and* by the magnetic length of the gap in inches or cm.

EXAMPLE 37.

A magnetic circuit, partly made up of a **U**-shaped bar of annealed iron 150 cm. long by 20 sq. cm. cross section, has a permeability of 3000 at a magnetic induction of 5,000 lines of force per sq. cm. The remaining parts are two air spaces 1 cm. long each. What magnetic pressure will set up a total of 600,000 lines of force?

$$\text{Reluctance of iron} = \frac{1}{3000} \times \frac{150}{20} = \frac{150}{60{,}000} = \frac{1}{400}$$

The air spaces must be considered to have the same cross section as the iron, of course.

$$\text{Reluctance of air} = \frac{2 \times 1}{20} = \frac{2}{20} = \frac{40}{400}$$

$$\text{total reluctance} = \frac{1}{400} + \frac{40}{400} = \frac{41}{400}$$

$$\text{Magnetic pressure} = \frac{600{,}000 \times 41}{400} = 61{,}500$$

61500 units of *Mmf.* Ans.

Questions and Answers.

Q. What is the origin of the word "magnet"?

A. It is derived from the Greek word *magnes,* the name of a mineral possessing magnetic quality.

Q. What is a good way of making a magnet out of a steel bar?

A. Place the bar within a coil of wire through which an electric current is flowing.

Q. How much strength does a well made magnet develop?

A. It will carry up to twenty times its own weight.

Q. What would such strength signify?

A. That the magnet has twenty times the strength of the force of gravity due to the earth.

Q. What effect has heat upon a magnet?

A. Cooling slightly increases the power of a steel magnet. Red heat will demagnetize a magnet.

Q. What is coercive force?

A. The resistance of a material to a change in its magnetic strength.

Q. Are other materials than metals magnetic?

A. Yes, oxygen for instance, and some salts of metals, also their solutions.

Q. How many lines of force per sq. cm. are there in a field of unit strength?

A. It is theoretically conceived to have one line of force per sq. cm.

Q. A field has 50 lines of force per sq. cm., and acts upon a pole with a force of 25 dynes. How strong is the pole?

A. $\frac{1}{2}$ unit.

Q. If a pole of 2 units strength is placed in a field of 6 units strength, what force will act upon it? A. 12 dynes.

Q. Why does not the compass needle point due north and south?

A. Because the magnetic poles of the earth do not coincide with the geographical poles.

Q. Why does not the compass needle show the same deflection from a true north and south position on all points of the globe?

A. Because the lines of longitude of two places do not form the same angle with the straight lines connecting them with the magnetic pole.

Q. Determine the direction of the lines of force by the right-handed screw?

A. If the current flows in the direction in which the screw is turned when driven into the wood, then the positive direction of the lines of force is the same in which the screw turns.

Q. If a flexible wire through which a current flows has wound around a fixed magnet, what will happen if the direction of the current is changed?

A. The wire will unwind and then wind around the magnet in the opposite direction.

Q. What is Ampere's theory of magnetism?

A. He assumed that the molecules of all magnetic substances are at all times surrounded by little electric currents, which make them into magnets. Ordinarily these currents flow in many different directions, neutralizing each other, but when the body is magnetized, the molecules array themselves parallel to each other and combine their magnetic forces.

Q. On what did Ampere base this theory?

A. On the effect which a solenoid has upon a bar of soft iron placed within it.

Q. Does this theory explain why the molecules are surrounded by electric currents, and how these currents produce magnetism?

A. It does not attempt to answer either question.

Q. Does the saturation curve give the permeability of a piece of iron directly?

A. No, indirectly.

Q. What is the reluctance in a piece of iron 36 inches long and 3 sq. inches cross section, at a permeability of 1000 units?

A. $1 \div 1000 \times (36 \div 3) = 12 \div 1000 = 0.012$

Q. What kind of an electromagnet will do the best work?

A. One, the circuit of which is made up of material of the highest permeability, and which is provided with as many ampere turns as possible.

Invention of Motor and Dynamo

78. The discovery of Oersted (see § 70) was soon followed by the brilliant achievements of Faraday and Henry * in making the close mutual relations between magnetism and electricity serviceable to man:

The first great step was Faraday's success in constructing an apparatus in which the action of lines of force produced continuous motion.

The second step was the grand thought proved to be correct by experiments, that this production of motion by an electric current in a magnetic field might have its counterpart in the INDUCTION (production) of an electric current by the motion of a wire near a magnet.

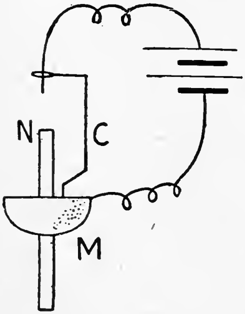

FIG. 26

The third step was the establishment of the fact that electric pressure will be INDUCED in a wire moved in a magnetic field only when it is moved so as to cut the lines of force.

The fourth step was the discovery that a change in a magnetic field INDUCES a current in a conductor under its influence, just as a change in the current brings about a change in a magnetic field near it.

79. Fig. 26 is a diagram of Faraday's apparatus, showing the copper wire (C) so bent and hung, with its lower end

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*Joseph Henry, American physicist, secretary of Smithsonian Institution. Died 1878. See page 29 concerning Faraday.

immersed in a cup (M) containing mercury, that it rotates around the pole of the permanent magnet (N) continuously, when the current is turned on. It was a MAGNETO, or *magneto-electric generator,* as it had a permanent steel magnet. Faraday also made the first dynamo: a copper disk revolving partly between the poles of a strong horseshoe magnet, and copper brushes collecting the electricity. In the first commercial small dynamos made, revolving coils of wire were substituted for the copper disk.

Induced pressure

80. If a coil of insulated wire is placed in circuit with a sensitive galvanometer, and the north pole of a strong bar magnet is suddenly thrust into the helix, the needle of the galvanometer will be momentarily deflected, showing that a current flows in the direction opposite to that in which the hands of a watch move. If the bar magnet is withdrawn, a momentary deflection to the opposite side takes place. Our earth being a magnet, a long wire stretched out and suspended so that it may be swung sideways and thus cut the terrestrial lines of force, will set up a current strong enough to deflect the needle of a sensitive galvanometer to both sides of the zero mark, as it swings back and forth.

RULE 30.—When a straight wire cuts 100,000,000 lines of force at right angle in every second of its motion, an electric pressure of one volt is produced.

Of course, the rate at which the conductor cuts lines of force depends on several circumstances, viz.

the number of lines of force in each sq. inch or cm.,
the length of the conductor in the field,

the speed at which the conductor moves, and
the angle at which it cuts the lines.

It is evident that at right angles the conductor will cut the largest number of lines in a given time.

EXAMPLE 38.

In a wire, cutting 50,000,000 lines of force at right angles and at a rate of 50 times per second, a pressure of 25 volts is set up.

(50 × 50,000,000 ÷ 100,000,000.)

If the average alternating pressure induced in a secondary coil having 1000 turns amounts to 250 volts, then a secondary coil having 200 turns will supply 50 volts under the same circumstances.

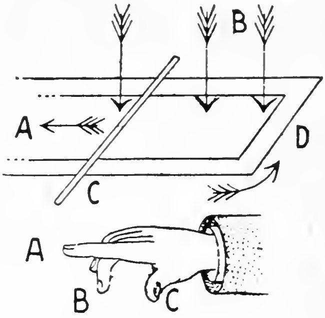
If the conductor is a coil of wire around the field of force, and if the face of the coil is at right angles to the lines of force, then each half of the coil will cut all the lines twice in one revolution

EXAMPLE 39.

A single coil of above description, including 2,500,000 lines of force, and turning at the rate of 40 revolutions per second, will develop a pressure of 4 volts. (4 × 40 × 2,500,000 ÷ 100,000,000. We must multiply by 4, because the two halves of the coil cut the lines twice each in every revolution.)

A coil of several turns must be considered a row of single coils connected in series, which we may compare to a Voltaic pile or a battery of cells connected in series. The E. M. F. set up in the coil equals the sum of the pressures developed in all its turns.

Assuming the direction in which a wire moves to be straight ahead in front of a person (A), and the direction of the lines of force vertically downwards (B), then the current flows from right to left in the wire C, (See fig. 27, representing a *slider* C moving in the direction A on *rails*. The circuit consists of slider, rails and crosspiece D.) This is easily remembered by holding out the right hand in the manner shown in fig. 28. The first or index finger represents direction A, the second or middle finger direction B, and the thumb direction C. This agrees with Ampere's rule, as stated in § 70.



Figs. 27 and 28.

Alternating current

81. If a single wire ring is moved straight across a uniform magnetic field, it does not set up a current, because the E. M. F. in each half of the ring balances or neutralizes that in the other half. But if it is mounted on an axis so it may be revolved in the field, then the two halves cut the lines in opposite directions during the two halves of each revolution; this produces a current around the ring *during* each half revolution, but at the moment each half enters into the second half of the revolution, the direction of the current is *reversed*. A continued revolving, therefore, produces an *alternating current*.

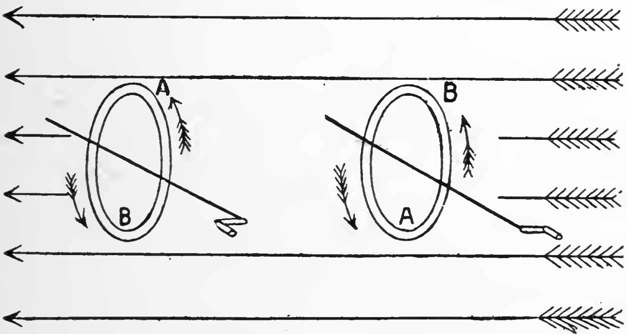


Fig. 29.

Fig. 29 shows the same coil in the two positions *during* and *after* one half revolution. The large arrows indicate the direction of the lines of force, the short arrows show the directions of the currents.

Induction coil

82. It is immaterial whether the conductor moves through a stationary magnetic field, or whether a magnet moves about a stationary conductor; the result is the same. Furthermore, the magnetic field may surround a magnet, or a charged wire; in either case a current will be set up in a conductor cutting the lines of force. If a small charged coil is thrust into the hollow of a larger coil, a current will flow in the larger coil *during the time of moving;* as soon as both coils are at rest in respect to each other, the current stops; while either coil is removed from the other, a current in the opposite direction flows. In this case the charged coil, which may also be the larger one, is called the PRIMARY COIL, and the other the SECONDARY. If the two coils are fixed to each other, any *increase* or *decrease* of the current in the primary coil also sets up a current in the secondary coil; this induced current lasts during the time of increasing or decreasing.

This action of two coils upon each other is called MUTUAL INDUCTION, and the two coils together are termed INDUCTION COIL. The effect of an induction coil is greatly enhanced, if it surrounds a core of iron wires. If the core were made of solid iron, local currents would be set up in the iron which would cause heating and loss of power. (Compare § 37.)

The relation of the E. M. F. in the secondary coil to that in the primary, depends upon the number of turns and the size of wire in both windings. If the primary coil has comparatively few turns of thick wire, and the secondary has many of very fine wire, a difference of potential between the two may be produced so great that the electrical discharge will leap across an air space of several inches; the efficiency of such apparatus is usually rated by the length of spark they produce.

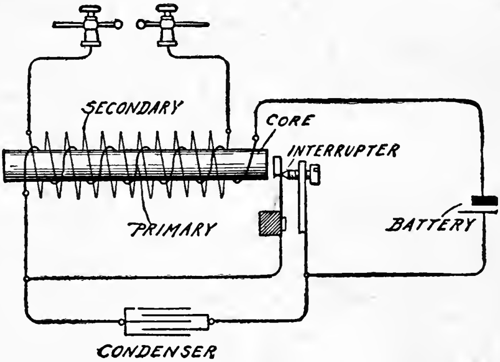


FIG. 30.

They are much used in producing Hertzian waves for wireless telegraphy and in X-Ray work. Fig. 30 is a diagram of a RUHMKORFF COIL. The core of the primary, wound 6 turns, operates as a circuit breaker by attracting a little armature mounted on a spring which normally presses against the point of a screw,closing the primary circuit. Of course, the moment the circuit is broken, the core loses its magnetism, and therefore releases the armature. only to attract it again immediately, because the moment the armature is in contact with the screw again, the current starts flowing. Thus the circuit is "*made*" and "*broken*" very rapidly and automatically, by the INTERRUPTER.

Self=Induction; Lenz's law

83. At every "*make*" the field of force of each turn in the coil grows rapidly, and cuts the neighboring turns, inducing an E. M. F. that opposes the increase of the current. On the other hand, at every "*break*" the primary field rapidly vanishes, the lines again cutting the turns, but in a manner that tends to oppose the decrease of the current. This SELF-

INDUCTION may be considerable, according to the number of wires; SPARK COILS used to light the gas, etc., are based on this principle; they may be supplied by a single cell. Ruhmkorff added to the apparatus a condenser (See fig. 36), connected in parallel with the interrupter. It takes up the SELF INDUCED currents, thus making a quicker break.

Induction coils transfer power from one circuit to another by the effect of magnetism, but *without any electrical connection.* They are a means, therefore, of *converting energy,* and here, as everywhere in such cases, the "input" must be larger than the required "output" by a percentage high enough to allow for the inevitable loss by conversion of energy into heat, by leakage, etc. A TRANSFORMER, or CONVERTER, is an application of the induction coil.

The directions of magnetic fields and induced currents, as mentioned throughout the preceding paragraphs, may be stated in this general law:

RULE 31.—The magnetic field of a current induced by a change in a magnetic field, opposes this change, and

The direction of an electric current induced by the movement of a conductor is such that its effect opposes the movement.

This law was first formulated by a German scientist, LENZ.

Questions and Answers.

Q. What is *induction density?*

A. The number of lines per square unit (inch or cm.)

Q. What is *total flux?*

A. The total number of lines of force.

Q. What causes the sparks in a spark coil?

A. Self induction of the many turns of the coil.

CHAPTER VII. — METERS AND MEASUREMENTS

Electrical units

84. At a meeting of electricians at Paris in 1881, an absolute system was agreed upon, the bases of which are the *centimeter, gramme* and *second.* (C. G. S. units.)

TABLE OF ELECTRICAL UNITS.

UNIT OF	SYMBOL.	NAME.	RELATION TO OTHER UNITS.	VALUE.	
				C. G. S.*	Equivalent.
Strength..	I	ampere	volt ÷ ohm	10^{-1}	·0000105 gr. hydrogen liberated per second.
Quantity.	Q	coulomb	ampere×second	10^{-1}	
E. M. F...	E	volt	ampere × ohm	10^{8}	·926 standard Daniell cell.
Resistance	R	ohm	volt ÷ ampere	10^{9}	106 cm. mercury. 1 sq. mm. cr. section at 0° C.
Capacity..	C	farad	coulomb ÷ volt	10^{-9}	
Power.....		watt	volt × ampere	10^{7}	·0013405 or $\frac{1}{746}$ H. P.
Work } Heat }..	W	joule	volt × coulomb amp.² × sec. × ohm	10^{7} 10^{7}	·7373 foot pound. ·238 calorie.

*$10^1=10$; $10^2=100$; $10^3=1000$; $10^6=1,000,000$; $10^0=1$;

$10^{-1}=\frac{1}{10}=0{\cdot}1$; $10^{-2}=\frac{1}{10^2}=0{\cdot}01$; $10^{-3}=\frac{1}{10^3}=0{\cdot}001$; $10^{-6}=\frac{1}{10^6}=0.000001$.

A *volt* is the E. M. F. which maintains a current of one ampere through a resistance of one ohm.

A *farad* is the capacity of a body to be charged to a potential of one volt by one coulomb.

An *ampere* is the strength of a current which is produced by the pressure of one volt against a resistance of one ohm; or which conveys one coulomb per second.

An *ohm* is the resistance of a column of mercury 106·3 centimeters in length, having an area of one sq. millimeter, at 0° C, or 32° F. (International or legal ohm.)

A *coulomb* is the quantity of electricity conveyed by one ampere in one second.

A *joule* is the work done in one second by one ampere passing a resistance of one ohm.

A *watt* is the power of a current of one ampere under a pressure of one volt, which equals one joule per second.

Classification of electric meters

85. It is evident that the strength of an electric current employed, whether infinitely small or of enormous magnitude, should be known, to assure safety and accuracy. Instruments for measuring currents are called AMPEREMETERS or *ammeters.* There are also *milliamperemeters* When used, they are connected *in series in the circuit.* Physicians measure a current by MILLIAMPERES (one thousandth part of one ampere); in the telephone service MICROAMPERES (one millionth part of one ampere) are used.

If the *electrochemical* effect of the current is utilized in this instrument, it is called a *voltameter.*

Most *amperemeters* take advantage of the *magnetic* effect of the current, while some make use of its *heating* effect.

Of magnetic amperemeters there are several classes:

Some use soft iron parts moved by magnetism; in others a permanent steel magnet is acted upon or acts; in others one of two coils move by the force produced by the mutual action between them. The first two classes mentioned are GALVANOMETERS, the third class are ELECTRODYNAMOMETERS.

Alternating currents cannot be measured by amperemeters of the second class, because the moving parts would be moved first in one and then in the other direction, and with a rapid alternation would stand still. Instruments having a soft iron core built up of thin parts serve well in this case, because it is *always attracted* by a current. Such a core is called a *magnetic vane,* Electrodynamometers can be used for alternating currents, as the current reverses at the same moment in both coils.

Voltameter

86. A voltameter measures currents by their *electrochemical* action. In § 50 the *water voltameter* has been fully described and explained. In all voltameters the cathode and anode are made of the same metal, so that the cell does not set up a current of its own.

METAL voltameters are made of copper, tin or zinc electrodes in a solution of the salts of the same metal. The electric current decomposes the solution, the metal part is deposited on the cathode, and the acid part attacks the anode, forming a new portion of the solution. The quantity deposited on the cathode is generally taken as the measure of the current. The solution for copper generally used is copper sulphate of a certain strength, for amalgamated zinc plates (see § 37) a zinc sulphate solution, for tin plates a tin chloride solution, etc. In a SILVER VOLTAMETER a solution of nitrate of silver is used, acting upon a plate of pure silver and depositing on a platinum plate. The international ampere (see § 48) is determined by means of a silver voltameter. In the table of equivalents (page 53), under the heading of "Electrochemical equivalent in milligrammes per coulomb," the quantities deposited in one second by a current of one ampere are given for all substances of importance in this connection.

EXAMPLE 40.

If a current of 3 amperes flows for 15 minutes through a silver voltameter, 3·0186 grammes of silver will be deposited. $(3 \times 15 \times 60 = 2700;\ 2700 \times \cdot 001118 = 3\cdot 0186)$

EXMPLE 41.

If 12 grammes of cupric copper are deposited on the cathode of a voltameter in 90 minutes, the current will be 6·74 amperes. $(12 \div \cdot 000327 = 36{,}697;\ 36{,}697 \div (90 \times 60) = 6\cdot 79)$.

Galvanometer

87. A GALVANOMETER measures currents by their *magnetic* effect. It consists of a magnetic needle, pivoted at the center of an electric coil, and a scale showing the angle of deflection. According as the coil has many fine turns and few coarse ones, the galvanometer will be more or less sensitive. Any common galvanometer is most sensitive when the coil is at right angles to the magnetic meridian. Some galvanometers have their needles made independent of the earth's magnetism by means of an adjustable CONTROLLING MAGNET, and if the meter is to serve for very delicate work, ASTATIC needles are used, consisting of one or more groups of 2 similar magnetic needles fastened to a thin light wire one above the other, and their north poles pointing in opposite directions. ("Astatic" means "not tending to assume a fixed position".) For the purpose of the galvanometer, even an agate or crystal pivot of the needle would offer too much friction; the needle is, therefore, usually fixed to a delicate, but strong fiber. The needles have shapes of great variety; a common form is composed of several parallel small magnets fastened on a disk.

In some kinds of galvanometers the deflections bear a fixed relation to their cause, the currents. This relation is called a CONSTANT, (resistance of circuit indicated by a deflection of *one* scale division). An instance is the SINE GALVANOMETER, in which the trigonometrical sine of the angle through which the coil is moved by the current, is proportional to the current. In the TANGENT GALVANOMETER, the trigonometrical tangents of the angle through which the needle is deflected by the current, is proportional to the cause, the current. In other kinds the relation must be established by actual experiments with currents of known strength. The results of such experiments are then entered on cross ruled paper in the shape of a CALIBRATION CURVE. Other kinds to be mentioned are MIRROR or REFLECTING galvanometers, DIFFERENTIAL galvanometers, etc. (See §93.)

Ammeters may be so calibrated that their indications read directly in volts instead of amperes. In this case they are called VOLTMETERS. The coil in an amperemeter has a few coarse turns, for measuring current, while that in a voltmeter has many fine turns, for measuring pressure. WESTON'S VOLTMETER is a galvanometer, with a permanent steel magnet, and a moving coil mounted on pivots and carrying a pointer playing over a scale.

88. When a sensitive galvanometer is to be employed for very strong currents, it is necessary to SHUNT it. The shunting is generally done with a view to having a unit ratio between the two parallel currents, such as $\frac{1}{9}$, $\frac{1}{99}$, or $\frac{1}{999}$ etc., and this is obtained by making the shunt resistance nine, ninety-nine, or nine hundred-ninety-nine times that of the galvanometer. A shunt box, providing these resistances by the simple insertion of one or more plugs into their proper holes, is generally sold with each galvanometer.

EXAMPLE 42.

When a galvanometer having a constant of ·00005 ampere per division, reads 100, when shunted by a $\frac{1}{99}$ shunt box, a current of 0·5 ampere is flowing.

(100 × 100 × ·00005 = 10,000 × ·00005 = 0·5 ampere.)

Electrometer

89. The electrometer is an instrument for measuring the attraction between two bodies, one charged with a high pressure, and the other charged with a low pressure, the deflection of the needle showing *the difference of pressure.* Such an ELECTROSTATIC VOLTMETER is much in use for everyday measurements of electric pressure in light and power stations. It may also be used for measuring the difference of potential between a charged body and the earth (zero), or between the two plates of a condenser. The QUADRANT ELECTROMETER is so called, because the principal part of it resembles a cylindrical box, divided into four wedges or quadrants, of which each pair of opposite quadrants are connected and charged, one pair positive, the other negative.

An electric pressure may also be measured by connecting a part of the resistance with a small battery of known pressure and a galvanometer in series, in such a way that the two currents flow in opposite directions.

EXAMPLE 43.

If the battery is of 1·4 volts, and the galvanometer indicates zero, when the $\frac{1}{1000}$ part of a total resistance of 50,000 ohms is connected, then the voltage in the $\frac{1}{1000}$ part balances the pressure of the battery, and this pressure of 1·4 volts must be to the unknown pressure, as 1000 is to 50,000.

$$1{\cdot}4 \times 50{,}000 \div 1000 = 70 \text{ volts. Ans.}$$

Such cells, constructed with a special view to serving for measuring pressure by COMPARISON, are called STANDARD cells. The Chicago Electric Congress, 1893, recommended *Clark's cell,* the pressure of which is 1·434 volts at 15° centigrade.

Electrodynamometer

90. The SIEMENS ELECTRODYNAMOMETER has a movable coil suspended at right angles around a fixed one. The terminals of the movable coil are immersed (below the fixed coil) in mercury cups which close the circuit. The tendency of the movable coil, when a current is flowing, to place itself parallel to the fixed one, is counteracted by a spring regulated by a thumbscrew, TORSION HEAD. The pointer of this torsion head indicates, on a scale, an amount proportional to the *square* of the current, because the current flows through the two coils, and the coils act on each other mutually.

In the KELVIN BALANCE, the tendency of two parallel coils to approach each other, is directly balanced and indicated by means of a slider on a scale beam.

Rheostat

91. The rheostat is a collection of resistances of various known heights, through any or all of which the operator may cause a current to flow at one time. It consists of a box holding a number of spools wound with various lengths and sizes of insulated wire, mostly of German silver or other alloys of high resistance and small temperature coefficient. Each wire is doubled up, to prevent self-induction, wound on a spool and immersed in paraffine. The spools are bolted to the inside of the box cover. The wire ends of each spool are connected to two brass blocks fastened on top of the cover. These blocks are placed in such a way, that by inserting a plug between a pair of blocks one spool is *short-circuited.* Each block being connected to two spools, all the spools are connected in series when no plugs are inserted. (See diagram, fig. 31.) Thus the resistance of any one coil or number of coils may be cut out by inserting the proper plug or plugs. The resistance of the plug is *negligible,* that is, so small that it may be disregarded. The wires are selected to furnish a set of resistances that have a certain ratio, generally a decimal one: $\frac{1}{100}$, $\frac{1}{10}$, 1, 10, 100, etc., ohms. and the final adjustment of all the coils requires great skill. But even with the most perfect rheostat it is necessary to make allowance for the temperature at the time of measuring, when great accuracy is aimed at.

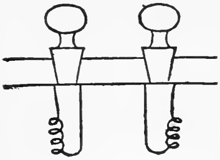


FIG. 31.

Wheatstone's Bridge

92. The coils for the rheostat are tested by means of an apparatus named after the English scientist WHEATSTONE, the inventor. Fig. 32 illustrates its principle. *A, B, R* are rheostats, *X* is the coil to be measured, *G* is the galvanometer. If key 1, near the battery, is depressed, the current flows to point *O* where it divides, to meet again at *N* and to return to the battery. The plugs of the rheostats are set in such a way that the difference of pressure between the two points *O* and *N* by way of *M* equals that by way of *P*. If this difference is called *E*, then the resistance (always proportional to the fall of potential; see § 58) between points *M* and *N* (called *b*) equals $E\,\frac{x}{x+b}$, where x represents the resistance of *X*, the coil to be tested, and *b* the resistance of the rheostat *B*. *A* and *B* are set at the same resistance, and then the key 2 near the galvanometer is pressed. If the pressure in *X* is greater than in *R*, a current will flow from *M* to *P*, indicated by the galvanometer. If the pressure in *R* is greater, the galvanometer needle will be deflected in the opposite direction. Then the plugs of *R* are manipulated until the bridge is

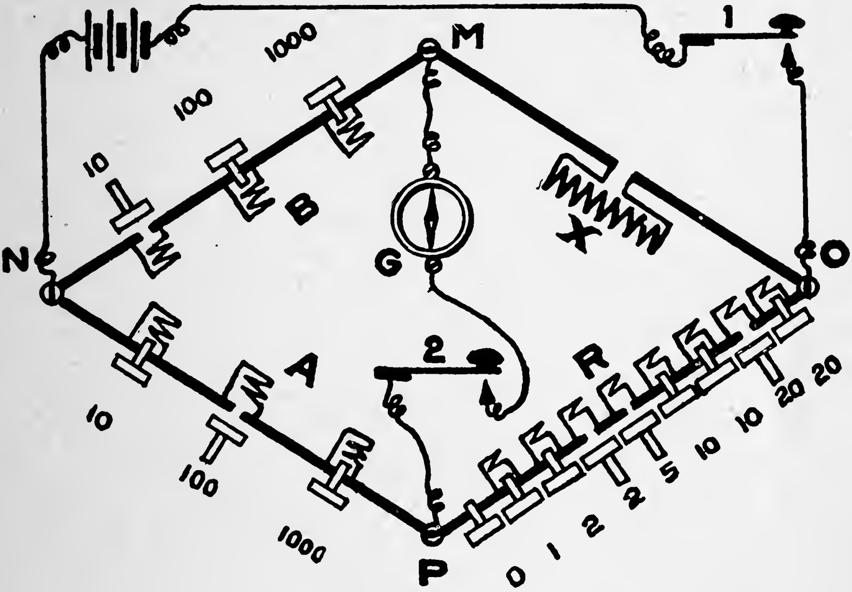


FIG. 32.

balanced, that is, until the galvanometer shows no current between *M* and *P.*

By varying the ratio of resistance between *A* and *B* from $1 \div 1$ to $1 \div 10$, $1 \div 100$ etc., the work is greatly facilitated, because, when the bridge is balanced, the resistance of *X* is to that of *B,* as that of *R* is to that of *A.*

$$x : b :: r : a. \quad \text{Or, } x = \frac{br}{a}.$$

EXAMPLE 44.

a. *R* reads 350, *A* 100 and *B* 10, when the bridge is balanced. What is the resistance of *X*?

$10 \times 350 \div 100 =$ 35 ohms. Ans.

b. What resistance should be given to *R, A* and *B*, to measure 836,500 ohms?

836,500 : 1000 :: 8365 : 10. *R* 8365, *B* 1000, *A* 10. Ans.

A simple form of Wheatstone's bridge is the DIVIDED WIRE BRIDGE, used especially for measuring a low resistance by another known resistance. In this instrument the connection with the galvanometer key is not fixed, (as at *M* in fig. 32), but contact may be made at any point of a wire stretched along a graded scale, from which the ratio of the two parts of the wire (which is the same as that between the known and the unknown resistance) may be read off.

Insulation resistance

93. Very great resistances, like the *insulation resistance* (of insulated wires) between wire and ground, are measured by means of a delicate reflecting galvanometer with shunt box and a portable *testing battery,* usually made up of 50, 100 or 200 silver chloride cells. The battery, galvanometer and unknown resistance are connected in series; the deflection of the galvanometer is then compared with its deflection at some STANDARD resistance, usually from 25,000 to 1,000,000 ohms; the resistances are in the same ratio.

Suppose a powerful *testing battery* of 200 silver chloride cells and a standard (known) resistance of two megohms (1 megohm = 1 million ohms), connected up in series with a fine galvanometer shunted by the $\frac{1}{99}$ shunt. If the galvanometer under these circumstances gives a deflection of 60 scale divisions, then 60 × 100 × 2 = 12,000 would be its *constant*, that is to say, if *not* shunted, it would indicate 12,000 megohms by a deflection of *one* scale division. If an unknown resistance, as the insulation resistance of a mile length of electric light cable, is to be measured, the cable is substituted for the known resistance, one end being grounded. If then the galvanometer, not shunted, shows 40 scale divisions, this will indicate the insulation resistance to be = $\frac{1}{40}$ × 12,000 = 300 megohms, because insulation resistance is the reverse of insulation conductance. (See § 53.) A length of 3 miles of the same cable would have an insulation resistance of 100 megohms, because the single miles with their paths of leakage are *in parallel.*

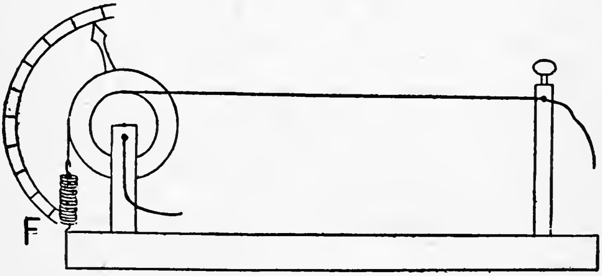


Fig. 33.

Hot wire instruments

94. Fig. 33 is the diagram of a simple instrument for measuring a current by means of the expansion of a wire by heat. The apparatus is, of course, carefully enclosed, to avoid the effects of air currents. The wire is fastened at one end to a metal wheel through which the current passes to one of its supports and to another wire, closing the circuit. The wheel carries the pointer, and is pulled around one way by the spring *F*, when the temperature of the wire is increased by the increasing current, and it is pulled around the other way by the wire, when the temperature decreases.

The CARDEW VOLTMETER, named after its inventor, is based on the same principle. It uses a platinum-silver wire, 25 ten-thousandths of an inch in diameter, and measures up to 120 volts.

As the direction of the current is immaterial, hot wire ampere meters can be used to measure alternating currents.

Wattmeter

95. In these instruments there is a fixed coil (current coil in series) and a movable coil (pressure coil), the two forming separate circuits. The fixed coil, wound with a thick wire of low resistance, carries, when connected, the *amperes* of the current; the movable coil is wound with a thin wire of high resistance (as in voltmeters) to receive a current proportional to the volts. When in use, the movable coil of the wattmeter is connected, by means of binding posts, across the terminals of the machine, as a shunt, and the fixed coil is connected in series to the circuit, the power supplied to which is to be measured. Then the entire current has to flow through the thick wire of the stationary coil, while only a part of the current flows through an auxiliary resistance and through the thin wire of the movable coil. Thus, the magnetic effect of the fixed current coil being proportional to the amperes, and that of the movable volt coil being proportional to the volts, the indications on the scale will be proportional to amperes times volts = watts.

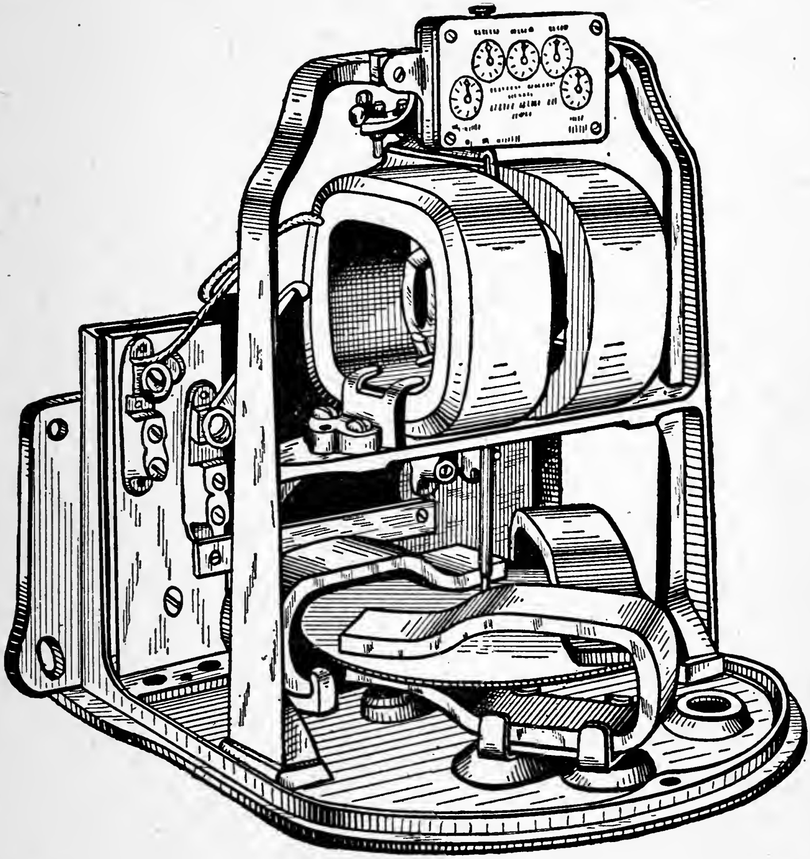


Fig. 34.

Some wattmeters have a set of dials like a gas meter, indicating the total number of watt hours (watts times hours) used. They are called RECORDING or INTEGRATING (adding) WATTMETERS. See fig. 34. In these the volt coil is arranged as an armature (revolving part), while the current coil forms the fixed magnetizing windings around it, so that the apparatus resembles a small motor. The speed of the revolutions of the armature is retarded by strong permanent magnets, between the poles of which a copper disk connected with the axis of the armature revolves, thus setting up electric currents which cause attraction by the magnets. Fig. 35 is a diagram of the manner of connecting a wattmeter (W) with a circuit. *CC* are the connections with the current coil, *VV* those with the volt coil. *L* indicates the lamps.

Others are arranged to show ampere hours; and they are called COULOMB METERS, because an *ampere second* means the flow of one coulomb of electricity. By multiplying the indicated ampere hours by the average pressure, the watt hours are found.

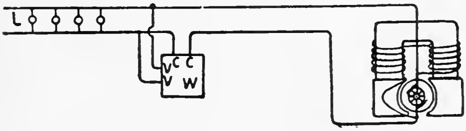


Fig. 35.

Capacity of condensers

96. From what has been said about the nature of a condenser (see § 19), it is evident that any two conductors lying close together, unless separated by a well *insulating dielectric,* will increase their *capacity,* acting inductively on each other and modifying their relative potentials.

Because of its high specific inductive capacity (see table in § 99), it is not advisable to use a good insulating material like glass for continuous insulation of wires and cables.

Condensers are usually mounted in bases of Ruhmcorff's induction coils to lessen the inverse current at the "make" and to increase the direct electro-motive force at the "break." The sparks of induction coils thus equipped are longer and only pass one way.

It is clear that the *charge of a condenser must vary directly with the capacity,* and, as the capacity of a water tank increases with increasing height, similarly *the charge of a condenser also varies directly with the pressure.* Therefore, if the capacity is fixed, the charge is proportional to the pressure; and if the pressure is constant, the charge is proportional to the capacity. A microfarad is one millionth of a farad; hence:

RULE 32.—C (capacity in microfarads) $= 1{,}000{,}000 \times Q$ (quantity on each plate in coulombs) *divided by* E (pressure in volts).

$$C = \frac{1{,}000{,}000 \times Q}{E} \qquad E = \frac{1{,}000{,}000 \times Q}{C} \qquad Q = \frac{E \times C}{1{,}000{,}000}$$

EXAMPLE 45.

a. If a condenser is charged with ·0002 coulomb, and the difference of potential is 10 volts, the capacity is 20 microfarads.

$$C = \frac{1{,}000{,}000 \times {\cdot}0002}{10} = 100 \times {\cdot}2 = 20.$$

b. A condenser of 2·5 microfarads capacity requires a pressure of 2,400 volts to charge it with ·006 coulomb.

$$E = \frac{1{,}000{,}000 \times {\cdot}006}{2{\cdot}5} = \frac{6{,}000}{2{\cdot}5} = 2{,}400.$$

c. If a condenser of 10 microfarads capacity is charged by a difference of pressure of 50 volts, the quantity of the charge is ·0005 coulomb.

$$Q = \frac{50 \times 10}{1{,}000{,}000} = \frac{5}{10{,}000} = {\cdot}0005.$$

Arrangement of condensers

97. Condensers usually consist of alternate layers, of equal size, of conducting sheets (as tin foil) and dielectric sheets (as mica, wax paper, or oiled silk). The adjacent layers of tinfoil are charged with opposite kinds of electricity, one positively, one negatively. The connection between the several plates will depend on the use to which the condenser is to be put. Its capacity is directly proportional to the area of the plates, and therefore, in order to have their total capacity equal the sum of their individual capacities, they are connected *in parallel.* (See fig. 36.)

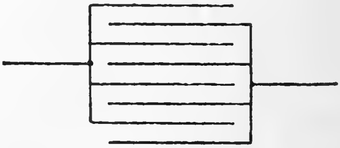


Fig. 36.

If on the other hand, it is the object to use the smallest possible capacity of the condenser, they are connected in series, which arrangement makes the total capacity equal to that of one condenser divided by the number in series, because in this the thicknesses of all the dielectric sheets must be added together.

When several condensers of different capacities are joined

a) *in parallel*, they will simply act as a large condenser of a capacity equal to the sum of capacities of all the condensers.

b) *in series,* the total capacity will be the reciprocal of the sum of the reciprocals of the capacities of all the condensers.

EXAMPLE 46.

6 condensers of $1{\cdot}5 \ (=\frac{3}{2})$ microfarads

(*a*) in parallel, $6 \times 1{\cdot}5 = 9$ mf. Ans.

(*b*) in series, 6 times the reciprocal of $\frac{3}{2}$;

$6 \times \frac{2}{3} = \frac{12}{3} = 4$. The reciprocal of $4 = \frac{1}{4}$ mf. Ans.

EXAMPLE 47.

Three condensers of $\frac{1}{3}$, $\frac{1}{2}$ and $\frac{1}{6}$ microfarads, connected in parallel, have a total capacity of 1 microfarad. If in series, the combined capacity is $\frac{1}{11}$ microfarad.

$$(\tfrac{1}{3}+\tfrac{1}{2}+\tfrac{1}{6}=1; \quad 3+2+6=11.)$$

By arranging 2, 3, 4 or more condensers in all possible combinations, as in parallels of 2 or 3 sets of series of 3 or 2 etc., a large variety of capacities can be obtained, as is the case in the standard condenser box.

Testing a condenser

98. In testing the capacity of an insulated wire or cable, a standard condenser of nearly the capacity of the wire is chosen, charged by a small battery, and then connected so as to discharge through a galvanometer, which will show a *throw* of the needle in proportion to the quantity of electricity discharged. The one end of the wire is connected with the battery, the other with the earth and the same two operations are carried out. As the pressure is the same, the two capacities (of the standard condenser and the wire) are in proportion to the quantities, and also in proportion to the throws. In speaking of the capacity of an insulated wire or cable, it must be remembered that it is considered a condenser in this case, the insulated wire forming one plate, the earth or return wire the other plate, and the insulation the dielectric.

In a similar way the pressure in a condenser is measured by means of an electrometer or electrostatic voltmeter. It cannot be measured with an ordinary voltmeter.

99. In the following table the inductive capacity of a number of substances is compared with that of air, which being the lowest, is taken as the unit (one).

TABLE OF SPECIFIC INDUCTIVE CAPACITY.

DIELECTRIC.	CAPACITY.	DIELECTRIC.	CAPACITY.
Vacuum, ...	0·9985	Resin, ...	2·48–2·57
Oxygen, ...	0·999674	Sulphur, ...	2·2–3 9
Air at 0° C. and 760 mm.		Sulphureted carbon, .	1·0023
barometric pressure, .	1	Kerosene, ...	2·69–2 8
Carbonic acid, ...	1·000356	Shellac, ...	2·74–3 73
Pitch, ...	1·8	Castor oil, ...	4·61–4 8
Paraffine, ...	1·68–2.	Glass, ...	2·8–9 9
Turpentine, ...	2·2	Mica, ...	4·6–8
Ebonite, ...	1·9–3 48	Iceland spar, . . .	8·0
Rubber, ...	2·12-2 69	Selenium, ...	10·2
Benzol, ...	2·3377	Alcohol, ...	24–27 0
Gutta percha, ...	3·3–4·9	Water, ...	80

Questions and Answers.

Q. How does a voltameter differ from a voltmeter?

A. A voltameter is used to measure electric *currents* by means of their electrochemical action. A voltmeter measures electric *pressure,* mostly by means of electromagnetic action.

Q. Is an electromagnetic voltmeter a milliamperemeter?

A. It is; only it is graduated to read in volts instead of amperes.

Q. What is the use of the spring in a simple amperemeter?

A. If it were not there, the smallest amount of electric current would draw the iron core completely into the coil.

Q. How is a voltmeter coil wound?

A. With many turns of very fine wire.

Q Is the Siemens electrodynamometer a wattmeter?

A. No; generally it is arranged to serve as an amperemeter, giving the square of the current, while a wattmeter indicates the watts product of current and pressure.

Q. Of what service is a recording wattmeter in a railway switchboard.

A. By its use it becomes possible to know exactly how many electrical H. P. hours are consumed each day.

Q. Describe the Cardew Voltmeter?

A. It is a very delicate instrument. The two ends of the platinum wire (of 0·0025 inch or 2½ mils diameter) about 4 yards long, are fixed to two small brass blocks, near together, then the two lengths of wire are laid around two small grooved wheels fixed one yard below, and are returned to a point between the brass blocks, where the wire is laid around one small insulating grooved wheel. This wheel is pivoted on a brass strip, which is connected with a spiral spring above by means of a fine platinum wire that is straight except that it makes one turn around a small pulley. The pulley is geared to a toothed wheel which carries a long pointer playing over a scale. The spiral spring holds the wires taut and is adjustable at the top of the instrument, by means of a thumb screw, so that the pointer can be set at zero at the beginning of a test. When the connections are made by means of the two brass blocks, the current passes only through the four yards of platinum wire. The two loops of wire (of 2 yards each) are heated by the current and expand alike, so that the spiral spring decreases in length, and the pulley turns. Even the slightest turn of the pulley will cause a considerable deflection of the long pointer. A hair spring presses the gearing of wheel and pulley together, so as to insure perfect action.

CHAPTER VIII.— THE DIRECT CURRENT DYNAMO

100. After Faraday's discoveries, stated in §78, improvements were made by various scientists, especially Siemens and Gramme, until by the year 1860 the dynamo became practically what it is to-day, aside from minor additions.

The alternating current produced in a coil revolving between the poles of a magnet (compare fig. 29) may be COLLECTED by two rings, each of which is connected with one end terminal of the coil, and by means of sliding BRUSHES passes from the rings into the external circuit which may consist of lamps, motors or other apparatus which consume the current. By splitting the ring into two half-cylinders, and by insulating these halves from each other and from the shaft of the revolving part (see fig. 36) and by setting the brushes so that they are exactly opposite each other and never rub against more than one half of the ring, or segment, the alternating current is changed or COMMUTATED into a continous or *direct current.* One of the brushes is always kept positive and the other negative, the current flowing from the positive brush through the external circuit

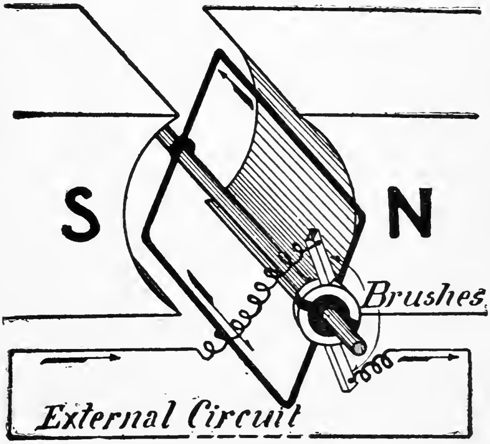
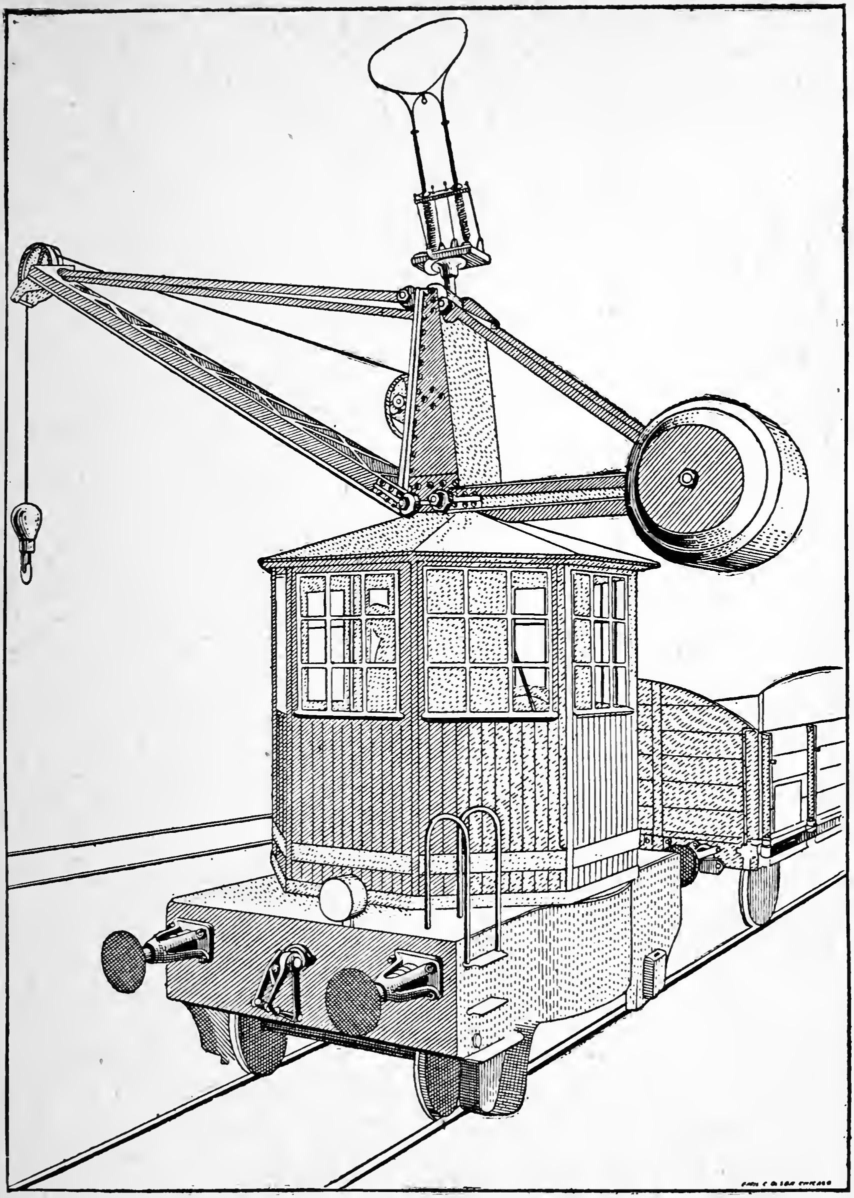


FIG. 36, A.



DIRECT CURRENT LOCOMOTIVE CRANE.

Raises five tons 20 feet in one minute. 6 H. P. Travels 100 yards a minute. 30 H. P. E. M. F. 110 volts.

back to the negative brush, and thence through the armature coil to the positive brush.

The brushes are usually mounted on a rocker arm, so that they may be nicely adjusted to the commutator segments, to avoid sparks, which would greatly injure the commutator.

Armature

101. The current is created by the wire cutting the magnetic lines of force, extending from the north pole (*N*) to the south pole (*S*). The effect is greatest when it cuts them at right angles (see § 80). In the position of the wire shown in fig 36A, it moves, at least for a moment, entirely parallel with the lines of force. When it turns in the direction of the lower arrow, the upper half moves toward the middle of *N*, and the lower half moves toward the middle of *S*, cutting the lines of force at an ever increasing angle, until both halves of the wire stand at the same level with the shaft. At this moment the lines of force are cut at right angles, and therefore the pressure produced is strongest, In the position shown in fig. 36A the pressure is 0. Thus a rise and fall of potential is produced during each half revolution. Because of this wavelike changeability, and because the commutation of large currents is impractical at the full pressure required by our industries, the one coil was replaced by *Gramme,* in 1870, by a number of coils, wound around a ring composed of iron wires, at equal distances from each other, and each connected with one of the equal number of segments of the commutator, on which two

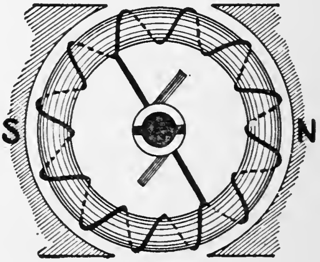


Fig. 37.

brushes are sliding. (See fig. 37.) The two brushes are set so as to take the current from the coils which at the moment are cutting the lines of force at the least angle. The current through the armature, from the negative to the positive brush flows in two paths, around each half of the ring, and this tendency is increased by the following interesting fact: The lines of force that strike the iron wire core of the armature, are deflected from their path because iron has a higher permeability than any other substance; they pass through the ring along the iron wire until they arrive at a point directly opposite the point where they entered, and then flow again in their first direction toward the negative pole. Consequently they are not cut by the wires lying in the inner hollow of the ring, but only by those on the outer circumference. This sets up pressure in two different directions, and both currents thus produced flow towards the positive brush.

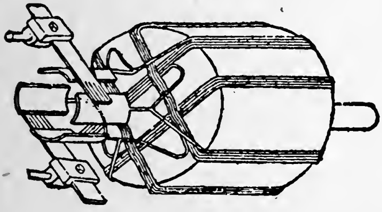


FIG. 38.

The principle of the Gramme Ring is also that of the SIEMENS DRUM ARMATURE. (See fig. 38.) A drum is substituted for the ring and the coils are wound on the outside surface of the drum only.

102. The Siemens drum is not made of one piece but is LAMINATED, that is, made up of thin disks of sheet iron, insulated from each other, to avoid the so-called EDDY CURRENTS, set up in the core when it revolves in the magnetic field, cutting the lines of force. These currents would flow from one end of a solid core to the other, heating the core. It takes power to keep these currents flowing, and besides, the heat would injure the cotton and shellac insulation on the wire of the armature windings. The several disks of sheet iron are insulated from each other by layers of thin tissue paper or coatings of linseed oil, which prevent the flow of current from one disk to the next, but do not interfere with the passage of the lines of forces through the core. Lamination does not prevent all loss of power, however. The armature of a running dynamo is always at a higher temperature than its surroundings, a sign that a part of the power supplied is lost somehow, probably by the resistance offered by the molecules to the reversing of the current at every half revolution. (Compare § 81). The softer the iron or steel in the core, the smaller is this loss by HYSTERESIS.

RULE 33.—The loss of power by hysteresis and eddy currents in any dynamo is proportional to the speed at which the armature revolves.

The Magnetic Circuit

103. The electromagnet between the poles of which the armature revolves, consists of the POLE-PIECES, of concave shape so as to embrace the armature, of the FIELD CORES, around which the wire is wound, and of the YOKE, the part which connects the field cores. The current required to set up the magnetic field (exciting current), is usually furnished by the dynamo itself, even at starting, when the residual magnetism in the magnets is utilized. At the first start the current of a small battery, or of a magneto machine is used.

The space between the iron of the magnet poles and the iron core of the armature is called the AIR SPACE or GAP, although partly occupied by the armature coil. This air space must be made as small as possible, in order to prevent immoderate leakage, principally due to the RELUCTANCE of the air space, and consisting in the going astray of magnetic lines of force, which are apt to cause mischief, as by drawing iron nails or scraps into the air space. The smaller the air space, the smaller the magnetic force required, and the smaller, consequently, the number of ampere turns needed on the field cores of the electromagnet. To reduce the air space as much as possible, the surface of some cores is grooved parallel to the axis, and the coils placed in the grooves, which arrangement does away with almost all the gap, as the teeth (iron core ridges) between the grooves may all but touch the poles.

104. The *total reluctance of the magnetic circuit* of a dynamo is the sum of all the reluctances of the yoke, field cores, pole pieces, air gaps and armature. The number of ampere turns on the field cores (nc) required to create a field of a given number of lines (N) through a given reluctance (P), is calculated by means of the following formula (see § 81):

$$nc = \frac{N\ P}{1{\cdot}257},$$

and the number of lines of force by the formula

$$N = \frac{1{\cdot}257\ nc}{P}.$$

EXAMPLE 48.

The reluctances of the parts of a magnetic circuit are; field cores ·0002 each; pole pieces ·0001 each; yoke ·0002; armature ·0006; air spaces ·0016 together. A current of 3 amperes flows through the magnet coils, and the dynamo has 2,000,000 lines of force. How many turns in the magnet coils?

Total reluctance $= (\cdot0002 \times 2) + (\cdot0001 \times 2) + \cdot0002 + \cdot0006 + \cdot0016 = \cdot003$

$$nc = \frac{2{,}000{,}000 \times \cdot003}{1\cdot257} = \frac{6000}{1.257} = 4773 \text{ turns. Ans.}$$

EXAMPLE 49.

Each conductor of a one-coil armature of 25 ampere turns cuts 1,500,000 lines of force in each half revolution; the armature makes 1200 revolutions per minute. What is the difference of potential between the brushes?

25 turns $=$ 50 half turn conductors. Each conductor cuts the lines of force twice in each entire revolution. $2 \times 50 = 100$. 1200 revolutions per minute $=$ 20 rev, per second.

$100 \times 1{,}500{,}000 \times 20 = 3{,}000{,}000{,}000$ lines of force per second. 100,000,000 lines of force cut per second make 1 volt, therefore $\frac{3{,}000{,}000{,}000}{100{,}000{,}000} = 30$ volts. Ans.

EXAMPLE 50.

1,500,000 lines of force pass through a Siemens armature having 40 coils of 6 turns each, and making 10 revolutions per second. What pressure is set up?

Each turn cuts the lines of force, not four times like a single coil, but only twice, because in the Siemens armature each ampere turn has only one conductor that cuts the lines of force. Therefore:

$2 \times 40 \times 6 \times 1{,}500{,}000 \times 10 = 7{,}200{,}000{,}000$ lines of force cut per second; $\frac{7{,}200{,}000{,}000}{100{,}000{,}000} = 72$ volts.

This pressure is divided between two paths in parallel:

$$\frac{72}{2} = 36 \text{ volts. Ans.}$$

NOTE. — Under the same circumstances, 20 coils of 6 turns, or 40 coils of 3 turns each, would set up 36 volts.

EXAMPLE 51.

A Gramme armature of 50 coils of 4 turns each, making 20 revolutions per second, sets up a pressure of 100 volts. How many lines of force are in the field?

100 volts in two paths = 200 volts.

$$2 \times 50 \times 4 \times 20 \times x = 200 \times 100,000,000$$

$$x = \frac{200 \times 100,000,000}{2 \times 50 \times 4 \times 20}$$

$$x = \frac{20,000,000,000}{8000}$$

$$x = 2,500,000 \text{ lines of force.} \quad \text{Ans.}$$

Classification of machines

105. Dynamo-electric machines may be divided into classes according to

1. the manner in which the magnetism of the field magnets is obtained, whether self exciting or separately excited.
2. the form and number of their field magnets.
3. the nature of their magnetic fields, whether uniform, alternating, symmetrical, dissymmetrical, pulsatory, reversing, or shifting.
4. the shape of the armature, whether drum or disk, pole or radial, ring or spherical.
5. the manner in which the windings of the field magnets, the armature and the external circuit are connected, whether series, shunt, or compound.
6. the nature of the current obtained, whether continuous or alternating.

Dynamo and Motor

106. In a DYNAMO the armature is revolved by an engine or other means, and the revolutions of the armature coils, cutting the lines of force of the magnetic field, set up a current in tne armature coils. In a MOTOR, the electric current supplied by a dynamo or GENERATOR, or by a battery, flows through the coils, of the field cores, setting up a magnetic field, which causes the armature to revolve. Any direct-current dynamo may serve as a motor, if an electric current is sent through its field coils. The armature will revolve in a direction opposite to that in which it revolved when run as a generator. The reason for this is that the mutual influence of a magnetic field and a conductor operates, whether the conductor is moved in the magnetic field, settling up a pressure, or whether a charged conductor is placed in a magnetic field, generating motion. (See §78). Generally speaking, the best dynamo will also make the best motor.

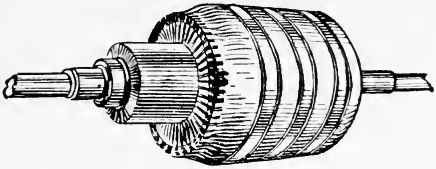


FIG. 39.

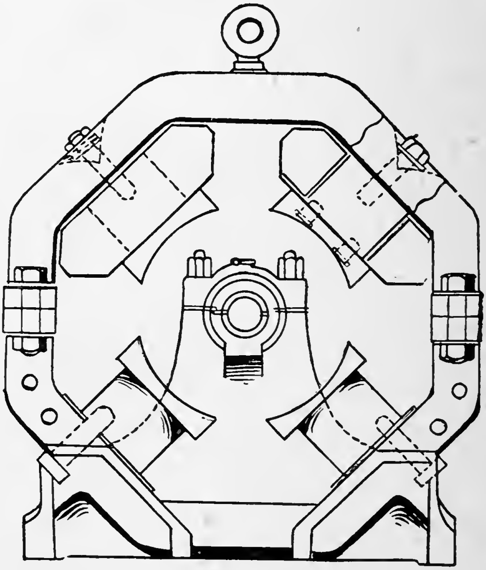


FIG. 40.

Either the armature or the magnetic field may be made to revolve. (See § 82.) Fig. 39 shows a stationary direct current armature and fig. 39 its rotary magnetic field. Fig. 41 represents a complete direct current generator of the most modern type.

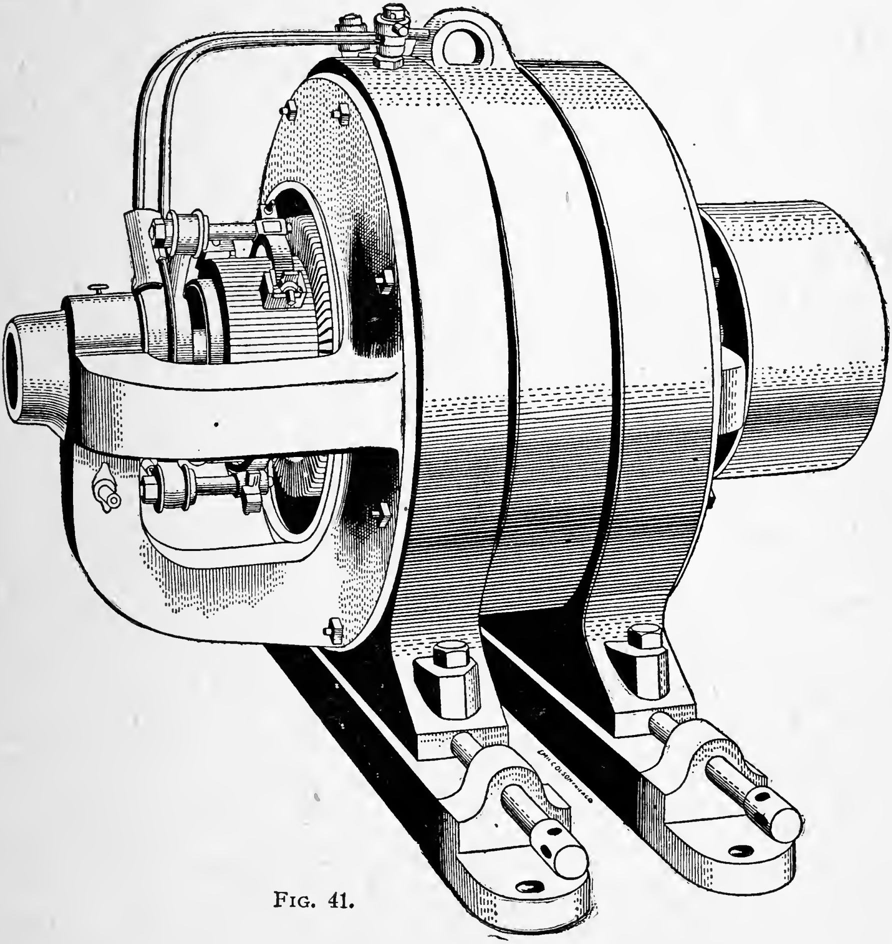


Fig. 41.

Various dynamos

107. An IRON CLAD dynamo is so called because armature coils are partly hidden from view, being embedded in grooves or slots cut in the surface of the armature. The iron parts between the conductors are called *teeth.* In multipolar machines there is a double magnetic circuit, the lines of force dividing as soon as they enter the armature and passing back to the yoke through the *two* adjoining opposite poles. As they pass into the original pole from the yoke, their paths reunite.

The name CONSEQUENT-POLE dynamo designates a machine in which the armature is placed between the field cores, so that the lines of force SEEM to lie, not between the pole pieces, but between two intermediate points. (See § 68.)

108. In order to couple the dynamo directly to the engine shaft, inventors first constructed armatures of large diameters, so as to cut a great number of lines of force *at low speed,* and finally, they multiplied the number of poles from two to four, eight, twelve, etc. The two, four, six, eight (or more) couples of poles (N and S) are all set in one heavy yoke surrounding the armature. The poles are alternately N and S, and the magnetic currents pass from each N pole through the armature core to the two neighboring S poles, and on entering the yoke divide again in two currents towards

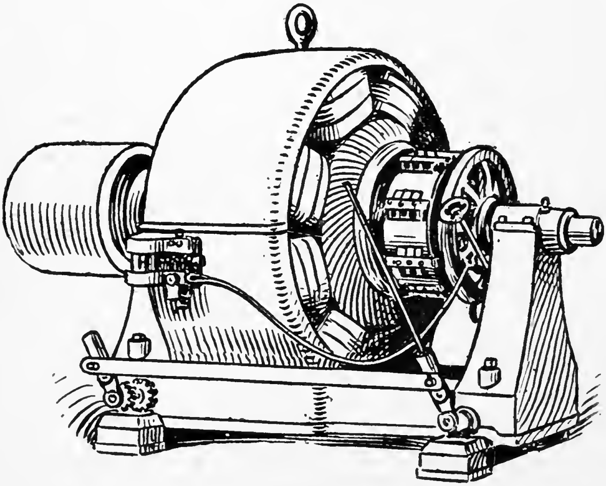


FIG. 42.

the two neighboring *N* poles. These machines are called MULTIPOLAR in distinction from two-pole, or BIPOLAR dynamos. (Fig. 42 represents an 8-pole dynamo.) As a rule, the number of brushes is equal to the number of poles, but by making proper cross connections between the commutator segments two brushes will suffice.

Series, shunt, compound

109. In a SERIES WOUND DYNAMO the field circuit and the external circuit are connected in series with the armature circuit, so that the entire armature current must pass through the field coils. (See diagram, fig. 43.)

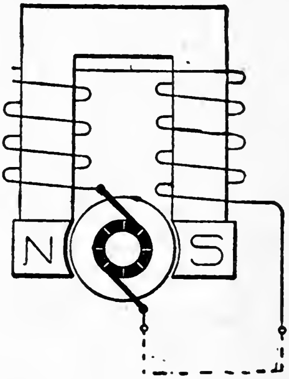


FIG. 43.

Series wound dynamos are used where a current of constant intensity is required, as in a series of arc lamps, because the magnetizing power of the winding increases with the increasing current. But where a constant potential is required, a series wound dynamo cannot be used, because an increase (or decrease) in the resistance of the external circuit (as by switching in or cutting out some arc lamps) will decrease (or increase) the E. M. F., from the decrease (increase) of the magnetizing current. An automatic regulating device is necessary to avoid these changes.

A series wound dynamo will not sufficiently magnetize its own magnets until the armature has attained a certain speed, or unless the external resistance is below a certain limit. It is also apt to reverse its polarity, with disastrous consequences.

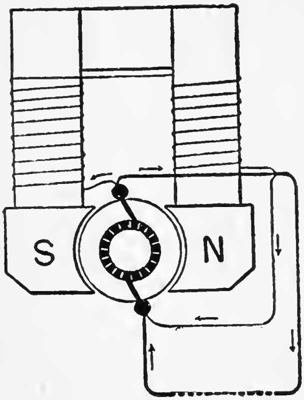


FIG. 44.

110. In a SHUNT WOUND DYNAMO (see diagram fig. 44) a field winding of high resistance is connected at the brushes in parallel to the external circuit, so that only a portion of the current generated by the machine passes through the field winding, which consists of a large number of turns of very fine wire, so that the small current may have the same effect as the large current in the series wound type. The resistance of the shunt coils is greater than that of the armature, therefore variations in the armature will not affect materially the magnetizing power of the shunt, which will act nearly uniformly as exciter. As the current generated by the dynamo increases, the difference of potential naturally decreases some, because of the resistance of the armature and because of the counter magnetism. (See §82.) For this reason, a field rheostat is generally connected in between the two field coils, by which the strength of the field magnetism can be regulated.

This dynamo makes both series and parallel circuits nearly constant as to their working. It is used to advantage for stationary machinery.

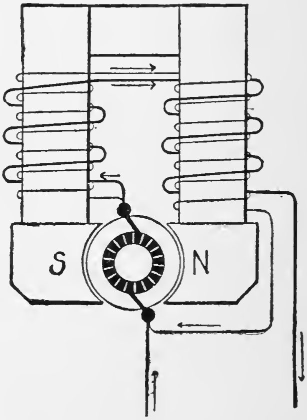


FIG. 45.

111. But multiple circuits require a very great *constancy of potential,* and for this purpose the COMPOUND WOUND

DYNAMO (See fig. 45) is the best. Each field magnet is wound with two separate coils, one of a few turns of thick wire, and the other with many turns of fine wire. The thick wire coils are in series with the armature and the external circuit, and the thin wire coils are, in shunt with the others, connected with the brushes only. The series winding counteracts the decrease of potential in the shunt.

In all these different styles, the field windings must be connected with the brushes, in order that the proper direction may be given to the current generated by the residual magnetism in the field cores. Whenever the direction in which the armature rotates, is changed, these connections must be reversed.

For *constant current* a combination of shunt and separately excited winding is preferred, or a combination of a series and a magneto machine (armature revolving between poles of permanent steel magnet).

Brushes

112. Dynamo brushes are generally made of compressed graphitic carbon Copper brushes were used formerly for dynamos almost exclusively, but were found to be objectionable. They consist of copper wire, gauze or strips, soldered together at one end; they touch the commutator on a bevel. In the case of carbon brushes the surface touching the commutator is fitted to its curvature, and touches it either radially or on a bevel. Brushes are pressed firmly against the commutator by spring holders, which in turn may be adjusted in place by a rocker to ensure always area of contact.

Unless the brushes are in their proper positions, there will be considerable SPARKING, which is destructive to the machine and wasteful of electrical energy. When rightly adjusted, two brushes are exactly opposite each other. In a dynamo they are placed a trifle in advance of a vertical line that might be drawn through the center of the armature in figs. 43—45, and in a motor a trifle behind this line.

Brushes should be adjusted before starting the generator, unless there is danger of starting it in the wrong direction. The current should be turned off before raising the brushes from the commutators. Otherwise, in both cases mentioned, a spark might arise that would tend to seriously injure the commutator.

Pure carbon is very extensively used as material for brushes. A carbon brush well made and properly mounted wears slowly and evenly, and it wears lightly on the commutator bars, gliding over, rather than gliding against them, without lubrication other than that supplied by the graphite of the brush. The bars are polished, rather than worn, so that they need not be wiped with an oily rag. Very little carbon dust is noticeable on the machine, consequently. A carbon brush cannot spread, as a copper brush often does, so that the area of contact is constant.

Armature winding

113. The manner of winding an armature is of considerable importance. The position of each single half turn of wire should correspond with that of the two adjoining half turns, as nearly as possibly. If one half turn from front to back (from commutator over to back) passes a north pole, then the return half should be laid in such a way that the next half turn from front to back may again pass near a north pole. Fig. 46 shows, how this is accomplished by LAP WINDING, each turn lapping over the preceding one. In the diagram, fig. 47, the winding in the back is the same as in fig. 46, but in front the two terminals of one full loop do not run parallel, but diverge, resulting in a zigzag arrangement. This is called *wave winding;* it takes only about one half the number of turns required in lap winding, produces a better magnetic balance in unproportional fields, and has four times the resistance of a lap winding. Wave winding permits the use of two brushes for a four pole machine, without cross-connecting the commutator.

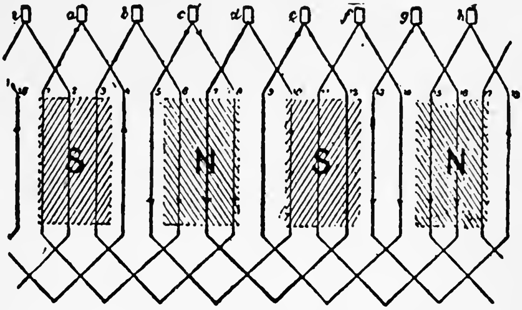


Fig. 46.

Fig. 48 shows a complete armature of modern type. The core consists of a number of very thin flat disks of well-annealed charcoal iron, the outer diameter of each disk being nearly 12 inches, and its inner diameter 9. Thin paper insulates each disk from its neighbors. The armature is mounted on a steel shaft, to which is keyed a non-magnetic gunmetal spider with four arms, the ends of which fit into notches cut into the inner edges of the core disks. The conductor consists of one layer of cotton-covered copper wire of No. 9 standard wire gauge, with

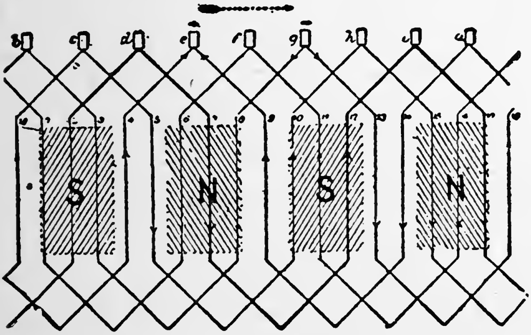


Fig. 47.

a resistance, from brush to brush, of 0·048 ohms. There are, in the commutator, 76 bars of hard drawn copper insulated from each other by mica strips 0·75 mm. in thickness. Corresponding to these, there are 76 sections, of two convolutions each, in the armature, the adjacent ends of neighboring sections being soldered to radial lugs projecting from the commutator bars. The armature is bound with turns of fine strong wire in four places, to prevent a bulging of the conductors when rotated at high speed.

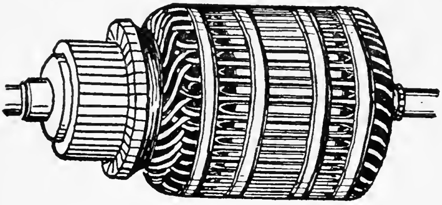


FIG. 48.

Calculation of ampere turns

114. The method of calculating the number of ampere-turns required on the field cores was stated in connection with the saturation card, in § 76. It may be repeated here as

RULE 34. — To find the number of ampere-turns required to drive a given number of lines of force through an iron ring, divide the total number of lines of force by the (number of sq. inches of) cross section of the ring. This gives the induction per sq. inch. Then find the corresponding number of ampere-turns per inch in length on the saturation curve of the iron; multiply this number by the length of the ring in inches.

When the magnetic circuit is not an iron ring, but consists of the parts of a dynamo, the ampere-turns must be calculated for each part separately.

EXAMPLE 52 .

How many ampere-turns in the field coils of a bipolar dynamo will be required under the following circumstances: Lines to be driven through sheet iron armature 1,200,000; armature cross section 12 sq. inches; armature magnetic length 8 inches; gap, cross section, 10 sq. inches, gap length $2 \times \cdot 11 = \cdot 22$ inches; leakage coefficient 0·9; cast steel field poles, cross section, 16 sq. inches; magnetic length 40 inches; cast steel yoke, cross section, 24 sq. inches; magnetic length 12 inches?

Armature induction, $1{,}200{,}000 \div 12 = 100{,}000$ per sq. in. Therefore ampere-turns per inch, by saturation curve: 60. $8 \times 60 =$ *480.*

Gap induction, $1{,}200{,}000 \div 10 = 120{,}000$; $120{,}000 \times \cdot 3133 = 37 \cdot 596$ ampere-turns per inch of length. $37 \cdot 596 \times \cdot 22 =$ *8,271.*

Pole induction, $1{,}200{,}000 \div 0 \cdot 9 = 1{,}333{,}333$; $1{,}333{,}333 \div 16 = 83{,}333$ per sq. inch, which, as the saturation curve indicates, require 90 ampere-turns per inch. $90 \times 40 =$ *3600.*

Yoke induction, $1{,}200{,}000 \div 24 = 50{,}000$ per sq. inch, which as the saturation curve indicates, require 55 ampere-turns per inch. $12 \times 55 =$ *660.*

$480 + 8{,}271 + 3600 + 660 = 13011$. 13,000 ampere-turns for the field coils. Ans

RULE 35. — The number of ampere-turns required per coil on a multipolar armature having one coil per pole, equals the sum of the ampere-turns required to drive the lines of force through the armature, one gap, one pole and the yoke as far as half the distance to the next pole. (See § 76.) The result must be multiplied by two, if there is only one coil to two poles.

EXAMPLE 53.

How many ampere-turns *per coil* will be required in an iron clad multipolar dynamo (see § 108), under the following circumstances:

Lines to be driven from *one* pole through the sheet iron teeth, 6,000,000; cross section of teeth of armature under one pole, 60 sq. inches; magnetic length of teeth 1·25 inches; cross section of armature core, 70·5 sq. inches; armature core magnetic length, 7 inches; gap cross section, 121 sq. inches; gap magnetic length, 0·1 inch; leakage coefficient 0·9; cast iron field pole cross section, 90 sq. inches; magnetic length of field pole, 15 inches; cast iron yoke cross section, 81 sq. inches; yoke length 12 inches?

Armature teeth induction, $6{,}000{,}000 \div 60 = 100{,}000$ per sq. inch. Therefore ampere-turns per inch, by saturation curve, 60; $1{\cdot}25 \times 60 = \mathit{75}$.

Armature core induction, $3{,}000{,}000 \div 70{\cdot}5 = 42{,}555$ per sq. inch. Therefore ampere-turns per inch, by saturation curve, 36; $36 \times 7 = \mathit{252}$.

Gap induction, $6{,}000{,}000 \div 121 = 49{,}669$; $49{,}669 \times {\cdot}3133 = 15{,}561$ ampere-turns per inch of length, $15{,}561 \times 0{\cdot}1 = \mathit{1556}$.

Pole induction, $6{,}000{,}000 \div 0{\cdot}9 = 6{,}666{,}666$; $6{,}666{,}666 \div 90 = 740{,}740$ per sq. inch, requiring, by the saturation curve, 500 ampere-turns per inch; $15 \times 500 = \mathit{7500}$.

Yoke induction, $3{,}333{,}333 \div 81 = 41{,}152$ per sq. inch, requiring, by the saturation curve, 40 ampere-turns per inch; $12 \times 40 = \mathit{480}$.

$75 + 252 + 1556 + 7500 + 48 = 9431$ ampere-turns for each field coil. Ans.

Efficiency of a motor; torque

115. The magnetism set up by the current in the coils of a revolving generator armature, interferes with the magnetic lines of force of the field, the effect of which tends to stop the motion. This *counter force* cannot be avoided; it must be overcome by bringing to bear a certain extra amount of power sufficient to keep the armature moving. The torque of a dynamo which the engine produces must be equal to the torque reaction of the load on the dynamo. From a mechanical standpoint it is measured in foot pounds, which is equal to the force applied times its arm. For instance an engine is belted to a generator. Assume that it applies a force of 8,000 lbs. at the rim of a 24-inch pulley on the generator. The torque is equal 8,000×1 (which is the radius of the pulley)=8,000 ft. pounds. Likewise or rather reversely, in a *motor* the magnetic field sets up a COUNTER ELECTRIC PRESSURE in the revolving armature, which tends to stop the motion, and consequently an extra amount of current must be supplied to the armature to keep it moving. If the *counter E. M. F.* in a motor is so strong that the motor cannot do its work, a slackening of its speed, or a weakening of the field, will mend matters, as by either of these means the counter E. M. F. will grow less.

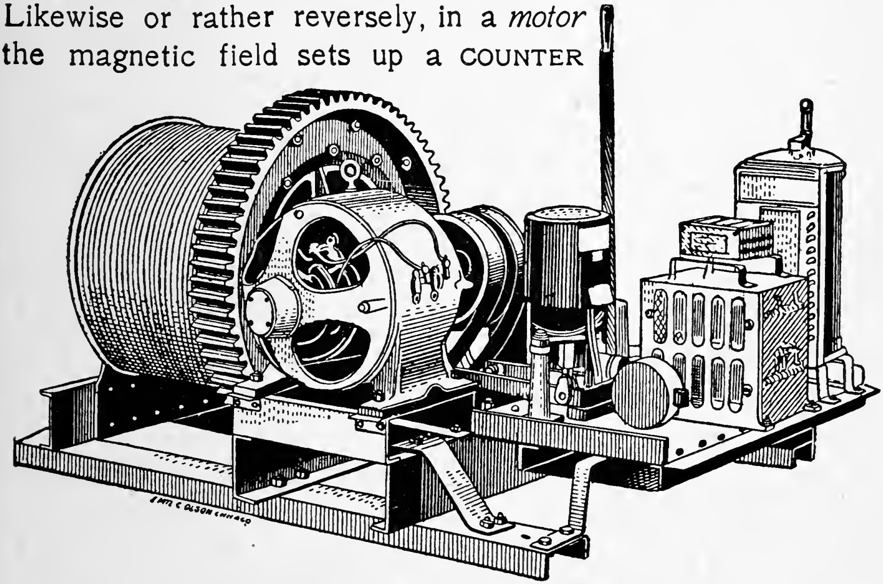


FIG. 49.—ELECTRICAL HOISTING MACHINE.
Direct current motor of 16 H. P. 1455 revolutions per minute. 550 volts.
Raises 11,000 pounds 1½ inches per second.

This amount of extra power must be added to other losses already mentioned, as hysteresis, the $I^2 R$ loss, eddy currents, and the friction converted into heat; and the aggregate of all these must be subtracted from the "input" power, to arrive at the *efficiency* of a machine, which is generally expressed by the *ratio:* output divided by input.

$$\text{Hence, efficiency} = \frac{\text{Power input} - \text{losses}}{\text{Power input}}$$

EXAMPLE 54.

A motor which at full load supplies 30 horse power and requires 50 kilowatts, has a full load efficiency of about 45 per cent. $(30 \times 746 \div 50{,}000 = 0{\cdot}4476.)$

EXAMPLE 55.

A dynamo which has an efficiency of 90 per cent and requires 30 H. P. at full load, supplies 24·8 kilowatts. $(30 \times 746 \div 0{\cdot}9 = 24{,}866.)$

Questions and Answers.

Q. What is the Board of Trade unit?

A. It is the amount of electrical energy of a current of 1000 amperes at a pressure of one volt during one hour. By this unit (kilowatt-hour) electricity is measured and sold.

Q. Does the going astray of lines of force on their way between the pole pieces of a dynamo cause a loss of power?

A. Not exactly.

Q. To what is it due?

A. It is due to a disproportion between pole pieces and armature core, in size or shape.

Q. What is meant by "overcompounded"?

A. If the effect of the series coils is made to preponderate over the shunt coils, resulting in a higher potential difference at the brushes, the machine is said to be over-compounded.

Q. What kind of winding is used on the fields of a street car motor. and why?

A. A series winding; because its torque in starting is great, and because it increases with increasing current.

Q. Of what kind of iron is the magnetic circuit in a machine made?

A. Where a great weight is not objectionable, cast iron is used. Wrought iron has a greater permeability and is therefore preferred because it allows of lesser weight, but it is more expensive. Where very light weight is desirable, soft cast steel is used, as in railway motors.

Q. How are armature cores fastened to the shaft?

A. The thin disks of iron or steel are fastened by means of clamps and keys.

Q. What is the advantage of having iron-clad motors in a street car?

A. The frame surrounding the armature protects it from dirt and especially from water, which would destroy the insulation of the armature wire very rapidly.

Q. How are the poles of multipolar machines wound?

A. The same as in bipolar machines.

Q. What is done, if the position of "no sparking" changes with the load on the machine?

A. As the load increases, the brushes must be moved forward on a dynamo, and backward on a motor. This is generally done automatically.

Q. What is meant by "load" on a machine?

A. It means the amount of current required by an electric circuit during a given time. When all the cars of an electric street railway are running, the load is heavy; when most of them happen to stop at street corners along the route at the same time, the load is light.

Q. What is the leakage coefficient?

A. The ratio of lines of force going through the field, to those going through the armature; In other words, the ratio of total amount of magnetic lines of force to the amount of "useful" magnetic lines of force.

Q. What does it mean, when it is stated that the leakage coefficient of a machine is 1·05?

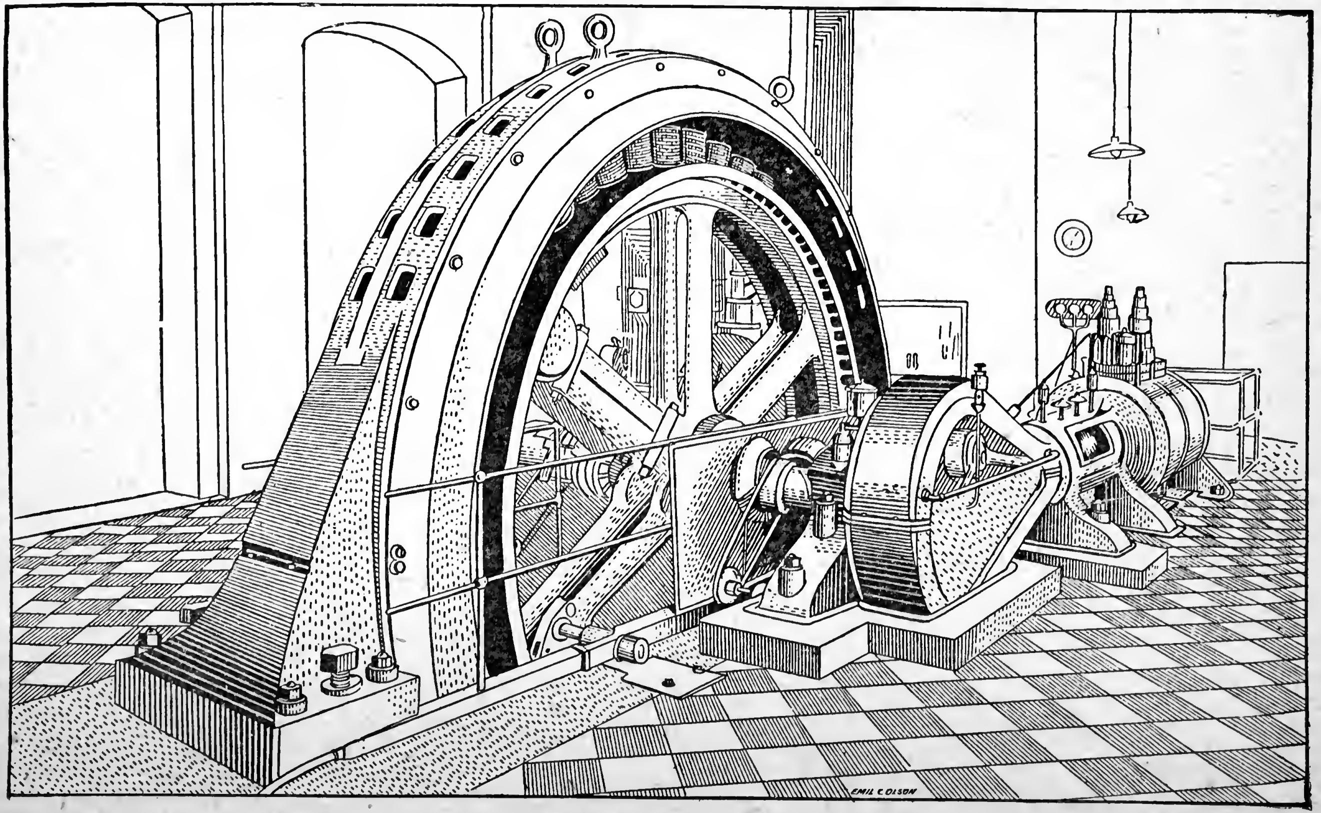
A. It means that the ratio of the total of the magnetic lines of force to the "useful" magnetic lines of force is 1·05.

Q. What advantages has a drum armature over a ring armature?

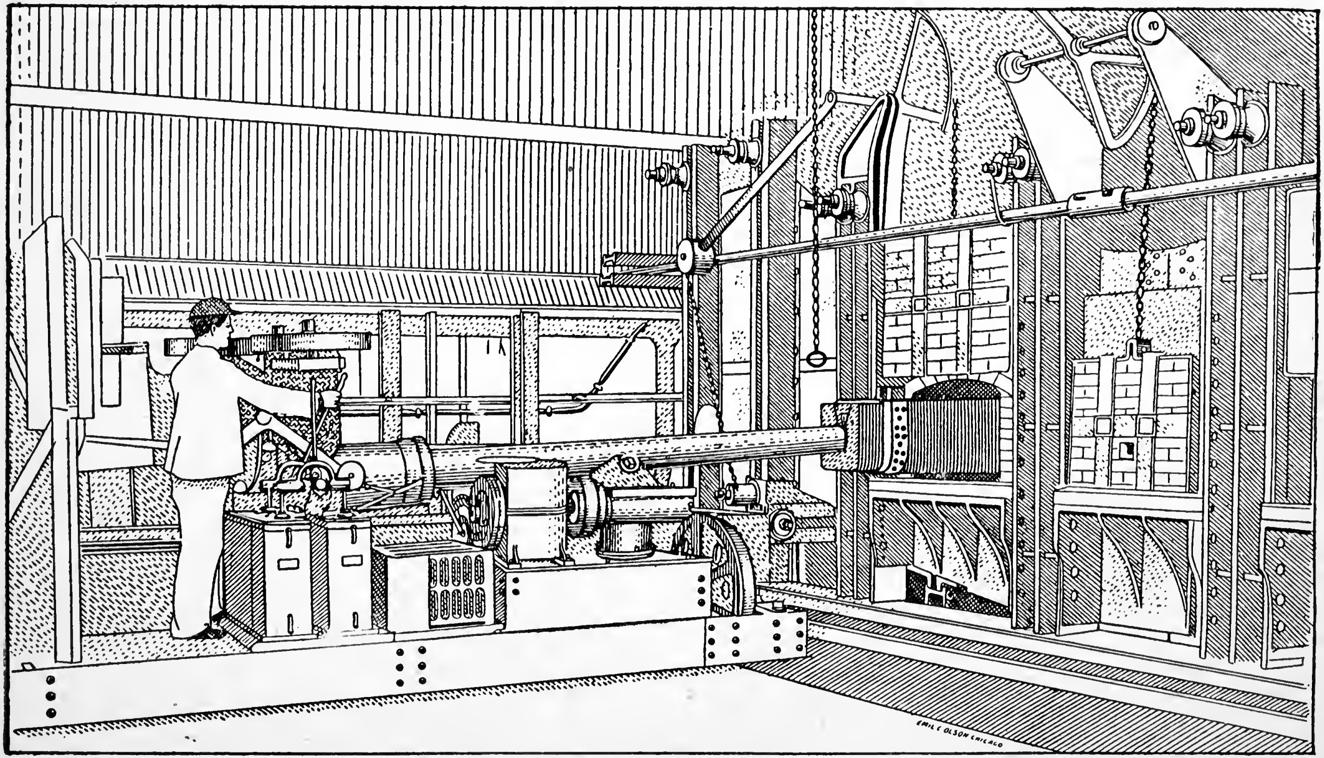
A. First, the drum armature offers less magnetic resistance, because a given magneto-motive force can urge more lines of force through its larger mass of iron. Second, all the lines passing the drum armature are usefully cut by the conductors, and for this reason a slow speed will set up an E. M. F. equal to that of a ring armature at higher speed. Third, having very little idle wire, the resistance is lower.

Q. What disadvantages has it?

A. It cannot be made as strong mechanically as the ring armature, and the cross connections are apt to give trouble.



Direct Connected Three-Phase Current Generator of 800 H. P.



ELECTRICAL SMELTING FURNACE CHARGING MACHINE.

Four direct current motors of 14 H. P. each at E. M. F. of 300 volts. Four controllers with two levers each.

Alternate Currents

116. A simple coil when revolving in a magnetic field so as to cut magnetic lines of force, sets up an electromotive force, which changes direction, according to the position of the coil, at every half turn. (See § 81.) The currents thus produced are called ALTERNATE CURRENTS, in contrast to the *direct* or *continuous current* received at the brushes of a direct current dynamo. In each half revolution of the ring in the magnetic field an electromotive force is generated which rises from naught to a maximum, and then falls again from the maximum to naught. The complete changes during one whole revolution constitute one PERIOD, and the total number of periods produced in one second is called the FREQUENCY. The frequency of a *two*-pole machine equals the number of revolutions per second. In any other machine, if p = number of poles, n = r. p. m., f = frequency, then $f = \frac{p\,n}{2}$

Hydraulic Analogy

117. A *continuous* current of electricity may be compared to the flow set up by a centrifugal pump, while a *pulsating* current resembles the flow from a common piston pump. The flow of *alternate* currents may be compared to the flow of water in the apparatus shown in fig. 50. A and B are glass cylinders of equal diameter, the bottoms of which are connected by means of a pipe C, which is of smaller diameter

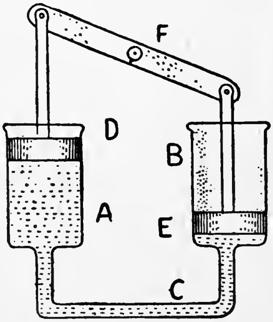


FIG. 50.

than the cylinders. The pistons D and E are connected by means of an arm F which is so pivoted that, when piston E is pressed down, piston D is forced up, and the water contained in cylinder B flows through the connecting pipe C into the cylinder A. When piston D is pressed down, piston E is forced up, and the current flows from cylinder A to B, in the opposite direction of the former current. When the pistons are rapidly moved up and down, an *alternate current* is produced in pipe C.

When each piston is moved up and down once in a second, then the *period* of their complete action is one second and the *frequency* is one period per second.

Pressure curve of alternate currents; Sine curve

118. Imagine that A in fig. 51 is the cross section of a wire of a simple coil revolving, in the direction of the arrow, around the axis O in the magnetic field between the magnet poles *N* (north) and *S* (south). At the instant when this wire is in position A or B, there is no current in the wire, because it moves, in that instant, almost parallel with the magnetic lines of force extending from *N* to *S*. At these points the pressure is said to be *minimum* (= 0). When

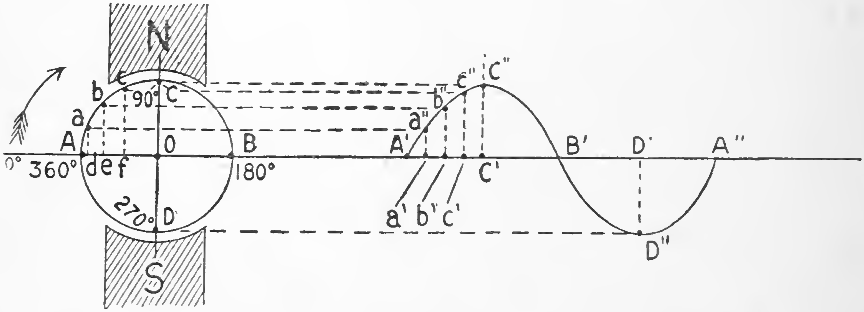


FIG. 51.

in position C or D, the *maximum* pressure is in the conductor, because it cuts the magnetic lines of force at right angles.

The pressure curve of this conductor may be constructed as follows: For convenience, assume the highest pressure, at points C and D, to equal one, and also take the radius ($CO = OD = \frac{1}{2}$ diameter CD) of the revolving conductor to equal one. (As *one* inch.) On the prolonged line A B measure off the line of travel described by the conductor A in one revolution from A, through C, B, D, back to A. As the diameter of the circle equals 2, the path of conductor A equals $\pi \times$ diameter $= 3{\cdot}1416 \times 2 = 6{\cdot}2832$, or about 6·3 times the radius (CO), taken as unit. Mark the ends of line thus obtained A' and A''. The position of A when it starts to revolve, is represented by the point A'; its path from A to C equals $\frac{1}{4}$ of the circumference of the circle, or, in the diagram, $\frac{1}{4}$ of the line A'A''. ($A'C' = \frac{1}{4} A'A''$.)

The wire's route from A to B equals $\frac{1}{2}$ of the circumference of the circle, or, in the diagram, $\frac{1}{2}$ of the line A'A'' ($A'B' = B'A''$), and so on. Then $A'C' = C'B' = B'D' = D'A'' = \frac{A'A''}{4}$.

In points C and D the pressure equals *one,* or, graphically, the length of radius CO. This pressure may be represented in the diagram by perpendicular lines of the length of CO in points C' and D'. Then $C'C'' = D'D'' = CO = 1$. Since the flow of the current during the $\frac{1}{2}$ revolution from B to A is opposite to that of the current in the first half revolution, from A to B, the perpendicular D'D'' must be measured off in the opposite direction from C'C''

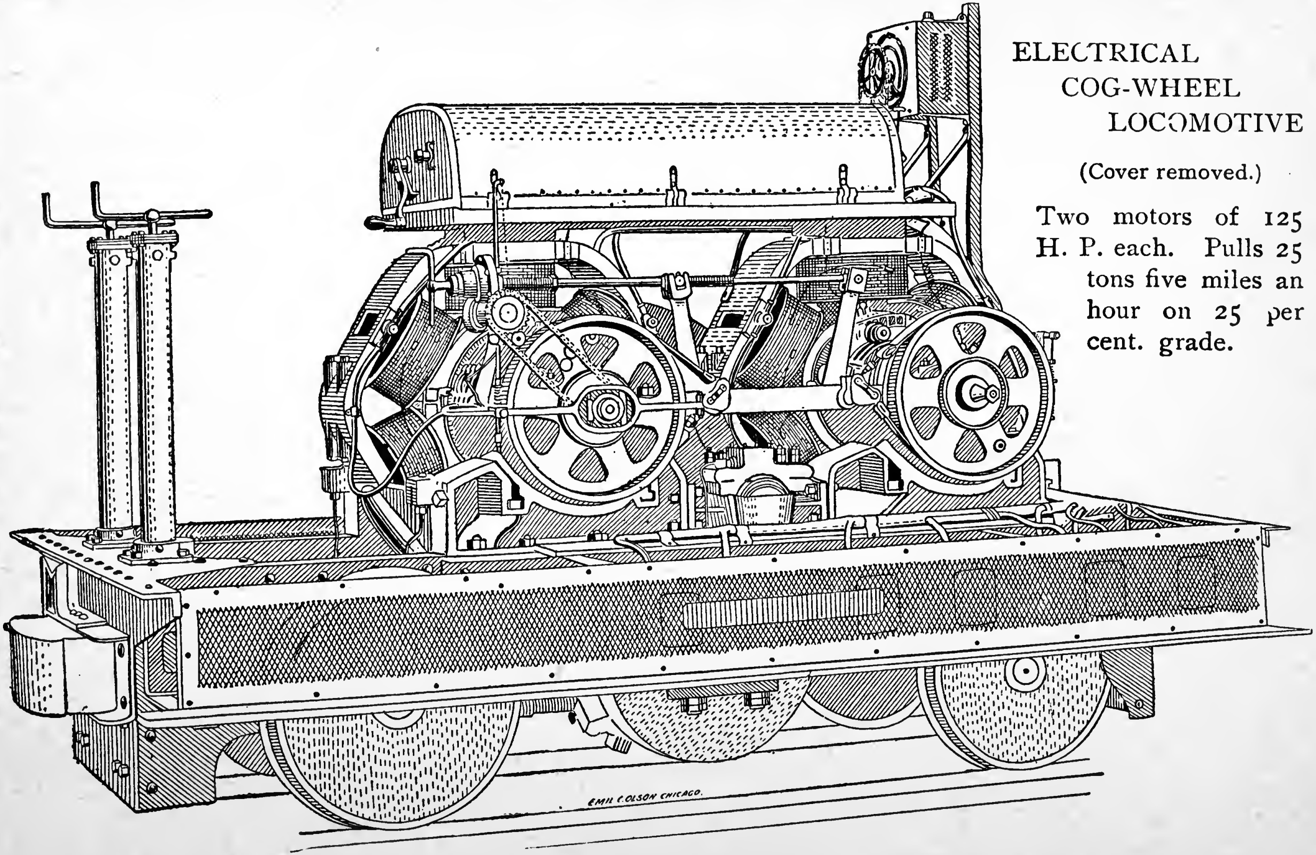
Pressure in the conductor A, when in position A or B, is = 0, and is therefore represented in the diagram by points A', B', A'' respectively.

The pressure curve of the current must therefore pass through A', C'', B', D'', A''. For the precise construction of the pressure curve, other points through which it must pass may be found as follows: Divide the quadrant AC in four equal parts by points a, b, c. These 4 parts may be represented in the diagram by lengths A'a' = a'b' = b'c' = c'C' = $\frac{1}{4}$ A'C'. The pressure in the conductor when at points a, b, c, therefore, equals the lengths of the normals falling from these points on the diameter A B: ad, be, ef respectively. Now draw perpendiculars in points a', b', c' in the diagram, and make a'a'' = ad, b'b'' = be, c'c'' = cf, in the same direction as C'C''. In the same manner points of the pressure curve above the line between C'' and B', and below the line, between B' and D'', and D'' and A'' may be found. By connecting the points thus obtained, the *pressure curve* of one *period* or *cycle* is established.

The result of this construction is a smooth curve; in practice the actual curves of pressure of alternate current dynamos are irregular, owing to various conditions affecting current. The curve A'C'' B' D'' A'' is termed the SINE CURVE.

Electromagnetic Inertia; Self-induction

119. Whenever the strength of a current in a conductor increases or decreases, another current is INDUCED, in the same circuit or in a neighboring one, by means of changes in the magnetic field surrounding the conductor. If these magnetic lines of force cut some parts of the circuit, the current of which induced them, they act inductively on



ELECTRICAL
COG-WHEEL
LOCOMOTIVE

(Cover removed.)

Two motors of 125 H. P. each. Pulls 25 tons five miles an hour on 25 per cent. grade.

this current. In § 83 it has been also mentioned that a coil possessing many turns, has a great *self-induction,* which will be all the greater if the coil contains an iron core.

A coil which generates a certain number of magnetic lines of force when a certain current is turned on to pass through its turns, will also generate a current, when a magnet pole having the same number of magnetic lines of force, as were generated in the coil, is plunged into the coil. And the drawing of this magnet from the coil will act in the same manner upon the turns of the coil, as the cutting off of the current of the coil would act on the magnetic lines of force within the coil. The current which is induced when the magnet is plunged into the coil, tends to push the magnet pole out of the coil, while the current induced by withdrawing the pole tends to keep the magnet in the coil. It is evident that in both cases the self-induced *E. M. F.* opposes any change; when the current is turned on, it tends to hinder the growing of the current; when the current is turned off, it tends to keep the current flowing. This tendency of self-induced electromotive force to oppose any change is called ELECTROMAGNETIC INERTIA. *It is due to the magnetic effect of the current, and, in its turn, it causes* SELF-INDUCTION.

All bodies have an inertia of their own, that opposes any change. Every body resists being moved from place to place, being bent, crushed, heated, or being stopped when in motion.

Angle of lag

120. Those familiar with the seashore know that the tide does not rise to the same height, and the ebb does not fall to the same level, in all channels. In a straight, deep and smooth channel, A, the flow is swifter than in a tortuous, shallow and rough one, B, and the result is, that the difference between the highest tide and the lowest ebb at a point remote from the open sea, is much larger in A than in B. The flow in B may be said to be, or *lag in phase, behind* the flow in A. Similarly, the alternating current generated in a dynamo never keeps step with the alternating electromotive force. The *self-induction* within the circuit (See § 119) causes the current to *lag* in *phase behind* its electromotive force by a small fraction of a second. Fig. 52 is a diagram of a current *lagging* in phase behind the electromotive force. The lagging current is shown in heavy line, the leading voltage in thin line. But self-induction does not only cause a lagging of the current; it also chokes the current down, the increasing current being opposed by the increasing self-induction.

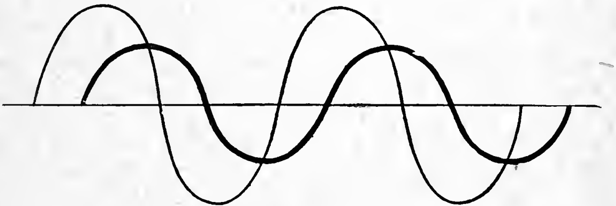


FIG. 52.

The amount of lag is expressed in terms of degrees. In fig. 51 the line A'A" may be considered to be divided into 360 parts, like the circumference of the circle A C B D. Then, if the wave line A' C" B' D" A" represents the wave of the *E. M. F.*, and a similiar *current* wave passes through C' and D', the current wave would be half way behind the *E. M. F.* wave, and the angle of lag would be 90°. As some power is required to send a current through a circuit of even the slightest resistance, it is impossible to have a lag of quite 90°.

Co-efficient of self-induction; Impedance

121. INDUCTANCE is that *property,* in virtue of which a given electromotive force acting on a circuit does not immediately generate the full current due to its resistance; and when the electromotive force is withdrawn, time is required for the current strength to fall to zero.

The number of the lines of force which, springing out from and collapsing upon the various convolutions of a coil, cut the other convolutions, depends upon the current strength, but *also upon the shape of the coil,* that is, upon the number of convolutions in the coil and their disposition. This latter factor is termed the CO-EFFICIENT OF SELF-INDUCTION *of the coil,* and it may be measured in terms of a unit called the *henry.* If a current is started in a coil, the inductance generates a counter *E. M. F.* proportional at any instant to the rate at which the current is changing in strength; and if the current rises uniformly during one second from zero to one ampere, and if the counter *E. M. F.* during that second is one volt, then the coefficient of self-induction of the coil is one henry. It is generally denoted by the symbol L, and it is constant in value for a coil without iron.

The total number of lines of force interlinked in the coils varies with the current strength, and is equal to the product of L and I. The total inductance is equal to L times the rate at which the current is changing in strength. It is evident that with an alternating current the inductance will increase as the maximum value of the current is increased.

If the coil has an iron core, the value of L is enormously increased, but is no longer constant, varying according to the permeability curve of the iron.

To set up a direct current of 60 amperes through a resistance of 3 ohms, an *E. M. F.* of 180 volts is necessary. In an alternate current circuit this voltage would not suffice to generate the required 60 amperes, in case there is self-induction in the circuit. By the aid of geometrical construction the formula for the alternate current has been found to be :

$$I = \frac{E}{\sqrt{R^2 + 4\pi^2 f^2 L^2}}$$ or in words

RULE 36.— The alternating current of a circuit equals the E. M. F. (E) *divided by the square root of the sum of the square of resistance* (R), *and four times the product of the squares of* π, *number of periods per second* (f) *and coefficient of self-induction* (L). (See footnote, p. 61).

From this formula the necessary voltage may be found:

$$E = I \times \sqrt{R^2 + 4\pi^2 f^2 L^2}$$ or in words:

RULE 37.— The E. M. F. in an alternate current circuit equals the current multiplied by the square root of the sum of square of resistance and four times the product of squares of π, *number of periods per second and coefficient of self-induction.*

The expression $\sqrt{R^2 + 4\pi^2 f^2 L^2}$ is usually called the IMPEDANCE (z). The *impedance* is the ohmic resistance of the circuit, *plus* the effect of self-induction, which depends upon the magnetic effects in the circuit, and upon the frequency of the current.

If R is of negligible value, the above formulas become:

$$E = I\sqrt{4\pi^2 f^2 L^2} = 2\pi f L I$$

and $L = \dfrac{E}{2\pi f I}$ or in words:

RULE 38. — E. M. F. equals two times π, times the number of periods per second, times inductance times current, and

RULE 39. — Inductance of a circuit equals E. M. F. divided by twice π, times number of periods per second times current.

EXAMPLE 56.

What is the coefficient of self-induction in a coil of negligible resistance, through which a current of 50 amperes and a frequency of 200 periods per second is sent at a pressure of 15,708 volts?

$$L = \frac{E}{2\pi f I} = \frac{15708}{2 \times 3{\cdot}1416 \times 200 \times 50} = \frac{15708}{62832} = \frac{1}{4}. \quad \text{Ans}$$

EXAMPLE 57.

What pressure is required to send a current of 4 amperes and a frequency of 250 periods per second through a coil of negligible resistance, whose coefficent of inductance is 0·75?

$$E = 2\pi f L I = 2 \times 3{\cdot}1416 \times 250 \times 0{\cdot}75 \times 4 =$$
$$6283{\cdot}2 \times 0{\cdot}75 = 4{,}712{\cdot}4 \text{ volts.} \quad \text{Ans.}$$

EXAMPLE 58.

$E = 20{,}000$ volts, number of periods per second 796, self-induction 10, resistance negligible, (0·5 ohm). What is the current?

$$I = \frac{E}{2\,\pi\, f\, L} = \frac{20{,}000}{5005 \times 10} = 0{\cdot}4 \text{ amp.} \quad \text{Ans.}$$

Choking Coils

122. It is evident that, when there is in a circuit a low ohmic resistance and a great effect of self-induction, the current will be governed by the self-induction. Coils of small resistance and large self-induction are used to *impede* alternate currents. They are called *impedance coils* or *choking coils.* The greater the coefficient of self-induction is, the lower will the actual value of the current fall below the value it would have, if no self-induction existed. See § 120

Chemical Effect of Alternate Current

123. When the poles of an alternate current dynamo are connected to an electrolytic cell, no metal is carried by the current from anode to cathode. *An alternate current has no electrolytic effect,* because of the rapid changes in the direction of flow, making one plate of the cell alternately for one instant an anode, and for the next instant a cathode. The particles detached from the plate when anode are driven back to it when cathode.

Effective current; effective pressure

124. The heat produced by a continuous current (see § 60), equals the current squared times the resistance of the circuit. In alternating currents the heating effect changes with the current at every instant, but the sum of all the *instantaneous* values is greater than that of a continuous current equal to its average value. The effective value of an alternating current is numerically equal to a steady direct current which will produce the same heating effect in a given time as will a changing alternating current. Effective value = ·707 maximum value = 1·11 average value.

The reason for this is that the differences and averages in a progression of squares are larger than those in the progression of their roots. The differences between 3, 6, 9, for instance, are 3 and 3, while the average of the three numbers is 6. But the differences between the squares of these figures, 9, 36, 81, are 27 and 45, and their average is 42. For the same reason, the heating effect of a *pulsating* current is greater than that of a continuous current equal in its average value, which in turn, = ·636 maximum value.

The current and pressure set up without self-induction or other disturbing elements, are called EFFECTIVE CURRENT and EFFECTIVE PRESSURE.

The value of an alternating current squared, times the resistance of the circuit, gives the heating effect of the current. The value is called the *effective current.*

The *effective pressure of an alternating current* is the value which, when multiplied by the effective current set up by it in the circuit, gives the power expended in the circuit.

RULE 40.—The effective current (or effective pressure) of an alternating current equals the square root of the average of all the squares of the instantaneous values of the current (or pressure) during one half period.

Measuring alternate currents

125. The watts expended by an alternate current dynamo cannot be measured in the same way as the power of a direct current generator, employing the voltmeter and the amperemeter separately, and multiplying the results obtained by these two instruments. Owing to the difference of phase, which does not interfere with the workings of these instruments, the results thus obtained would greatly differ from the true watts which the dynamo expends.

Therefore, in measuring the power of alternate currents a wattmeter is used (usually an electrodynamometer, see § 90), with a high resistanse coil for connecting across the terminals, and a low resistance coil for connecting in series with the circuit. However, if the E. M. F. and the current are in phase the watts are equal to the product of the two. If they are not in phase the angular difference must be taken into account. The power is $P = E\,I \cos\phi$. Cos ϕ is called the power factor. The power factor times the E. M. F. times the current equals the true power.

EXAMPLE 59.

An alternate current makes 9000 alternations in five minutes. What is its frequency?

$$\frac{9000}{2 \times 5 \times 60} = \frac{9000}{600} = 15 \text{ periods per second.} \quad \text{Ans.}$$

EXAMPLE 60.

An alternating current has a frequency of 150 periods per second. How many alternations does it make in one hour?

$150 \times 2 \times 60 \times 60 = 300 \times 3600 = 1{,}080{,}000.$ Ans.

EXAMPLE 61.

What is the coefficient of self-induction of a coil whose resistance is negligible, through which flows a current of 100 amperes and a frequency of 100 periods per second, at a pressure of 15 708 volts?

$$\frac{15708}{2 \times 3{\cdot}1416 \times 100 \times 100} = \frac{15708}{62832} = 0{\cdot}25. \quad \text{Ans.}$$

EXAMPLE 62.

What pressure is required to send a current of 100 amperes and a frequency of 200 periods per second through a coil of negligible resistance and of a coefficient of self-induction, 0·2?

$$2 \times 3{\cdot}1416 \times 200 \times 0{\cdot}2 \times 100 =$$
$$1256{\cdot}64 \times 20 = 25{,}132 \textit{ volts}. \quad \text{Ans.}$$

EXAMPLE 63.

What are the periods in the above four examples?

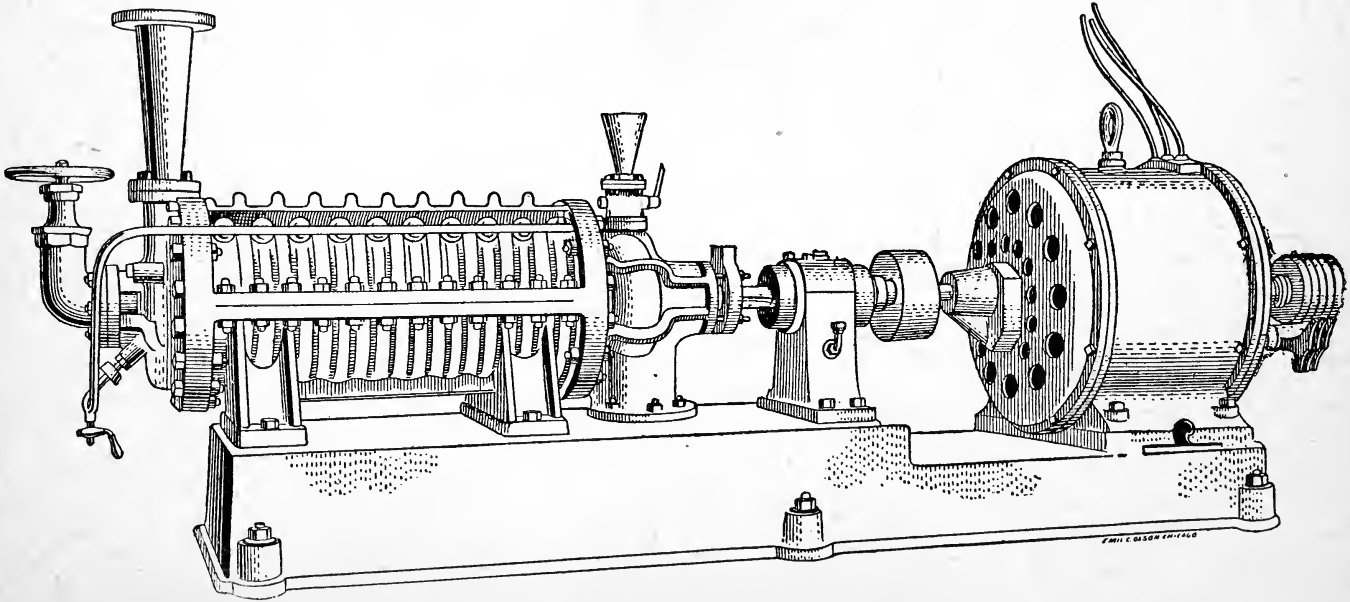
$$1.)\frac{1}{15}, \quad 2.)\frac{1}{150}, \quad 3.)\frac{1}{100}, \quad 4.)\frac{1}{200}. \qquad \text{Ans.}$$

Alternate currents of high frequency

126. Formerly currents of a frequency of not more than 100 to 150 periods per second were employed; nowadays currents of 1000 and more periods per second are in practical use. For electric lighting the frequency varies from 60 to 120 periods per second. In cases, where a frequency of 1000 and more periods per second is used, the current does not seem to flow through the whole cross section of the wire, but rather to be confined to its outer surface, as the conductor offers a great impedance to it. And this fact lends a certain strength to the most modern supposition of scientists, that after all "*electrical energy is not transmitted through the wire itself, but through a medium surrounding the wire.*"

Alternate current in electromagnets

127. If an alternate current is sent through the coil of an electromagnet, an alternating magnetic field will be produced, and the core of the electromagnet will be alternately magnetized north and south. Electromagnets to be supplied with alternate currents are usually designed with fewer turns than those which are supplied with direct current.



ELECTRICAL HIGH PRESSURE CENTRIFUGAL PUMP.

Raises 200 gallons a minute 170 yards. Revolutions 1,450 a minute. E. M. F. 1,000 volts. Current 22.5 amperes. Size of bed 10 feet × 2.9 feet.

Their cores are laminated, in the same manner as the drums of direct current dynamos (see § 102), to avoid eddy currents which are set up by the alternate current to such an extent, that even electromagnets with laminated cores repel particles of copper.

Transformers

128. For the sake of economizing copper in feeders for long distances, the current is transmitted through them at a high pressure, permitting a smaller section of wire. But arriving at the point of distribution, where the current is to be utilized, say for lighting incandescent lamps, the high pressure current (of 5000 or 10,000 volts and higher) must be transformed to one of low pressure (of say 110 volts). Apparatus designed for this purpose are called *transformers*. They are modified induction coils, (see § 82 and 83), with well laminated cores composed of thin soft sheet-iron of such a shape that the magnetic circuit is closed. Upon this core (C in fig. 53) there are two coils: the primary (A) which receives the alternate current, and the secondary (B) which gives out the transformed current. The primary consists of many turns of fine, well insulated copper wire to receive a small current at high pressure; the secondary consists of a few turns of thick wire, to give out a large current of low pressure.

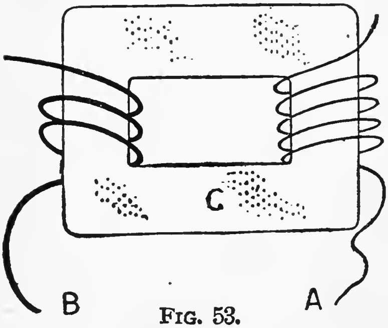


FIG. 53.

If the primary coil has 2500 turns, and the secondary 50 turns, then the ratio of their windings is 2500 ÷ 50 = 50 ÷ 1, and if the secondary coil is to furnish 200 amperes at 50 volts, then the primary coil must supply at least 4 amperes ($200 \div 50$) at 2500 volts (50×50).

On the other hand, in a transformer which is to transform 5000 volts down to 100 volts, the ratio of the primary and secondary windings must necessarily be $\frac{5000}{100} = 50 \div 1$, which means that for every 50 windings of thin wire on the primary coil 1 winding of thick wire on the secondary coil is required. The current, without regard to the pressure, is in the inverse ratio, as the power (in watts) put into the transformer equals the power taken out of it.

There is only small loss in transformation. The *iron loss* (caused by eddy currents and hysteresis of the core,) and the *copper loss,* (due to the ohmic resistance of the copper wire), either of these amounting to about 0·8 to 1 per cent of the supplied power, are negligible quantities. It is important to keep these losses low, because the secondary coil of a transformer is generally on open circuit during the greater part of the time.

If the rate of alternation is 100 per second, the *E. M. F.* will be applied to the primary coil in one direction during $\frac{1}{200}$th part of a second, and during the greater part of this small period it is far below its maximum value, the angle of lag being nearly 90°; the reversal takes place long before the current has had time to rise to any appreciable strength. This fact, and the high self-induction of the primary coil are the causes of the smallness of its current

Automatic self-regulation

129. When the secondary circuit is closed, the alternating potential difference at the terminals of the secondary coil sets up a current, which is *inversely proportional to the resistance of the external secondary circuit*, if the resistance of the secondary coil is negligibly small.

This secondary current has a REACTIVE effect enabling the primary coil to take up more power from the mains, first by increasing the primary current, and second by reducing the angle of lag between the *E. M. F.* and current. In a perfect transformer this power would be inversely proportional to the resistance of the secondary circuit. (See § 82.) When the current starts in the secondary coil, its lines of force, in springing out to pass the iron core, must cut the primary coil convolutions, and the *E. M. F.* thus generated is in such a direction as to assist the primary *E. M. F.* in increasing the primary current, while the collapsing secondary lines of force assist the reversal of the primary current. This *reaction* is greatest when most needed, making the transformer self-regulating. The eddy currents in the iron core have the same reacting effect on the primary current.

This self-regulation of the transformer is assisted by several devices. In the Thomson SLIDING-COIL TRANSFORMER one winding is movably mounted, and any increase in the secondary current, due to short-circuiting some of the devices, or to a similar cause, will produce an increased repulsion between the two windings, driving them farther apart. When sufficiently far apart to reduce the mutual induction enough to bring the secondary current back to normal strength, a state of equilibrium sets in again, and the windings resume their proper distance. In other types of transformers, the axis of one winding is pivoted, so that it may turn out of and into parallelism with the axis of the other winding, with the same results as above described.

Location of transformers

130. A transformer is usually well insulated and enclosed in a cast iron box which keeps it free from moisture. The high pressure currents are carried either from the central station to special sub-stations, (or transformer stations,) from where low pressure mains distribute the current to the houses, or the high pressure current enters each building in high pressure mains, and is transformed in the building by means of a transformer placed in the cellar. Such distributing systems are shown in figs. 54 and 55. Transformers are also placed on the poles carrying the wires.

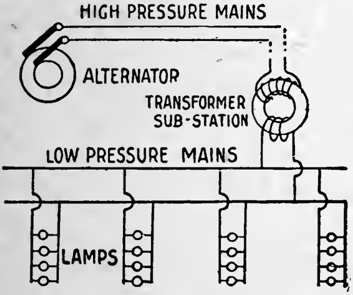


FIG. 54.

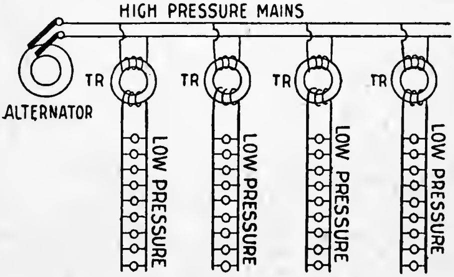


FIG. 55.

EXAMPLE 64.

The primary coil of a transformer has 1000 turns, the secondary 100 turns. What is the ratio of their windings?

$$\frac{1000}{100} = 10. \quad 10:1 \quad \text{Ans.}$$

EXAMPLE 65.

A transformer of 4000 turns in the primary coil gives the secondary winding a pressure of 250 volts. How many turns has the secondary winding, when the primary pressure is 1000 volts?

$$\frac{1000}{250} = 4; \text{ ratio of windings is } 4:1.$$

$4000 \div 4 = 1000$. The secondary winding has 1,000 turns. Ans.

EXAMPLE 66.

The primary coil of a transformer is supplied with a current of 2000 volts at 25 amperes. The pressure received from the secondary is 250 volts. What is the current from the secondary coil, if the iron and copper losses are of negligible value?

Input = output. $2000 \times 25 = 50{,}000$ watts. Watts $\div$ volts = amperes. $50{,}000 \div 250 = 200$ amperes. Ans.

EXAMPLE 67.

The primary coil of a transformer whose ratio of windings is $20 \div 1$ receives 15 kilowatts at 2000 volts. What is the output of this transformer in volts and amperes, when the losses are of negligible value?

In the primary $\frac{15000}{2000} = 7{\cdot}5$ amperes; in the secondary $\frac{2000}{20} = 100$ volts, and $\frac{15000}{100} =$ *150 amperes.* Ans.

Transformers designed for the purpose of reducing high-voltage currents into low-voltage currents are commonly called *step-down transformers.* Sometimes transformers are used to raise the pressure in order to economically transmit energy over long distances, and this kind of transformers is called *step-up transformers.*

The booster

131. Of late the system of having a large number of small insulated transformers delivering currents at about 50 volts, has been superseded in many cases by installing large transformers in sub stations, and by the use of 100 to 500 volts on the secondary side. This renders possible a considerable increase in secondary output, but, of course, it also necessitates a corresponding increase in the length of secondary feeders, and these feeders must be large enough to avoid an excessive drop, even though the maximum load may be on for a very small portion of the time only. In such a case the use of a BOOSTER (subsidiary generator) is very economical, as by its aid the size of wire may be reduced considerably. For instance, there are three main generators, over-compounded so as to give a pressure of 500 volts at no load and 550 volts at full load. The dynamos being joined in parallel to the bus bars, would suffice for an increase in the total load, but not for a heavy increase in any one feeder circuit. In such an event a BOOSTER set is employed, consisting of a 20 volt series wound dynamo, joined directly in the feeder circuit, and driven at a constant speed by a shunt motor connected directly across the mains.

Alternators

132. Alternate current generators or ALTERNATORS are constructed upon the same principles as direct current dynamos, but are readily distinguished from them by the fact that they possess collecting rings in place of the commutator. In practice alternators are used which generate currents of 1000 to 5000 volts pressure, with frequencies of 25 to 120 periods per second, because of the economy in copper when transmitting power over long distances. Therefore almost all alternators are designed as multipolar generators, with stationary armature and rotating field magnets. Alternators possess the advantage over direct current generators, that they do away with the commutator and with the great difficulties connected with its use.

Armatures are mostly wound in coils connected together in series, the ends of the first and last coil being connected to the two separate *collecting rings* or *slip-rings.* (See fig. 61, § 136.) The number of poles of the field magnet equals usually the number of coils on the armature.

RULE 41.— The number of alternations in a certain time equals the number of polepieces in the field magnet times the number of revolutions of the armature in that time.

Types of alternators

133. There are various types of alternators, the most important of which are the following:

1. Alternators whose armature is stationary, and whose field magnet revolves. From this kind of alternators the current is taken from the stationary armature by means of connecting posts (Ferranti, and Mordey types.)

2. Alternators, whose field magnet is stationary and whose armature revolves. From these machines the current is taken by means of brushes rubbing against two or more collecting rings. (Siemens and Schuckert types.)

3. Alternators, whose field magnet and armature are both stationary. The current is induced by means of revolving iron keepers or inductors which induce currents in the stationary armature by making and breaking the magnetic circuit

of the field magnets. From these machines the current is taken as under 1.

The rotating keepers, laminated masses of iron, carried on a circular non-magnetic framework, effect the cutting of the armature conductor by the lines of force set up by the field magnet, in such a manner that first a very good and then a very bad magnetic circuit are alternately set up. A typical *inductor alternator* may be described here.

The stationary outer iron ring has inwardly projecting pole-pieces which are wound alternately with field magnet and armature coils. The field magnets alternate in polarity. (In the diagram, fig. 56, the armature cores are marked A, the pole-pieces are marked *N* and *S*, and the arrows indicate the direction of the exciting current. The keepers are lettered K.) In the position shown in the diagram, the maximum number of lines pass from the adjacent magnet pole through each armature coil, and the *E. M. F.* is zero, the reversal in the direction of the current taking place at this moment. As each mass K moves onward, the air gap increases, and the number of lines of force from, say, an *S* pole, threading an armature coil, is lessened, while lines of force from the next *N* pole are beginning to thread through the armature in the opposite direction. When the middle of each keeper is directly opposite the middle of an armature coil, two

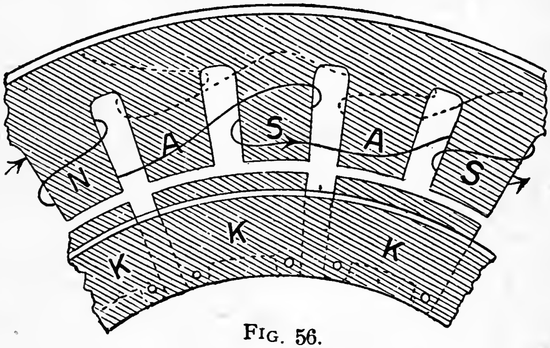


FIG. 56.

sets of lines of force, equal in number, opposite in direction, pass through the armature coil, and the *E. M. F.* is at its maximum.

The keepers are rotated at the speed necessary to produce the desired rate of alternation or periodicity. If the revolving part is truly balanced, this speed involves no mechanical difficulty, such as arise in rotating the complicated mass of iron, copper wire and insulating material in an armature.

Field excitation of alternators

134. As the current generated by alternators cannot be used to excite the field magnet, another, direct current is employed for this purpose. This current is usually generated by a small separate direct current dynamo—the *Exciter*. A rheostat connected in the field of the exciter or of the alternator, or both, regulates the pressure.

Regulation may also be done by having a *rectifying commutator* near the collecting rings, which allows a small direct current to pass through a few turns of wire on the field magnets This *composite* excitation may be compared to the compound winding of direct current machines.

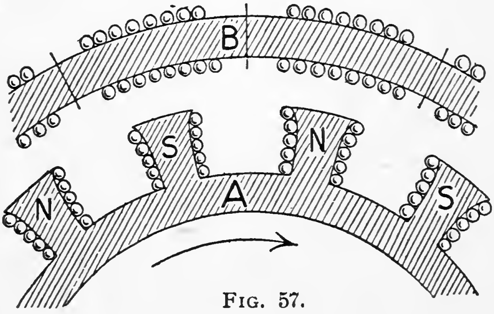


Fig. 57.

Field magnets of alternators

135. Some kinds of field magnets of alternators differ from the field magnets of direct current generators. A special form of field magnets, known as Elwell-Parker type, is shown in fig. 57. The magnetic poles are marked *N* and *S*.

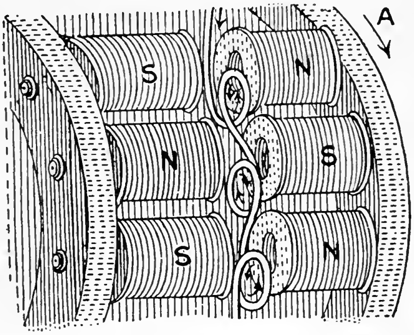


FIG. 58.

The SIEMENS alternating current dynamo (see fig. 58) has two opposing crowns of cylindrical electro-magnets, the face pole-pieces being of opposite polarity. The armature coils in fig. 58 are only indicated. The lines of force pass from pole to pole, straight across the armature space. The armature coils, in revolving, cut through a series of powerful fields, with the lines of force alternating in directions. The armature coils equal the fields in number, therefore they are equally active at any given moment. In the position shown in fig. 58 the coils are just opposite the bobbins, and the two halves of each coil are cutting lines of force all due to one pair of opposite magnets, and, therefore, all in one direction. The two E. M. F.'s induced in the two halves of the coil neutralize each other. At this moment the reversal of the current direction takes place. As the coil moves onward, the front half of each coil cuts less lines of force than the rear half, in ever increasing ratio until the coil arrives at a position midway between the two pole-pieces where the E. M. F. is a maximum, because at that instant every line of force cut by the coil is utilized, and the induced currents, flowing outward in one half and inward in the other, coincide in direction round the coil.

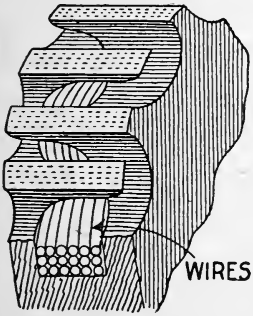


FIG. 59.

The OERLIKON type shown in fig. 59 has a stationary armature and a rotary magnet field. The latter consists of one solid disk of iron, the circumference of which is of a peculiar shape, clearly shown in the cut. The field coil is also plainly seen.

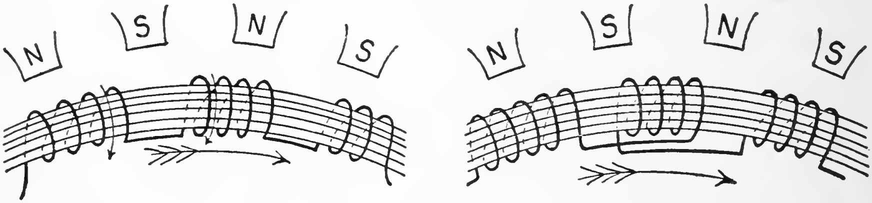


Fig. 60.

Armature of alternators

136. As in direct current dynamos, there are ring and drum armatures in alternating current machines.

Fig. 60 shows two diagrams of ring armatures, with the difference that in the one on the right the coils are wound in opposite directions, and in the other they are wound in the same direction.

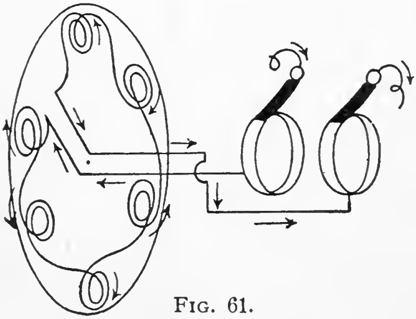


Fig. 61.

Fig. 61 shows a diagram of the connections of an alternator armature. The six coils represent the coils of the armature, and the arrows show the direction in which the current flows, from and to the collecting rings and brushes.

The connection of armature coils may be either in series or in parallel, as shown in fig. 62.

Coupling of alternators

137. Two shunt-wound continuous current dynamos of similar construction may be connected in parallel, and will work well together, if they are brought to their usual speed, and if their field excitation is adjusted so that they will gen-

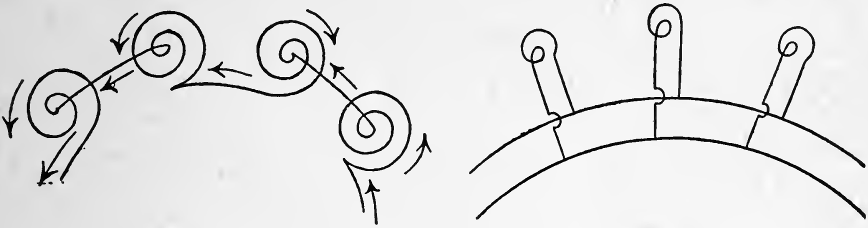


Fig. 62.

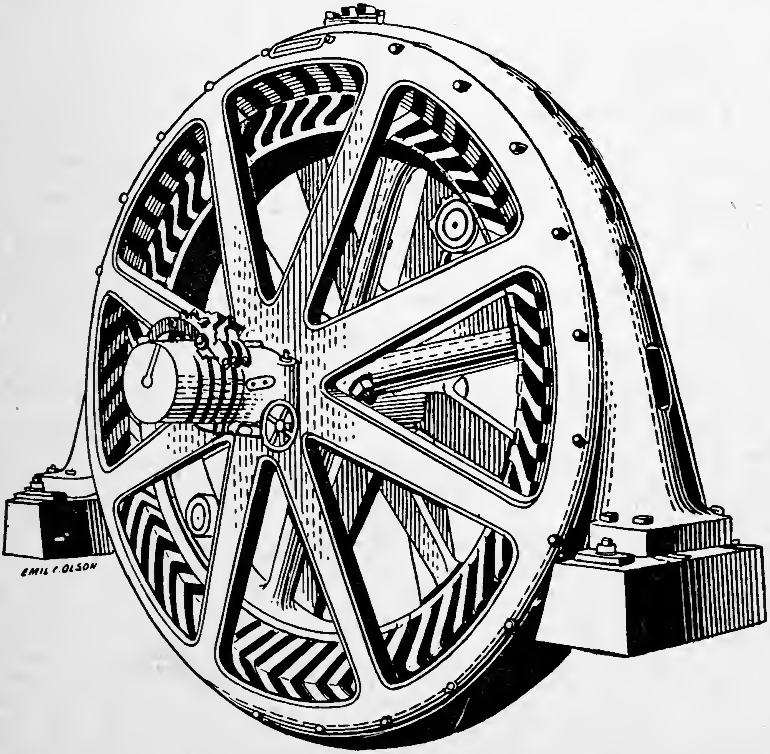


Fig. 63.—Three-phase Motor. 68 revolutions per min. 150 H. P.

erate the same pressure. The coupling of two alternators is not so simple a matter, because, besides the same pressure, two other conditions must be fulfilled: first they must be SYNCHRONIZED, that is, they must be made to have the same *frequencies* exactly, and second, the alternations must be CO-PHASAL, that is, their current loops must keep perfect step. Two well designed machines will *correct each other* and *maintain synchronism.*

Thus, two (or more) alternating-current dynamos may be joined up so as to feed a number of lamps simultaneously when required, switching out and stopping one when the other is able to meet the low demand alone. The armatures must be joined up *in parallel,* not in series, since alternators in series are not stable in operating. The machines may be driven by belts from the same shafting, or from two independent engines running at about equal speed. The latter way is generally preferred for economical reasons.

If an alternator running as a generator, is brought to *synchronism* with another, the latter will run as a motor (*synchronous motor*). But such a motor will never start itself. as a direct current motor does. It must be started by a small engine, or other means. Neither can the field magnets of the motor be excited from the alternating current circuits. For these reasons synchronous motors are not generally used.

Polyphase currents

138. In §120 the term *phase* has been explained by analogy of the tide in two channels of different nature. Now, by having two coils, one of which may be considered wound in, half way between the turns of the other, it is possible to send two alternating currents around a ring. Then, if the connections are made as in fig. 64, one wire at A and C, the other at B and D, the current waves or loops in one wire will be at their height at A and C, at the moment when the waves in the other wire are at their heights at B and D. These waves chase each other around the ring, keeping perfect step, at a distance of one quarter the circle, or 90°. This can be proved by adjusting a magnetic needle in the center, which will rotate at an even gait, following the circling motion of the magnetic field, as long as the currents are supplied.

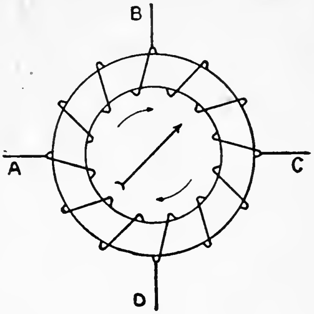


FIG. 64.

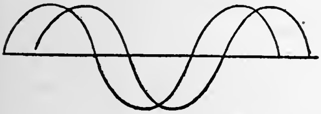


FIG. 65.

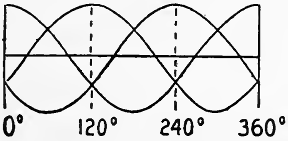


FIG. 66.

Fig. 64 shows the currents of a TWO-PHASE system in diagram.

If three separate windings (see fig. 67) are on the ring, wound so that each turn is at the distance of one third of the diameter of the ring from the corresponding turns of the other two, then the current phases differ from one another one third of the period (120°), as shown in fig. 66. Such currents are called THREE-PHASE CURRENTS.

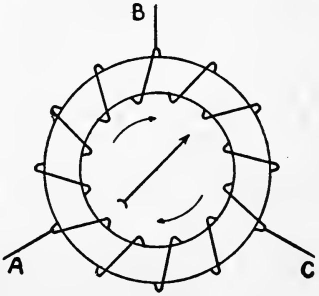


FIG. 67.

Polyphase circuits

139. Alternators designed to furnish two or three-phase currents require at least three collecting rings, if the currents generated by them are to be furnished to three wires only. If each of the currents is to be supplied to a special wire, four and six rings must be used.

If the two circuits of a two phase alternator are to be kept separate, four wires, A, B, C, D, are required. as shown in fig. 68.

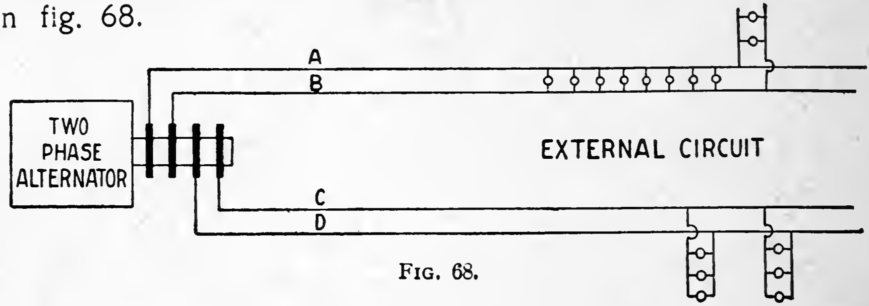


Fig. 68.

One wire may be saved by combining B and C, as shown in fig. 69. This arrangement is preferable for long distances, because of the saving in copper wire, but the chance of trouble increases. The wire B in such a case must have a cross section 41 per cent greater than it would have otherwise.

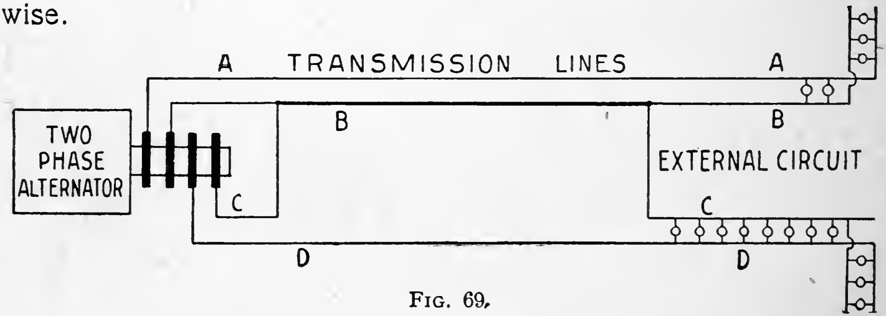


Fig. 69.

Fig. 70 is the diagram of a three-phase circuit with transformers (T_1, T_2, T_3).

Induction motor

140. An armature placed in a POLYPHASE or MULTIPHASE magnetic field will rotate at a uniform speed. The armature conductors are cut by the lines of force, by which process a current is induced in them which causes the armature to rotate. Motors operated on polyphase systems are called induction motors. They may be used as synchronous polyphase motors. It must be understood, however, that a generator and a motor cannot be synchronized *exactly,* as there will be a slight difference in phase, amounting from 1 to 5 per cent. This difference is called SLIP, and is due to self-induction of the motor.

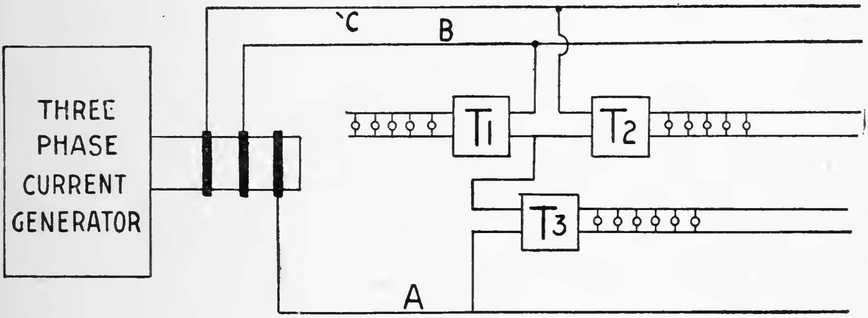


FIG. 70.

Sometimes these motors are so constructed that the part which causes the induction is stationary. In such a case it is more correct to distinguish the parts of an induction motor as *rotary and stationary, or primary and secondary.*

Induction motors are self-starting, and have a considerable torque. In practice they are arranged so that a resistance may be introduced in their secondary circuit in order to prevent too great a rush of current, and to give them full torque (see § 115) when starting.

Fig. 71 shows a diagram of power transmission by means of a three phase current.

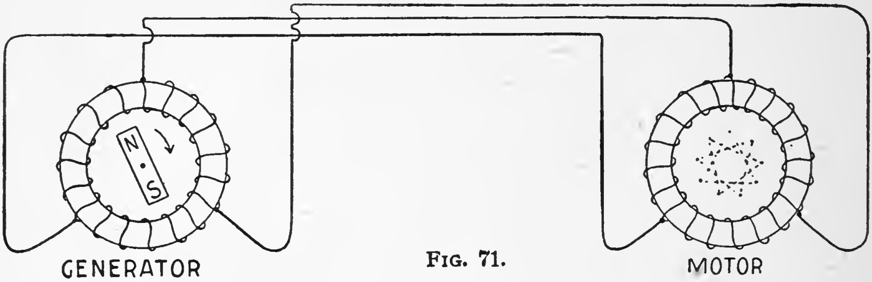


Fig. 71.

Rotary converter

141. It has been mentioned (see § 100) that the currents induced in the armature of a dynamo are alternating, when the armature is not provided with a commutator, to change them into direct currents. If there are two armature windings placed on the same core and acted upon by the same field magnets, the ends of the windings of the first armature being connected to a commutator, and those of the other to two collecting rings, alternate currents may be drawn off the collecting rings when the machine is run as a motor with direct current; or direct current may be drawn from the commutator, if the machine is run as a synchronous motor with alternate currents. For three-phase alternating currents, three collecting rings are connected to three points that are 120° apart. In a multipolar machine each pair of poles must be connected with the rings.

These machines, used as the most economical means of converting alternate currents into direct currents, or vice versa, are commonly called ROTARY CONVERTERS. When it is driven by direct current and delivers alternating current to the line, it is termed an inverted rotary converter; when so run it has features similar to that of a direct current shunt motor.

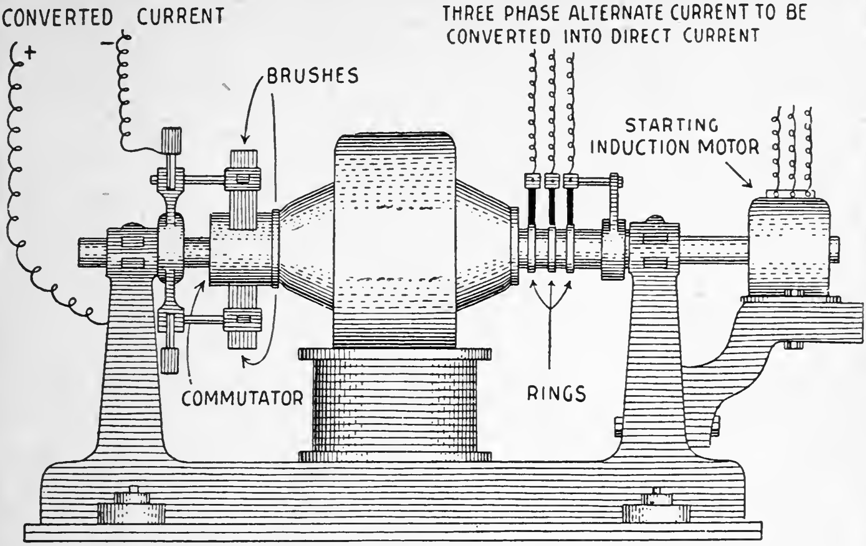


FIG. A.

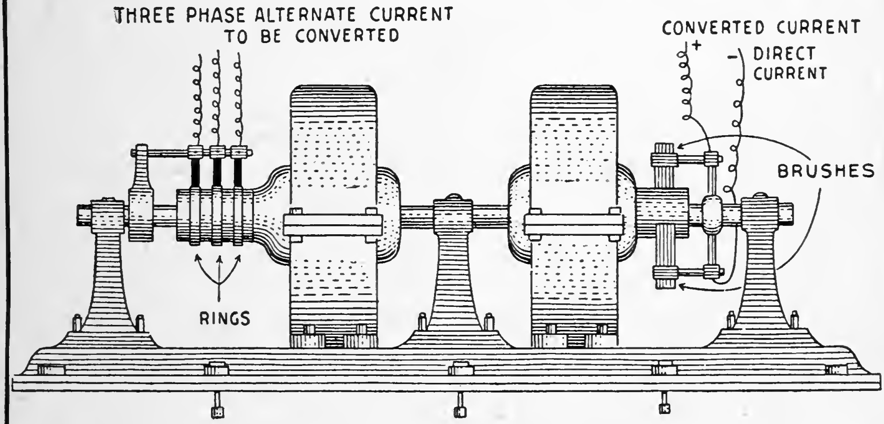


FIG. B.

Fig. 72 — ROTARY CONVERTERS.

Fig. A represents a rotary converter with single magnetic field, equipped with starting induction motor.

Fig. B shows a motor generator with two separate fields. This machine is, not improperly, called a motor generator, consisting of two direct-coupled machines, one of which is run as motor, the other as generator.

In order to secure independence of action between the motor and dynamo parts of the motor generator. the two armature windings are wound upon two separate rings. each of them being acted upon by its own field magnet.

A motor generator has the following disadvantages: It is more complicated, considerably higher in price, requires much more space, and is less efficient than a static transformer. But it gets out of order very seldom, and demands but little care.

Rotary converters are mostly used, when a direct current is to be carried cheaply over long distances. Alternate currents are generated and transmitted over the long distance to the place of use, where they are converted at will into a direct current by means of rotary converters. This arrangement is shown in fig, 73.

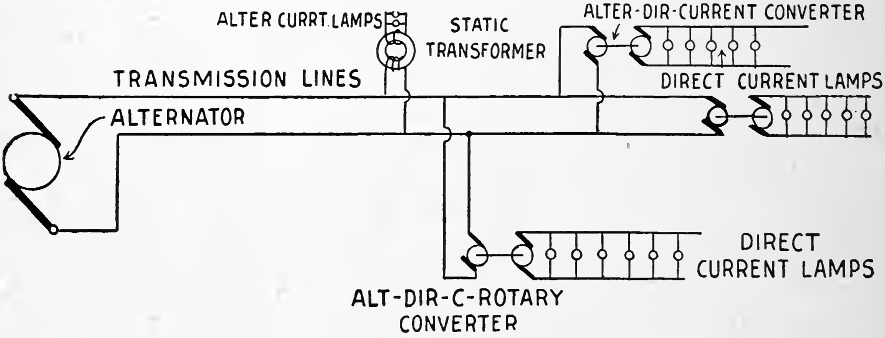
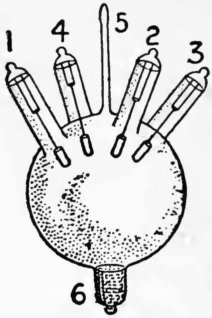


FIG. 73.

Static converter

142. An apparatus, much simpler than the rotary converters described in § 141, but doing almost the same service, is the *static converter,* invented by Cooper Hewitt, and first exhibited in London. January 9th, 1903.



Fig, 74.

The static converter, in its present form, consists of a glass globe (see fig. 74) about 8 inches in diameter, on the top of which there are four glass tubes (1, 2, 3, 4), closed at the outer ends and sealed into the globe, in which four positive iron-cup terminals are sealed. Three of these terminals (1, 2 and 3) serve as connection with the three wires of the three-phase current circuit, the fourth (4) being connected (only when the apparatus is started) for a short time to a circuit in which a "kicking" coil is inserted. At the bottom of the globe the negative terminal (6) is affixed, consisting of a glass cup filled with quicksilver which connects to the external circuit by means of a platinum wire sealed into the tube. The connection tube (5) on top of the globe serves only to exhaust the air from the globe, and is sealed off during the process of manufacture. This converter permits conversion of single phase or polyphase alternate currents into direct currents and has, with a weight of about 3 pounds, the same capacity as a rotary converter weighing about 700 pounds. A prominent advantage of this invention is the fact that there are no parts to rotate, so there is no need of supervision. Fig. 75 shows a diagram of connecting the static converter into the circuit of a three-phase current generator. The three positive electrodes connect to the terminals of the three phase current generator, the negative electrode connecting with the external circuit,

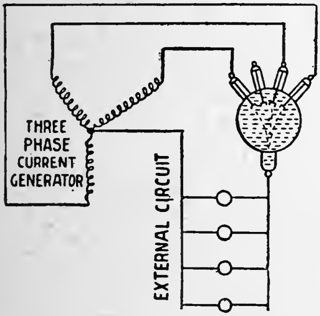


Fig. 75.

which returns back to the neutral point of the generator, When starting the converter, a current is sent first through the globe by means of terminals 4 and 6, to convert the quicksilver contained in tube 6 into vapor, filling the globe. Then terminal 4 is disconnected, and the main current is introduced through terminals 1, 2, and 3. The vapor of mercury in the globe permits the *positive* alternations of the current to flow successively from the three positive terminals 1, 2 and 3 toward the negative terminal 6 The negative alternations, owing to a peculiarity of mercury vapor, are cut and become inert.

This converter may be used for voltages ranging from 100 to 2000 volts, and several similar converters may be worked in parallel. The drop in the voltage is constant without regard to the number of lamps operated by the circuit, about 14 volts.

The loss at 140 volts is about 10 per cent; at 1000 1·4 per cent. The efficiency of this converter at 1800 volts is about 99 per cent.

Questions and Answers.

Q. What is frequency?

A. The number of double alternations per second.

Q. What frequency is common now in alternating current dynamos? A. 60 periods, or 120 alternations, per second.

Q. What is ohmic resistance?

A. It is a term used to distinguish the resistance (ohmic r.) to a steady current from the *impedance* or *virtual resistance* to simple periodic alternate currents. The latter increases with the increase in the rapidity of alternations and also depends on the form of the conductor.

CHAPTER X. — POWER STATION AND ELECTRIC RAILWAY.

Faults in machines

143. In the actual service of electrical machines there are a great number of points to be observed, to avoid mishaps and accidents. Attention is called here to the most important ones.

If a dynamo fails to generate a current, the fault may lie either in the machine or in the external circuit. In the machine it may be due to a short circuit in the armature or pole pieces, or to poor construction, or a broken wire, or a faulty position of the brushes, or a too small residual magnetism. In the outside circuit it may be due to an open switch, or a broken wire, or burnt-out fuse.

For the windings of armature and fields the best copper wire should be used. It is covered with two or three layers of raw cotton thread, which when in place, is varnished and baked. Moreover, the wires are insulated from each other and from the iron by mica, asbestos, oiled paper and other insulators. Notwithstanding the greatest care in manufacturing these armature and field windings, the insulation is broken occasionally by chafing or by heat generated by too great a current, resulting in a SHORT CIRCUIT and BURNING-OUT, especially in motors. In such a case, the current must be shut off instantly, and the necessary repairs made.

If the mica insulation of the commutator segments is injured, the defective place is most easily found by testing each pair of opposite segments by means of a small current, from a battery or other source, and a galvanometer, which will indicate the faulty spot by a greater fall of potential.

The commutator must be kept exactly cylindrical, and perfectly smooth and clean. It should be wiped with an oily rag, but must not be oiled. Flat spots on commutators are caused by heat, too much end play, a loose commutator, bad belt splice, heavy short circuits on the lines, brushes not being set exactly to the diameter of the commutator, copper brushes having been welded to their holders, (caused by not being pressed firmly enough to the commutator), the brush ends being burnt off, or by a heavy overload. The whole machine must be kept scrupulously clean and dry, as dirt and dampness, even in the smallest quantities, at once render the insulation imperfect.

When an arc on the commutator indicates an open circuit (break in the armature winding), a temporary repairing is done by connecting the two commutator bars and lead-wires where the arc occurs.

A short-circuited armature becomes heated, but a short-circuited field does not. In the armature each turn produces a constant E. M. F. ; in the field coil the voltage decreases with the resistance.

If one field coil is short-circuited, it will almost certainly burn out its mate, because four times the amount of heat will pass through the coil in good condition.

Practical points

144. When a compound generator is to be put on an already live circuit, four distinct points must be observed:

First: the generator must be at its normal speed.

Second: the rheostat in the shunt windings must be adjusted so as to give the same voltage between the terminals of the generator as in the line.

Third: The equalizer switch and one of the main switches must be thrown in first, and then the second main switch.

Fourth: the ammeter of the generator must be watched, and the field rheostat adjusted, so as to make it take its proper share of the load.

If a generator is thrown in parallel with another generator, before its voltage is up to the same point, it will not do its proper work, and it may even be run as a motor by the stronger current of the circuit. If this happens, the resistance should be thrown out of this machine.

When shutting down a generator, running in parallel, these points must be observed:

First: cut down its load, by throwing in resistance in the magnetic field with the rheostat.

Second: open the circuit breaker and then the main switches.

Third: slow down and stop the engine.

If the shunt circuit is broken, and the other machines are not instantly cut off by their fuses melting, the armatures and series windings of one or more of the generators will be burnt out.

If the bearings get heated, the load should be lightened, and if belts are used, they should be slackened, the box caps slightly loosened, and more oil put on the bearings, before the machine is shut down. If these remedies fail, shut down. If the machine is belted, the belt should be taken off as quickly as possible, the box caps taken off and a flow of oil kept on the journals while the machine is still revolving; this prevents sticking. Then the linings of the bearings should be taken out and allowed to cool in the open air.

When a generator is shut down, great care should be taken that the brushes are lifted off the commutator, and that all switches and circuit-breakers are open.

The fault most difficult to find about a generator is a short circuit in the armature that takes place only when the armature is revolving, but cannot be discovered by the detector when the machine is standing still. It is generally due to two consecutive armature windings being forced together by centrifugal force, or magnetic drag, just at a point where a fault in the insulation exists.

If generators have been standing idle for some time, the armature should be thoroughly dried in a regular drying oven, if possible, so as to remove any moisture that may have settled in the windings, as dampness will most likely cause a short circuit, and burn out the armature winding. The same result may be reached by putting all the resistance of the field rheostat in series with a shunt winding, and slowly running the generator on an open circuit, so as to attain from a third to half the normal voltage at the terminals, for some hours. When a current from other sources is available, the armatures can be fixed so as to prevent them from rotating, a heavy resistance put in series with them, and a small current run into them, as well as through the field windings.

In putting generators in parallel, where the switching arrangements of some electric companies are employed the equalizing switch is first closed, then the positive switch is thrown in. This throws the series winding of the field into parallel with the generator already running. Then the field switch is closed. This puts the shunt-winding of the field in parallel on the circuit. The generator is then run up to full speed, and when the voltage at its terminals is equal to the voltage of the line, the negative switch is closed.

The switchboard

145. From the generators the electric current passes to the switchboard, through conducting cables which connect with the main switchboard conductors, commonly called *omnibus bars,* or BUS BARS. Here are also to be found the required switches and meters, starting box, rheostats and circuit breakers. See cut on page 191.

A switchboard must be so placed as to reduce to a minimum the danger of communicating fire to any combustible material. It should be one foot from the floor and three feet from the ceiling. It should be made of non-combustible material, or of a framework of hardwood, filled in to prevent absorption of moisture.

The meters on the switchboard serve a double purpose, to help the engineer regulate the machinery according to the service required, and to furnish the manager with the necessary facts from which to calculate the expense and the value of the plant's work. It is possible to figure the cost in labor, fuel, oil and other items, of every kilowatt hour generated. It is also possible to keep an approximatively accurate account of the output of the plant, by entering every fifteen minutes, in a properly arranged book, the readings of the feeder amperemeters and the volt meters on the switchboard. Or these instruments may be arranged to make their own records. Fig. 76 shows a one day's automatic record of an amperemeter. The heavy irregular line indicates the strength of the current during the 24 hours, each hour being divided into 4 quarters. Each interval between two adjacent concentric circles signifies one ampere. A voltmeter record is arranged in the same way, except that the distance between two circles represents two volts. Exact voltmeter records are of the greatest importance.

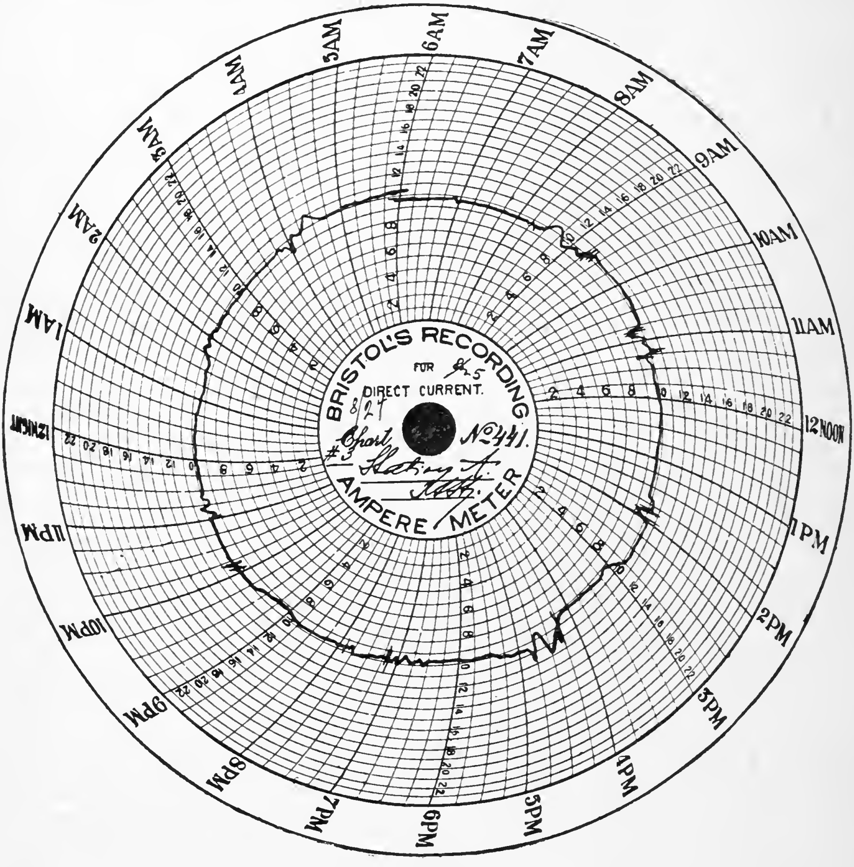
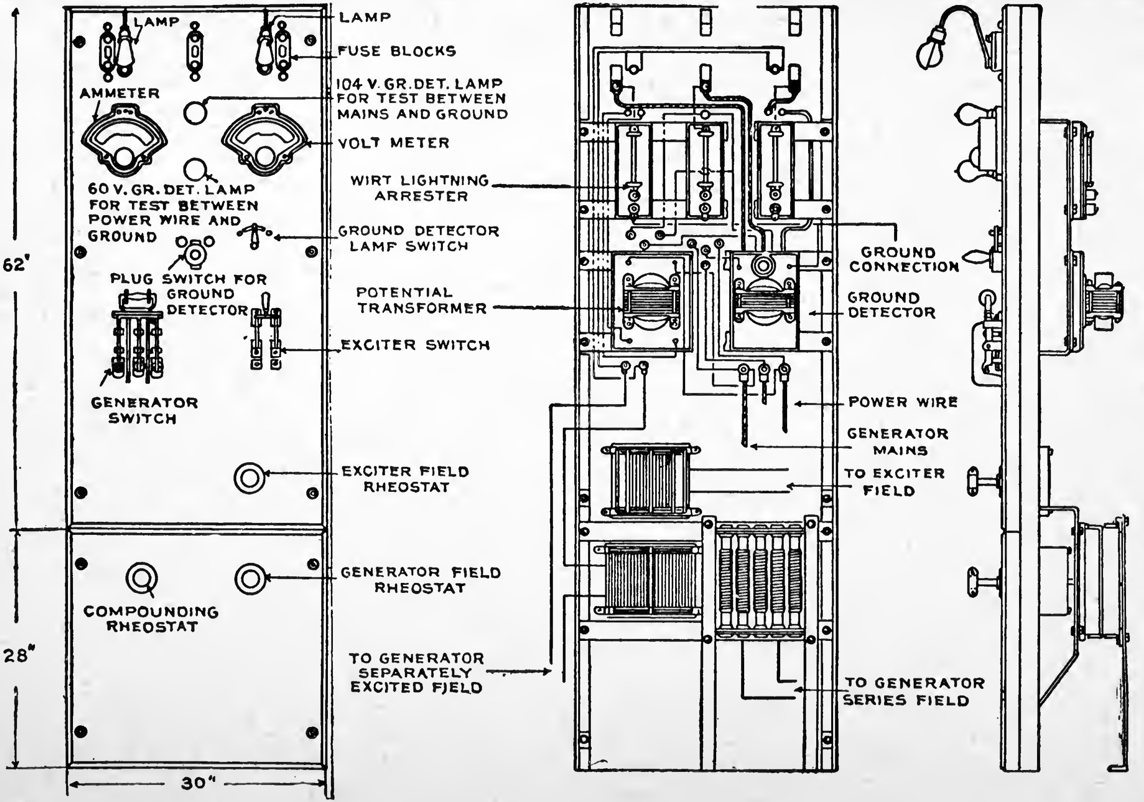


Fig. 76.



Front View. Rear View. Side View.

Fig. 77. — The Switchboard.

The circuit breaker

146. The CIRCUIT BREAKER is a safety device, which automatically opens a circuit when the current exceeds a given value. The excessive current sets up a magnetic force which overcomes the power of a spring holding two contact pieces together, and their contact is broken. See fig. 78.

When the contact is broken, the inertia of the current causes a destructive sparking between the contact points to obviate which several different means are employed. One is the *magnetic blowout,* consisting of an electro-magnet so designed and placed that one of the extensions of a divided pole-piece is fixed

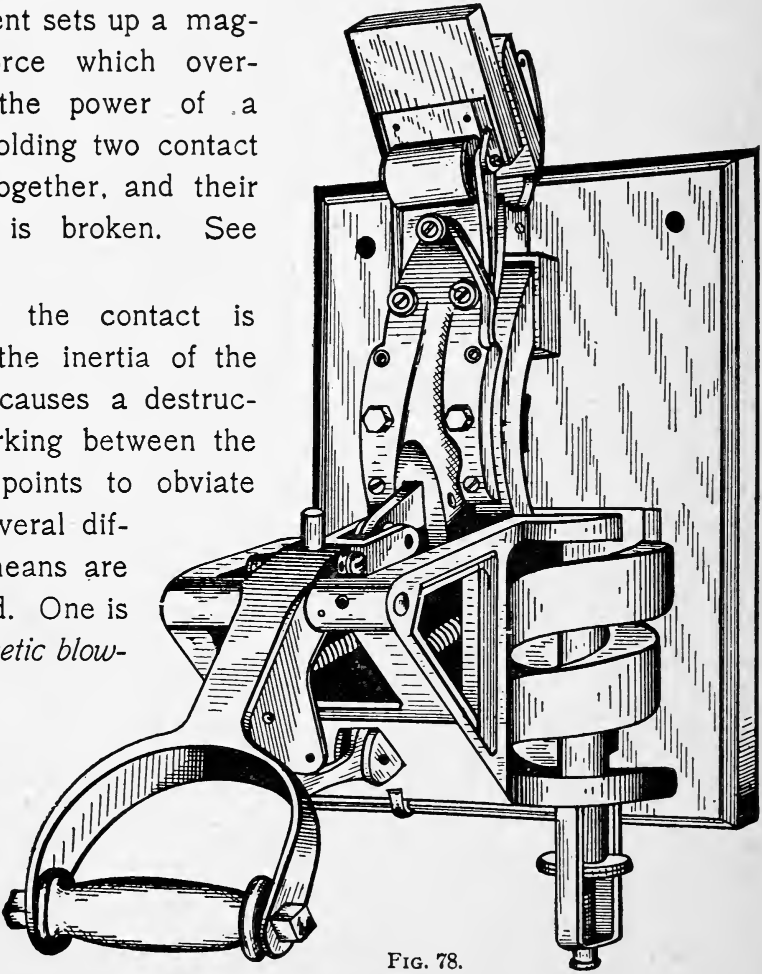


FIG. 78.

opposite every point where contact has to be broken. If the magnetic lines of force are projected at right angles to the spark current, the spark is deflected and practically blown out.

Other ways of avoiding serious damage are: to let the sparking take place between small *contact-tips* of copper, that can be easily replaced; or to break up the spark into a number of small sparks, passing at various points, all connected in series.

Switches

147. The controlling of high-pressure currents in large quantities is a serious matter, and the switches are one of the most important parts of a large alternating current station. In the most modern plants, the switch contacts are broken in oil, each switch being surrounded by a fireproof brick casing and worked by the aid of a motor running on an auxiliary circuit controlled by the switchboard attendant. No high voltage current is brought to the switchboard. In order that any section may be insulated in case of a short-circuit, the bus-bars are divided into sections.

A switch, in order to functionate well, should have metallic parts of sufficient massiveness to carry the required current without opposing any noticeable resistance; the contact surfaces must be of ample area, firmly pressed together, and rubbing against each other, not merely touching. It is not well to make the lever-spindle a part of the circuit, as it may become insulated through dirt. The best switch is one whose arm is forced between two contact blocks, joining them. But in breaking the circuit, the arm must be so far removed, by a strong spring, from the contact blocks that a spark or arc cannot be set up; as this might cause a fire, and would certainly soon injure the switch. The base of the apparatus should be of pure slate or some equally good insulating material, that does not warp, or condense moisture readily. The wires to be fastened to the switch should be soldered into thimbles or sockets, which are then bolted to the contact blocks. Fig. 79 represents a section of a standard single knife switch designed for 50 amperes.

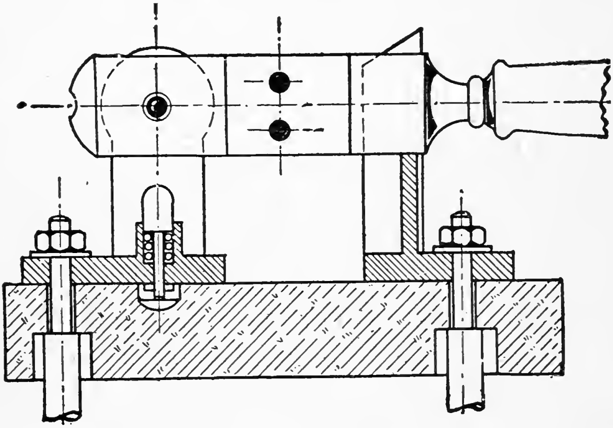


Fig. 79.

Cut outs

148. A cut-out is a device to prevent damage to the apparatus or to the building in which it is located, from an unduly strong current. There are two kinds of cut-outs: those actuated by an electro-magnet, and those in which a current of a given strength melts or *fuses* a piece of wire or foil. The best material for a FUSE is tin, because it is very durable, and melts at so low a temperature. 2359 C, that it cannot kindle a fire. The fuse must be long enough so that the heat generated in it by the excessive current will not too readily be conducted or radiated away by the screws holding its terminals in place. The size of a fuse, in general, depends on the size of the smallest conductor it is to protect.

The fuse is generally placed within, or at least mounted on, glazed porcelain so as to avoid any danger from the melted metal. For heavy currents a number of small fuses in parallel are frequently used. In spite of every precaution, a fuse is necessarily always a source of danger, and is, at best, a clumsy device. They should not be used any more than absolutely necessary.

A MAGNETIC CUT-OUT consists of a solenoid and an armature to which a horseshoe-shaped copper rod is attached, the two ends of which are immersed in two cups of mercury, thus completing the circuit. When the current strength rises beyond a fixed point, the armature is drawn into the solenoid, lifting the copper rod out of the mercury, breaking the circuit. Circuit breaker described in §146 serves the same purpose.

The starting box

149. The best type of starting box has cut-out devices for both excessive current and no current. The starting lever returns automatically to the cut-out position, whenever the current attains a dangerous strength, or falls to zero. The former takes place when the motor is overloaded, and when the difference of potential becomes very low; when the current is broken, either purposely or by the blowing of a fuse; and when the magnetic circuit is broken.

Lightning arrester

150. Each wire of every overhead circuit must have a lightning arrester near its connection with the station; and also at intervals over the whole system, in such numbers and at such places as to prevent ordinary discharges from entering (over the wires) buildings connected to the lines. A lightning arrester (see diagram, fig. 80) must be mounted on a non-combustible base, and so constructed as not to maintain an arc after the discharge has passed. It must have no moving parts, must be readily accessible, away from combustible materials, and as near as practicable to the building it protects. All sharp bends, coils and kinks in the wires between the arrester and the outdoor lines must be avoided as far as possible. It must be connected with the ground directly (not by a gas pipe), straight and permanently, by metallic strips or wires of a conductivity not less than that of a No. 6 B and S gauge copper wire. The ground wires must not be put into iron pipes, as these would tend to impede the discharge. Choke coils are often introduced between the arresters and the dynamo.

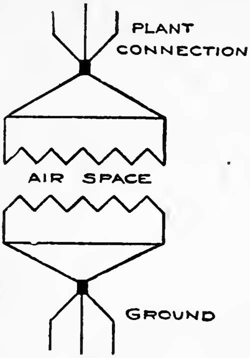
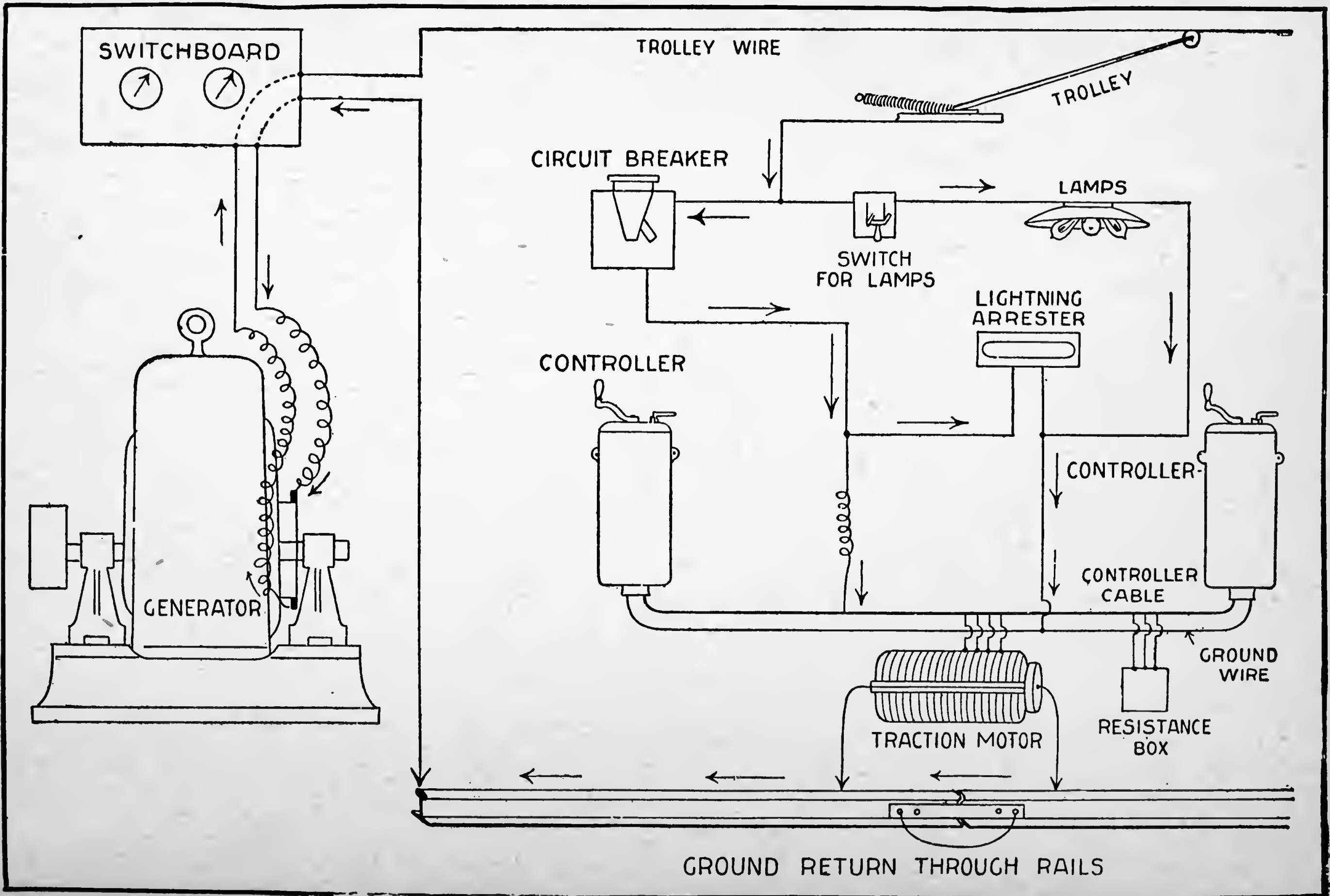


FIG. 80.

Electric railway

151. Siemens and Halske built the first short electric railway, in Berlin 1879. From that time until 1888 many scientists and engineers studied the problem, before a really serviceable electric motor car could be constructed. But since then, numerous successful systems of electric traction have been devised. The electric service therefore has nearly replaced all others in street cars. The plate opposite shows the electrically important parts of an electric motor car, and its connections with the dynamo, in diagram. Fig. 81 is a diagram of a street railway line.

The E. M. F. commonly used on electric railways is 600 volts. A shock from such a wire is not deadly to man


SWITCHBOARD
TROLLEY WIRE
TROLLEY
CIRCUIT BREAKER
LAMPS
SWITCH FOR LAMPS
LIGHTNING ARRESTER
CONTROLLER
CONTROLLER
GENERATOR
CONTROLLER CABLE
GROUND WIRE
TRACTION MOTOR
RESISTANCE BOX
GROUND RETURN THROUGH RAILS

and this pressure may therefore be carried in bare overhead wires. If the system is very extensive, as in large cities, high pressure alternating currents are generally employed, which are then, at sub-stations, converted by means of rotary converters to direct current.

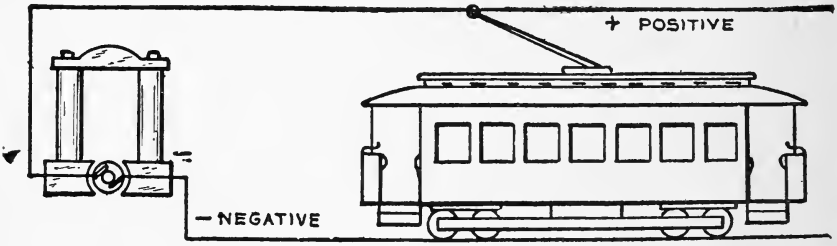


FIG. 81.

Most traction motors are designed for direct currents. They are iron clad to protect them from dirt and especially from the water splashed by the wheels in rainy weather, The armatures are of the type shown in fig. 48, Two motors are usually combined on a heavy truck, one geared to each axle; heavy cars in large cities at present usually are equipped with four motors. In order to secure a firm grip on the rails, as well as to render the whole structure strong and able to stand the exceedingly hard service, the truck, wheels and motors are built very heavy. Short cars have one truck with four wheels, long cars have two such trucks.

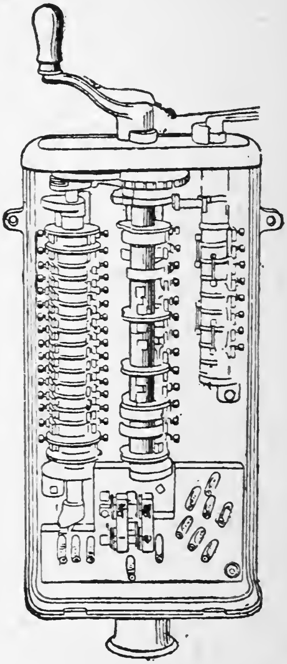
The trolley

152. The overhead trolley wire far surpasses all other means for transmission in electric railways for convenience and inexpensiveness, although the numerous poles and wires are not sightly and may be a hindrance to the fire department in the case of a fire. The path for the returning current is through the rails, the ends of which are electrically joined together by BONDS, short pieces of thick copper wire, riveted into holes provided for this purpose. (See p. 197.) Or, the two ends of each rail are connected by bonds to a copper wire lying between the rails. The conductor consists of a hard drawn copper wire, over a third of an inch in diameter, suspended at frequent points throughout its length from insulators which in their turn are supported either from horizontal arms projecting at right angles from poles erected at the side or middle of the roadway, or from *span-wires,* stranded galvanized iron or steel wire rope stretched between poles, one on each side of the road. Connection between the wire and the car is made by means of the trolley, a deeply grooved, insulated wheel of brass or gun-metal, pressed against the wire by a powerful spring. A flat spring rubs against the wheel, and passes the current to an insulated wire which runs inside the hollow trolley pole to the controlling switch. (see fig. 156.)

Other systems are the underground trolley or plough, the storage battery, and third-rail systems. In the latter, a shoe sliding on a third rail takes from it the current and transmits it to the controller and motors. It may be raised from the rail by a short lever in the controller room, thus breaking the circuit.

The controller

153. The CONTROLLER (see fig. 82) is a resistance box, put in series with the motors, which are joined in parallel. When the car is to be started, a slight turn of the main lever switches the car into the circuit with high resistance. By turning the lever further, this resistance is gradually cut out, as the speed of the car is to be increased. Another switch on the apparatus is used for breaking the circuit, or reversing the motors. In another type the speed is controlled by having the motor fields wound in three or more separate divisions and by connecting these divisions in various combinations: at starting all in series, at full speed all in parallel, and between these two points in five or six other intermediate arrangements.



FIG, 82.

As the torque (see § 115) at starting is considerable in motor cars, and as it may easily happen that a number of cars on a line start at the same moment, the sudden increase in the load, or current required, at such a moment may be very great. This increase, however, has been diminished by arranging the controller in such a way that the two motors of a car at starting are in series. In this way they take but half the current they would otherwise require.

Heavy service

154. Electric locomotives are used to some extent on elevated roads, in long tunnels, and in many other cases where the smoke of ordinary steam engines is objectionable, or where great power is required and water power is to be had cheaply. Notable examples are the elevated railroads of New York and Berlin, the tunnels under the cities of Chicago and Baltimore, the underground Central London Ry., the South London Ry., Eng., and on the New York, New Haven and Hartford Ry. in this country, with an operating voltage of 11,000 volts.

Several firms have built electric locomotives capable of pulling a heavy passenger train over 100 miles an hour, but under present conditions, this speed would involve too great a danger on surface lines, while an elevated track would have to be constructed of solid masonry to stand the strain.

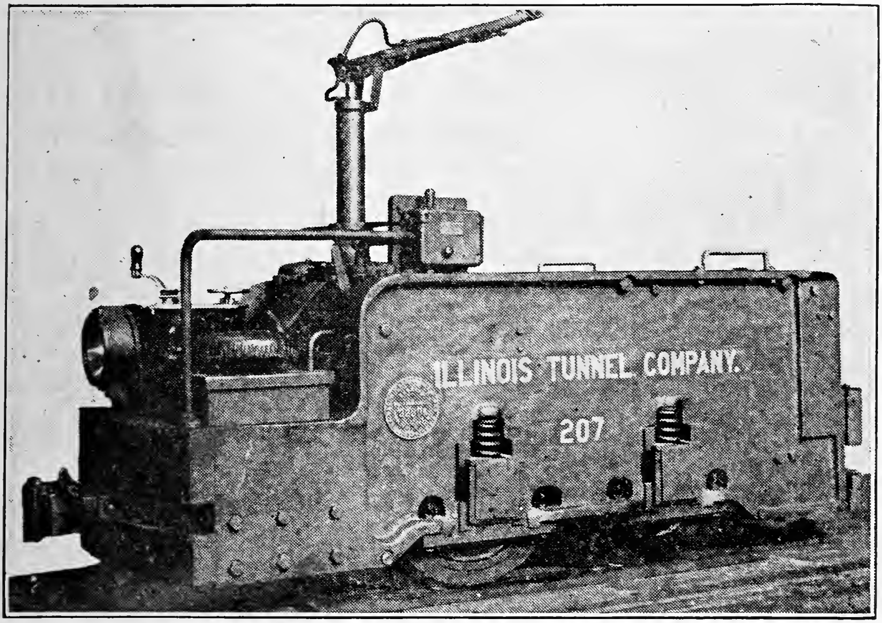


FIG. 83.

Fig. 83 shows a Baldwin-Westinghouse electric locomotive, for tunnel service. Dimensions: Gauge, 2 ft; motors, two, 220 volts; wheel base, 2 ft. 7 ins; diameter of drivers, 28 ins.; journals, $3\frac{3}{4} \times 5$ ins.; width, 3 ft. 5 ins.; height, 3 ft. 6 ins.; length 9 ft. 3 ins.: weight, 11,000 lbs.

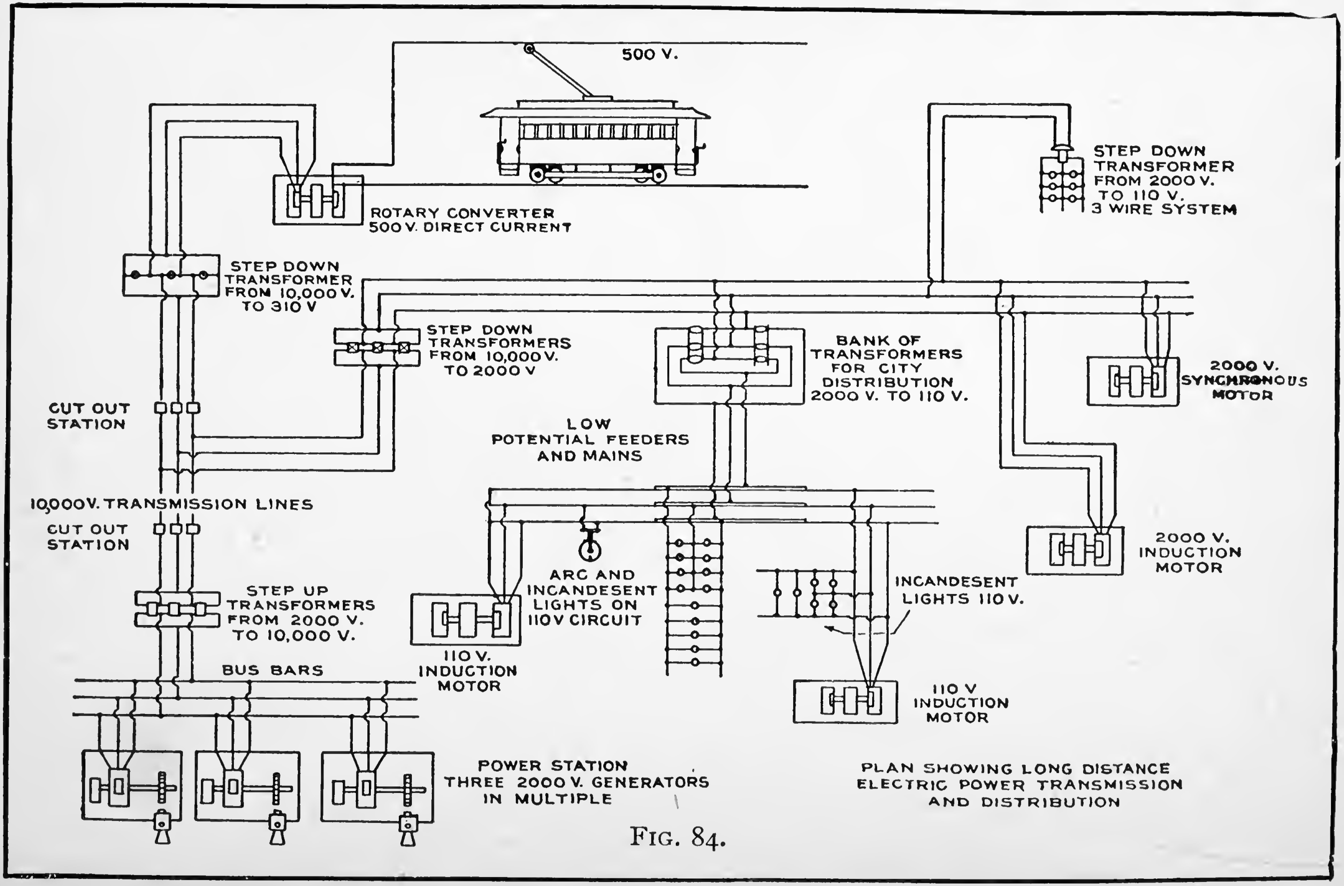

500 V.
ROTARY CONVERTER 500 V. DIRECT CURRENT
STEP DOWN TRANSFORMER FROM 2000 V. TO 110 V. 3 WIRE SYSTEM
STEP DOWN TRANSFORMER FROM 10,000 V. TO 310 V
STEP DOWN TRANSFORMERS FROM 10,000 V. TO 2000 V
BANK OF TRANSFORMERS FOR CITY DISTRIBUTION 2000 V. TO 110 V.
2000 V. SYNCHRONOUS MOTOR
CUT OUT STATION
LOW POTENTIAL FEEDERS AND MAINS
10,000 V. TRANSMISSION LINES
CUT OUT STATION
2000 V. INDUCTION MOTOR
ARC AND INCANDESENT LIGHTS ON 110 V CIRCUIT
INCANDESENT LIGHTS 110 V.
STEP UP TRANSFORMERS FROM 2000 V. TO 10,000 V.
110 V. INDUCTION MOTOR
BUS BARS
110 V INDUCTION MOTOR
POWER STATION THREE 2000 V. GENERATORS IN MULTIPLE
PLAN SHOWING LONG DISTANCE ELECTRIC POWER TRANSMISSION AND DISTRIBUTION

FIG. 84.

CHAPTER XI.—TRANSMISSION AND DISTRIBUTION.

Two-wire system

155. The distribution of a light constant current does not offer any difficulties, but where a constant potential is required, as in a set of lamps, the problem may indeed be a difficult one. Usually, as shown in § 128, a small current at high pressure is transmitted to points where, by means of transformers, the pressure is reduced to the desired values, But this system demands a very expensive insulation, and a constant running of dynamos, and besides, the iron loss by eddy currents, hysteresis and heating in the transformers and the mains is the same, whether the secondary circuit is at no load or at full load. Small as this loss may be in itself, it amounts to a considerable waste in the course of a day.

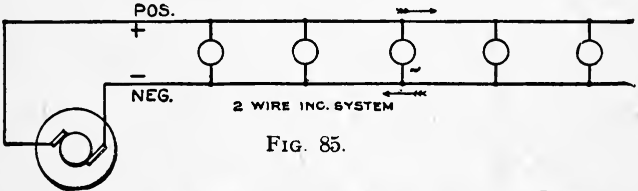


FIG. 85.

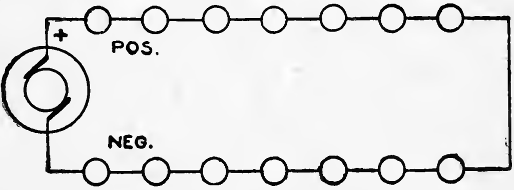


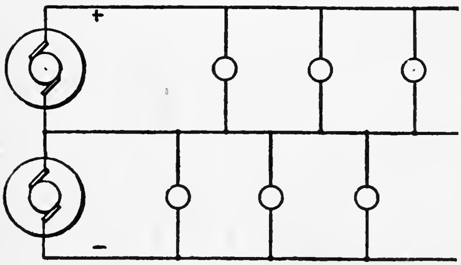
FIG. 86.

Fig. 85 shows a diagram of a two-wire system of 110 volt incandescent lamps, in parallel, supplied by a direct current dynamo. Fig. 86 is a diagram of the same system with lamps in series.

If the continuous current is led directly from the dynamo to a number of lamps joined in parallel, it is impossible to regulate the difference of potential. The nearest lamp will have a higher difference than all the others, and the farthest lamp will have a lower one than all the others. Thus it would become necessary to use different types of lamp, and even such an arrangement would not work, unless all the lamps were burning all the time. One way out of this difficulty would be to have as many wires as lamps, or to use a smaller wire for each following lamp. Another method is to have subsidiary feeders, connecting the dynamo with various points in the circuit directly. The regulation of the pressure is made possible in such case by thin *pilot wires,* connecting the nearest and the most distant lamp terminals with a voltmeter in the power station. Usually, one or more storage batteries, joined in parallel with the dynamo, are switched in or out temporarily, when the voltmeter indicates a fall or rise of potential

Three-wire system

156. Not more than two incandescent lamps are generally placed in series, because the breaking of one filament in a set would extinguish all the lamps of that set. The employment of groups of two lamps in series is made convenient by the THREE-WIRE SYSTEM, in which two equal dynamos are used, joined in series, so that the positive terminal of one is joined by the positive main conductor and the negative terminal of the other is connected to the negative main. The lamps are placed in groups of two in series across the two



THREE WIRE SYSTEM

FG. 87

mains, and a thinner third wire runs from the junction of the two dynamos across the junctions of each group of two lamps. See fig. 87.

When the number of lamps on both sides of the third wire is equal, there will be no current either way in the third wire. If one lamp is cut out on the positive wire side, the potential will fall in the third wire, because the resistance between the positive wire and third wire becomes greater. As the potential at the junction of the two dynamos has remained unaltered, a current will flow from that point through the third wire, supplying the extra lamp on the negative side. On the other hand, if a lamp is cut out on the negative side, the potential of the third wire is raised, and a current will flow toward the junction of the two dynamos. If lamps are burning on one side only, and none on the other side, the dynamo on the other side will do no work, while the neutral wire will act as positive or negative main, according as the working dynamo is connected to the negative or positive main wire.

When the same number of lamps is supplied on both sides, the system is said to be *balanced.* In such a case the third wire may be quite small. The less the system is balanced, the larger must be the third wire. It should be of the same size as the mains, when the whole set of lamps on one side is cut out, because in that event it must carry the whole current. Pilot wires are used, connecting each point to two separate voltmeters.

This system amounts practically to connecting the lamps in series, and still making them independent of each other. It may be extended to *five wires,* with 4 dynamos supplying groups of 4 lamps in series, but such methods of distribution are economical only where the area to be supplied is very extensive.

One secondary battery may also be used, connected in series with one of the dynamos, in order to dispense with the other generator, or two batteries together with the dynamos, connected in parallel with them. Or subsidiary machines, called BOOSTERS, are employed to maintain the pressure in the feeders, or at certain points. See § 131.

The wire

157. In this country uniformity was brought into the rules for wires, insulation, etc., by the National Electrical Code of 1903, the result of the united efforts of the various insurance, electrical, architectural and allied interests. This code contains detailed rules and requirements for the installation of electric wiring and apparatus, and every electrician should possess a copy.

In overcoming the resistance of a conductor electrical power is wasted, which means expense. Economy therefore demands a reduction of resistance to a minimum. But as enlarging the size of wire, also, means expense, it is acknowledged as a rule, that the size of a conductor must not be so large that the additional expense will more than balance the cost of the power saved. The cost of the energy wasted in heating the conductors should not be more than the interest on their original cost. On the other hand, a conductor should never be so small that the maximum current to be transmitted can appreciably raise its temperature.

If one of two round wires has double the diameter of the other, its sectional area is four times as large, and so is its conductivity, but its circumference (surface) is only doubled. This means that the heat generated will be quadrupled, if a current four times as great passes, while the radiation is only doubled. Consequently the thicker wire will show a higher temperature. As the presence of any foreign matter increases the resistance of a conductor enormously, it is economical to use the purest copper obtainable.

Proper size of wire

158. A pure copper wire, one foot long, and of a cross section of one circular mil has a resistance of about 10·8 ohms at 75° F. (See § 56.) Consequently the resistance of any pure copper wire may be expressed by the formula

$R = 10{\cdot}8\ L \div C.\ M.$ or, in words,

RULE 42. –The resistance of a pure copper wire is equal to 10·6 times its length in feet, divided by its cross section in circular mils.

The drop in pressure (loss of volts, V) of a current I in a conductor with the resistance R, according to Ohm's
law is $V = R\ I$
therefore, $V = 10{\cdot}8\ L\ I \div C.\ M.$
and $C.\ M. = 10{\cdot}8\ L\ I \div V$ or, in words:

RULE 43.—The circular mils in the cross section of a pure copper wire must equal the specific resistance times the length in feet times the current in amperes, divided by the drop in volts.

This *drop* is determined by the pressure at the source (dynamo or battery,) and that percentage of pressure which may reasonably be lost in transmitting. If the pressure at the dynamo is 150 volts, and the loss is 10 per cent, then the drop is 15 volts.

(Continued on page 210.)

PROPERTIES OF BARE COPPER WIRE.

Brown & Sharpe Gauge.						Birmingham or Stubs Gauge.
Number.	Diameter in parts of an inch.	Diameter in mils.	Area in circular mils.	Weight in pounds per 1000 feet.	Resistance in ohms per 1000 ft. at 60° F.	Diameter in mils.
0000	.46	460.	211 600	624.	.048	454
000	.4096	409.6	167 800	546.	.061	425
00	.3648	364.8	133 100	437.	.076	380
0	.3249	324.9	105 500	350.	.096	340
1	.2893	289.3	83 690	272.	.122	300
2	.2576	257.6	66 370	244.	.153	284
3	.2294	229.4	52 630	203.	.194	259
4	.2043	204.3	41 740	172.	.245	238
5	.1819	181.9	33 100	146.	.307	220
6	.1620	162.	26 250	124.	.388	203
7	.1443	144.3	20 820	98.	.491	180
8	.1285	128.5	16 510	82.	.621	165
9	.1144	114.4	13 090	66.	.783	148
10	.1019	101.9	10 380	54.	.979	134
11	.0907	90.74	8 243	43.	1.229	120
12	.0808	80.81	6 530	35.	1.552	109
13	.072	71.96	5 178	27.	1.964	95
14	.0641	64.08	4 107	21.	2.485	83
15	.0571	57.07	3 257	15.	3.133	72
16	.0508	50.82	2 583	12.	3.914	65
17	.0453	45.26	2 048	10.	5.028	58
18	.0403	40.3	1 624	7.3	6.363	49
19	.0359	35.89	1 288	5.3	7.855	42
20	.032	31.96	1 022	3.7	9.942	35
21	.0285	28.46	810 1	3.1	12.53	32
22	.0253	25.35	642 4	2.4	15.9	28
23	.0225	22.57	509 5	1.9	19.93	25
24	.0201	20.1	404	1.5	25.2	22
25	.0179	17.9	320 4	1.2	31.77	20
26	.0159	15.94	259 8	1.0	40.27	18
27	.0142	14.2	201 5	0.7	50.49	16
28	.0126	12.64	159.8	0.6	64.13	14
29	.0113	11.26	126.7	0.51	79.73	13
30	.01	10.03	100 5	0.43	101.8	12
31	.0089	8.93	79 7	0.30	128.5	10
32	.0079	7.95	63.21	0.24	159.1	9

In studying the table on page 208 it will be seen that the weight and area about double with every three numbers. For instance, No. 11 weighs 43 lbs. per 1,000 feet, No. 8 weighs 82, No. 5 100, No. 2 244, No. 00 437.

TABLE OF SAFE CARRYING CAPACITY OF INTERIOR WIRES.

Size of Wire, B. & S. Gauge.	Circular Mills.	Current in Amperes.	
		Rubber Insulation.	Other Insulations.
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
300,000 CM.	300,000	270	400
500,000 CM.	500,000	390	590
1,000,000 CM.	1,000,000	650	1,000
2,000,000 CM.	2,000,000	1,050	1,670

Wire smaller than No. 14 is never used except for wiring metal fixtures of incandescent lamps.

For aluminum wire the safe carrying capacity is 84 per cent. of that in the above table.

EXAMPLE 68.

A current of 80 amperes is to be transmitted over a wire 800 feet long with a drop of 10 volts in pressure. What size of wire is required?

C. M. $= 10{\cdot}8 \times 800 \times 80 \div 10 = 69{,}120$ According to the table on page 208, a number 2 wire, *B* and *S* gauge. Ans.

EXAMPLE 69.

Two arc lamps connected in parallel require 6 amperes each at a pressure of 90 volts. The positive and negative wire are each 2500 feet long. The voltage at the dynamo terminals is 95 volts. What size of wire is required?

C. M. $= 10{\cdot}8 \times 5000 \times 12 \div 5 = 129{,}600$ According to the table on page 208, a number 00 wire, *B* and *S* gauge. Ans.

RULE 44.— The cross section of a wire is in inverse proportion to the square of the pressure.

Explanation: The weight of copper required to supply, at a fixed percentage loss of pressure, a given number of 100 volt lamps, will supply *four* times as many lamps at *double* the pressure and the same distance. And at a pressure of 300 volts, the same wire will supply *nine* times as many lamps.

Wire tests

159. *Hard-drawn copper wire* is subjected to a double test, that of bending and that of twisting. It must be capable of being wrapped in six turns around wire of its own diameter, unwrapped, and again wrapped in the same manner and direction, without breaking. A piece of say six inches is gripped between two vises, one of which revolves at a speed not exceeding one revolution per second, and each wire of a certain diameter must stand a given number of twists without breaking. An ink mark the length of the wire shows in a spiral on the twisted wire, indicating the number of twists.

Galvanized iron telegraph wire must be soft and pliable, capable of elongating 15 per cent without breaking. It must not break under a strain less than two and one half times its weight in pounds per mile. In the test for ductility, a piece of six inches must stand being twisted between two vises 15 revolutions without breaking. At 68° *F.*, the electrical resistance in ohms must not be greater than the quotient arrived at by dividing the constant number 4800 by the weight of the wire in pounds per mile. For each degree *F.* above or below 68°, the coefficient ·003 is allowed. The galvanizing is tested as follows: The wire is plunged into a saturated solution of sulphate of copper for one minute, then taken out and wiped clean. This is done four times. If the wire has a copper color after the fourth time, it is a proof that the iron is exposed and that the zinc was too thin. The wire must show black.

Insulation

160. *An electric current returns to its source by the easiest possible path,* or *along the line of least resistance.*

The ground, whether earth or lake or sea, always affords an easy and the shortest path back to the source, and in order to compel an electric current to flow through all the parts of the circuit in undiminished

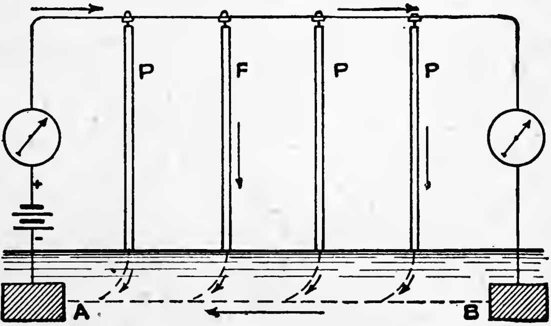


FIG. 88.

force, provision must be made against any portion of it taking a *short circuit,* that is returning to its source through the ground. In fig. 88 imperfect insulation of a telephone or telegraph conductor causes portions of the current to *short-circuit* down the poles P P P, and return to the source through ground plate A.

It might be argued that the expense of the negative wire could be saved by connecting the end of the positive wire to the ground, and likewise the negative terminal of the dynamo or battery, as shown in the diagram. It is done in telegraphs and other apparatus where a very small current is required. A ground plate buried in the earth is connected with the positive wire and another with the negative dynamo brush. But where a large current or a very high pressure is employed in buildings and must be kept under constant control, nothing is safe except an arrangement by which every part of the entire circuit can be perfectly watched and easily reached.

All conductors exposed to possible contact with the ground, directly, or indirectly through a good conductor, must be insulated, that is, covered with damp-proof, water-proof, non-conducting material. Moisture is the thing mostly to be avoided, as many materials that are good insulators, lose this quality if water can affect or penetrate them. It has been found impossible to keep dampness out of any empty space under ground.

Paraffine oil, even in a very thin film, is a damp-proof insulation; so is India rubber. Guttapercha is practically imperishable, if not exposed to light and air, but it softens at a low temperature, and the wire would sink through it if heated by the current. Vulcanized rubber cannot be used on bare copper because of the sulphur it contains, the copper must be heavily tinned. A more economical material than any of these consists of fibre impregnated with an insulating oil. It is generally sheathed in lead, to protect it from both moisture and mechanical injury. See § 162.

Overhead wires

161. Where the difference of potential between the positive and negative conductors is less than 300 volts, as in the ordinary three-wire system, bare overhead wires are perfectly safe. Beyond this voltage, at least in cities and towns, it is customary to insulate the wires, generally with three layers of braided cotton soaked in some insulating and *weatherproof* compound. A No. 6 *B* and *S* gauge wire so insulated carries safely over 2000 volts, when the current is small, as in an arc-lamp circuit, where it rarely exceeds 10 amperes.

Since dry air is a non-conductor, bare copper wires strung at a certain distance from the ground, will carry a strong electric current without leakage. The cheapness in construction is not the only advantage of the system of placing the conductors overhead. It affords, also, great facilities for inspection and repair, and for extension. Wherever, therefore, the voltage is not exceedingly high, and where the conductor is not too massive, the overhead system is employed whenever local conditions permit it. It is very appropriate for a series circuit of arc lamps requiring a constant current of not more than about 10 amperes. The size of the wire depends more on mechanical than on electrical necessities. For instance, a wire No. 10 *B* and *S* (Brown and Sharpe gauge) would safely carry the above mentioned current of

10 amperes, but usually a much heavier wire, No. 8 or 7, is used to stand the strain, which is very severe in a gale. Such wires must be made of hard drawn copper, which is now produced, with a breaking weight of about 30 tons per sq. inch, from pure copper, with an increase of electrical resistance of not more than two per cent.

Bare wires are supported on glass or porcelain insulators fastened to poles of iron or wood. The porcelain must be of the best quality, however, because if the glaze is chipped or cracked, and the inner mass is not impervious to moisture, it loses its insulating properties at once. Wooden poles have the advantage that, in case an insulator is broken, the pole does not short-circuit the conductor as badly as an iron pole would. The trunk of a fir or pine, thoroughly impregnated with creosote, makes an excellent pole, and lasts a very long time.

Underground circuits

162. Conductors can be laid underground in many different ways, in subways, conduits, channels, or pipes. The leading principle in all underground work of this kind must be perfect insulation and exclusion of moisture.

A subway is a tunnel underground, of sufficient dimensions to permit the easy passage of a man. In the tunnel the electric cables and wires, also gas and sewer-pipes etc., can all find place, and it is easy to reach any spot. But the great expense of construction, and the want of room are serious objections, and even with the greatest care in providing drainage and ventilation, dangerous accumulations of gases cannot be altogether avoided in a subway.

One kind of conduit is made of perforated blocks of earthenware or wood, six feet long, especially prepared with creosote or asphalt, see fig. 89. The blocks are laid end to end and jointed by a saddle piece of the same material. The cables or wires are drawn in by means of ropes, from one manhole to another. The ropes are preferably pulled into the ducts or holes of each block as it is laid down in place.

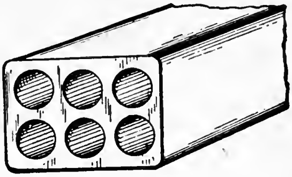


FIG. 89.

Another system of conduits consists of troughs or channels. One type of these is a rectangular (or semi-circular) cast iron trough laid in a trench. The troughing is made in six-foot lengths, about a quarter of inch thick, the cross-section varying according to the number of cables to be placed. Each piece fits into a socket of the next piece and is bolted to it, the joint being sealed with bitumen. In the trough, at intervals of 2 feet, wooden supports (bridges) are placed, treated with bitumen and provided with slots into which the cables are laid, so as not to touch each other or the iron. The trough is then filled up with bitumen, and covered with an inch of concrete or an iron lid. This system allows of such careful work that no repairs need be apprehended under ordinary circumstances.

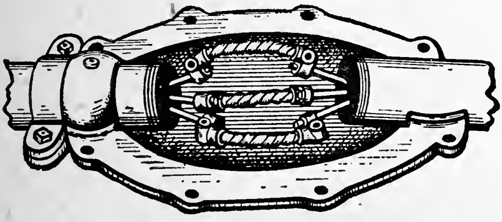
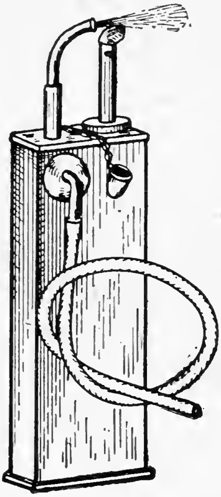


FIG. 90.

A similar system has iron pipes in sections of 20 feet each, containing the wires and finally filled up with some bituminous insulating material. These pipes are laid about 30 inches deep, and about 20 inches from the curb. They are jointed by means of coupling boxes, (see fig. 90,) cast iron shells made in halves. The bottom half is clamped over collars at the tube ends, then the three flexible copper stranded connectors are forced over the opposite wires, and by aid of the plumber's torch (see fig. 91) the couplings are heated and soldered so that a solid metallic junction is formed. Then the upper half shell is bolted to the lower one, and hot bitumen poured in through the opening provided for this purpose at the top.



POCKET BLOW TORCH
Fig. 91.

Fig. 92 represents the kind of coupling-box used where a corner is to be turned, and fig. 93 shows a triple or branch coupling-box for connecting a house service with the mains. This method is widely used in the three-wire system.

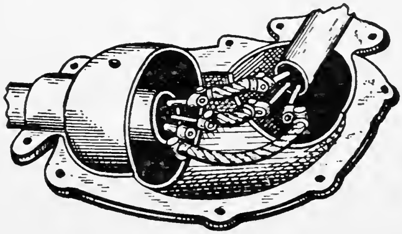


Fig. 92.

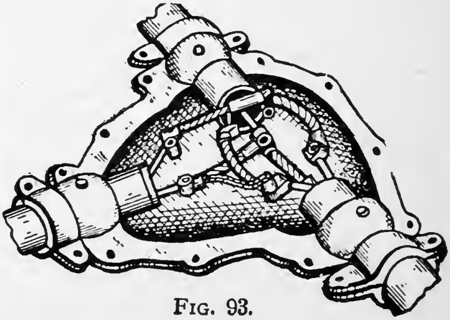


Fig. 93.

Where a feeder joins the mains, a JUNCTION BOX is sunk in the ground, flush with the street level. The conductors and thin tubes enter this box from below. In a three wire system, there are three metallic rings provided in the junction box, insulated from each other. To one of these rings all the positive conductors are connected through fuse

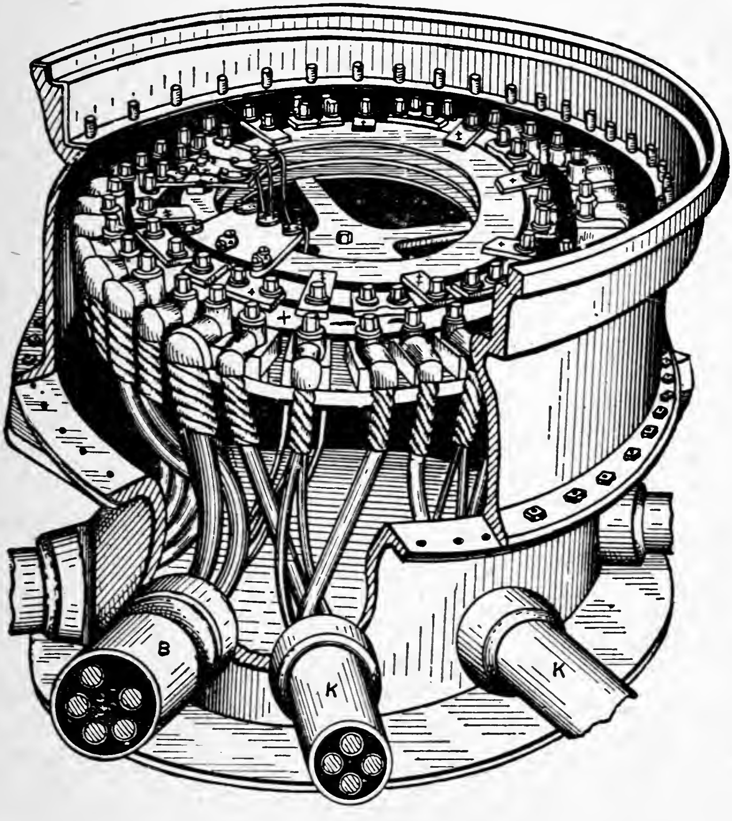


FIG. 94.

strips, to the second all the negatives, and to the third all the neutral wires. The box is kept watertight by a rubber gasket and by an iron cover bolted down. Bitumen is poured over the bolts. In fig. 94, the letter A marks one of the slabs of insulating material for the pilot wires; B is a feeder tube containing five conductors, two positive, two negative and one neutral, and also the pilot wires. K K are main tubes.

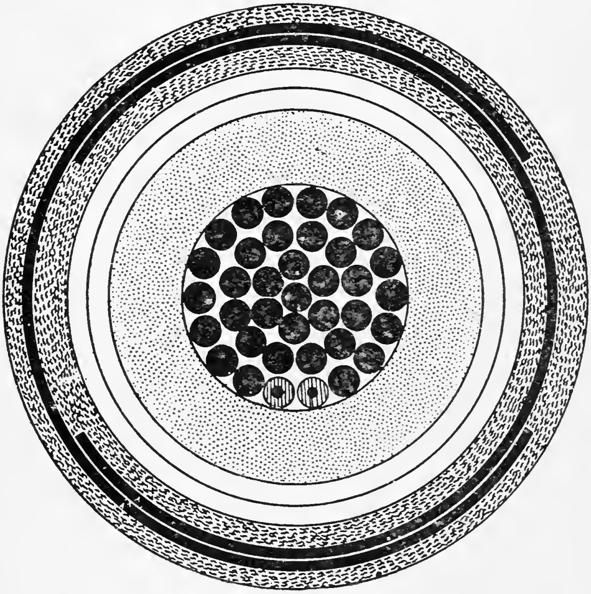


FIG. 95.

163. In a third system of underground cable, a layer of fibre impregnated, under pressure, with bitumen is laid around the stranded core of copper conductors. (See fig. 95, in which the two small wires separately insulated are pilot wires.) The layer of fibre is about one half as thick as the strand. Immediately after the impregnation is completed and while the bitumen is still hot, two coverings of lead are put on, one over the other, with the aid of hydraulic pressure, squeezing the fibre into a solid mass. Over this is a layer of jute, treated with an impervious compound. A double sheating of iron ribbon protects the jute from mechanical injury, and is itself protected against moisture by another coating of some impervious compound. Such a cable is laid bare in a trench. If an iron trough is provided, the iron sheathing, of course, is dispensed with, and the pilot wires are laid separately.

Tough paper forms an excellent insulating material for electric light and power cables, but it must be kept perfectly dry, and for this reason is encased in a lead sheathing. Such a cable is especially suitable for alternating current transmission because of the very low inductive capacity of paper and the air between its crinkles or loose folds, which insures a much lower electrostatic capacity than can be obtained in any other way except at great expense.

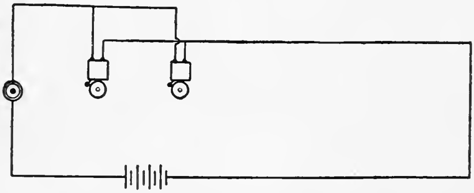
Wiring buildings

164. Conductors of electric bell, telephone, or similar systems using the current generated by a battery, are not dangerous in themselves, but may become so if they are improperly crossed by a light or power wire.

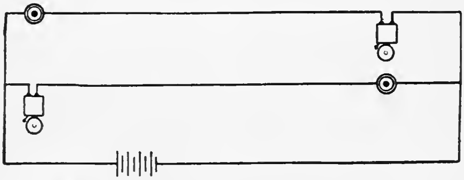
For ordinary wiring for incandescent lamps in buildings the very best rubber-covered wire should be used. Great care should be exercised in selecting the wire, as there is much poor material in the market. Inside wiring which is well planned and executed, cannot possibly cause a fire.

In wiring a building, connection with the street main is made through a cut-out. The two service wires end in a cabinet located centrally and convenient. In this cabinet there are as many fuse-blocks as there are small circuits in the building. Each small circuit is separately connected with the service wires through a fuse block. This arrangement is much better, than having the fuse blocks scattered all over the building. Of course, in very large buildings there may be several such distributing cabinets, as there may be, also, several main service wires or feeders, all connected to a large special circuit, the CRIB, from which the TAPS or small circuits radiate.

Where there is no objection to leaving the wires in plain sight, as in small shops or stores, they are not covered up, and are held in place by means of porcelain knobs or cleats. But they must be so placed that they are not liable to mechanical injury. An excellent protection is afforded by placing the wires in wooden casings or mouldings, nailed to the ceiling or walls, but they cannot be said to be ornamental. It is no longer permitted to run the wires along the walls before the plastering is done, and then cover them with plaster. They are easily injured that way, and hard to find and reach when in need of repair. The best method is to construct in the walls a water-tight conduit of iron pipes, enamelled or varnished inside, into and out of which the wires may be pulled at any time.



2 Bells operated by one push.



Three line return call.

FIG. 96.

As a precaution against moisture from rain water, wires must have drip loops outside, where they enter buildings, and the holes through which the conductors pass must be bushed with non-combustible, non-absorptive insulating tubes, slanting downward toward the outside.

Electric bells

165. The common electric bell has a very simple mechanism. Opposite the poles of an electro-magnet fixed on a board, there is an armature or key (see § 64) attached at one end to a spring, and carrying at the other end a bell clapper. Ordinarily the spring holds the armature lightly against a contact point completing the circuit. When the button is pushed in, the current from a cell or battery of cells flows through the magnet coils and the armature is attracted, making the clapper strike the bell, and at the same instant also breaking the circuit by separating from the contact point. The current stops, the armature flies back against the contact point, the current flows anew, the clapper strikes the bell again, and so on in rapid repetition, as long as the button is pressed.

When an electric bell is out of order, the cause may be poor contact at the contact point or in the push button. This fault is easily remedied by cleaning or scraping. Or the contact points may be out of adjustment, or there may be a short circuit in the field winding. But usually poor insulaation of the wire is the cause.

For electric bells so-called *annunciator wire* is much used, a No. 16 B. and S. copper wire insulated with two thick layers of cotton, wound in opposite directions, paraffined and varnished, but the extra cost of using rubber-covered or other *weather-proof* wire is so small that it is poor economy not to use it.

Faults in wires

166. Telephone and telegraph wires, being exposed, are liable to many injuries, causing faults that may be classified as *breaks, poor connections, grounds* and *crosses.* A line is said to be *dead grounded,* when the leakage is large enough to render impossible the proper use of the conductor. The leakage may take place at one place, or may be distributed over a number of places. Two lines are said to be *crossed,* when sufficient current leaks from one to the other to interfere with their proper working. A *break* will cause the armatures of the relays to fall back from their magnets. A poor connection may be due to a working loose of the wire or the binding screw, or to corrosion, a thin film of which will seriously increase the resistance. For this reason *joints* of wires must be made very carefully. The two ends are generally well cleaned, wound tight around each other and then covered with solder, in order to exclude any moisture that would cause corrosion.

An experienced telegraph operator will notice instantly a variation from the wonted distinctness of the signals. If this lack of distinctness is the same on both ends of a line, it must be the fault of the battery, or of poor connections. If the battery is at one end, and the incoming signals are fairly strong, but the outgoing signals are weak, it is clear that the outgoing current is weakened by too much leakage, while the incoming current through the ground has no such fault. See fig. 88, page 211, in which A marks the groundplate of the battery station and B the other If it is possible to signal over a part of a line only, there is a break beyond the last station to which signals can be sent, and the broken end of the wire is grounded.

Line testing

167. All new lines should be carefully tested, as explained in the following paragraphs. When a test discloses a ground, cross or break, but does not locate it, as in a large system of incandescent circuits, one branch after another is cut out, until the fault is no longer noticed. It can then be found in the branch last cut out.

Direct electrical measurement is employed for testing the conductivity of long distance telegraph and telephone lines. Where two wires can be used for testing, both are connected at one end, and at the other end they are connected to a Wheatstone bridge and a sensitive galvanometer, (at points O and M of fig. 33, page 115) The two wires being of equal size and length, one half the resistance shown by the test pertains to each wire. Where there is one wire only, the further end is grounded, the near end is connected to point O or M of the bridge, and M or O is connected with the ground. If the ground connection is perfect, the resistance indicated is that of the wire, except at times when the ordinary electrical condition of the earth is disturbed by *magnetic storms*.

The individual resistance of three or more wires on one line is easily found by establishing that of each pair of them. If, for instance, wires a and b together show 1200 ohms, wires b and c 1500, and a and c 1700, then all three wires together have a resistance of 2200.

$$\begin{array}{lr} & a+b=1200 \\ & b+c=1500 \\ & a+c=1700 \\ \hline \text{Add:} & 2a+2b+2c=4400 \\ \text{Divide by 2:} & a+b+c=2200 \end{array}$$

By subtracting $a+b$ from 2200, c is found = 1000

By subtracting $b+c$ from 2200, a is found = 700

By subtracting $a+c$ from 2200, b is found = 500.

In § 93 it has been shown how *insulation* measurements are made, when the insulation resistance is higher than could be measured by a Wheatstone bridge. For ordinary purposes, and especially in the daily measurement of the conductivity of a long distance telegraph or telephone line, a milliamperemeter placed in series with the battery at one end of the circuit will suffice. The proper resistance of the circuit being known, also the E. M. F. of the battery, a simple comparison with the daily entries of the readings will show the amount of leakage.

Locating a ground

168. A dead ground is easily located by dividing the resistance of line and ground return by the known number of ohms for the whole line. If the whole line of 1000 miles usually shows a resistance of 10,000 ohms, or 10 ohms per mile, a resistance indicated by the bridge at 6500 ohms would prove that the *fault* is 650 miles from the station.

If the ground is only partial, the method of calculating the distance at which the fault lies from a station, is more involved. To the known resistance of the line (say 3500 ohms), when in good order, is added the resistance (4500), indicated by the bridge, through the fault from *one* station, the other end being open. From this sum (8000) is subtracted the resistance (4100) through the fault from the other station, measured by the bridge, with the other end open. In this way the line resistance and the leak resistance are both counted twice, and by dividing the difference (3900) by two, the resistance of the line from the first station is found. Dividing this figure (1950) by the ohms per mile (say 10 ohms,) gives the distance in miles (195) of the fault from the first station.

The methods described here are also employed for testing and locating faults in underground cables.

A cross of two wires is located by using them as one circuit, measuring their joined resistance along one wire through the cross and back along the other wire, and dividing this quantity by the sum of the known individual resistances of the two wires per mile. The result is the distance of the cross from the station.

Lineman's detector

169. A handy instrument for localizing faults or tracing circuits is the so-called lineman's detector, consisting of two common spools mounted vertically and wound with two coils of wire, one consisting of a few turns of thick wire having 0·2 ohm resistance and the other of many turns of fine wire with a resistance of 100 ohms. The magnet, about an inch long, is mounted on a horizontal axis, which carries also the long non-magnetic pointer playing over a scale. Each coil is connected with one end to one of two terminals, the other ends being both connected to a third terminal, A current from a single Daniell cell, of about 10 milliamperes, flowing through the thin-wire coil, deflects the pointer about 45°; a current of 150 milliamperes from the same cell, flowing through the switch-wire coil, causes a deflection of about 25°.

Magneto bell

170. Another practical device is the *magneto bell,* used for arc-light and other series circuits, which are in use during a part of the day only. As the name implies, it has a call bell and a magneto in a small portable box, connected in series with the two terminals. After the two ends of a line are connected with the terminals, a crank is turned; and if the bell does not ring, this is a proof that the circuit is broken. When one terminal is connected with the ground through a water or gas pipe, and the other terminal with the line, the turning of the crank will cause a lively ringing of the bell if the line is grounded.

The tests described in § 169 are employed during the time when the line is not in use. When in use, an arc-circuit may be tested for a ground by connecting in series as many incandescent lamps as there are arc lamps, and of the same resistance, between one terminal of the dynamo and the ground. Then, if one incandescent lamp after the other is cut out, until those remaining show full candle power, their number is the same as that of the arc lamps between the dynamo and the fault. The same result can more simply be obtained by connecting a voltmeter between one dynamo terminal and the ground. Dividing the voltage indicated by the pressure required by each lamp, gives the number of the lamps on the near side of the fault.

Ground detector

171. A ground of one wire in a two-wire incandescent circuit may be shown by a single incandescent lamp connected, by a switch, between the other wire and the earth. The current flowing through the ground will cause it to burn, the brighter the more nearly dead grounded the faulty wire is. Such a lamp is called a GROUND DETECTOR. A voltmeter connected in the same manner instead of such a lamp will show full pressure at dead ground, and zero at no ground. Two lamps may be used between which a connection by a switch is made to the earth. Each lamp is connected to one conductor. If either wire is grounded, the lamp connected to the other wire will burn brighter than the other one, when the switch is closed. For three-wire systems one such pair of lamps is used for each side.

Questions and Answers.

Q. What is a metallic circuit?

A. One in which wires are used for both outgoing and return conductors, as distinguished from a grounded circuit.

Q. Suppose there are 20 lamps burning on one side (A) of a three-wire system, and 42 lamps on the other (B), each lamp taking $\frac{1}{2}$ ampere, what would be the result?

A. Dynamo A would return 10 amperes through the neutral wire; dynamo B would send 21 amp. out through it; therefore, a current of 11 amp. would flow out. (21—10=11.)

Q. What is meant by low and high potential?

A. In a low-potential system less than 550 volts are carried, in a high-potential from 550 to 3500, and in an extra-high-potential over 3500.

Q. How could a single stroke bell be made out of an ordinary vibrating electric bell?

A. By omitting the contact point back of the armature, and connecting the two magnet coils directly with the battery, leaving the armature and spring out of the circuit.

Q. When was the electric bell invented, and by whom?

A. In 1830, by Professor Joseph Henry of the Smithsonian Institute, Washington, D. C. See § 78.

The Voltaic arc

172. The electric arc was discovered by Sir Humphry Davy, the famous English scientist. In 1808, during a lecture before the Royal Institution in London, he employed 2000 primary cells, connected to two little rods of light-wood charcoal, an inch long and one sixth as thick. When these were brought near each other, point to point and horizontally, (within the thirtieth or fortieth part of an inch) a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and by withdrawing the points from each other, a constant discharge took place through the heated air in a space equal to at least four inches, producing a most brilliant ascending arch of light. Any substance introduced into the arch became incandescent: platinum melted like wax in the flame of a candle; sapphire, magnesia, lime were fused. The explanation is that the space between the two points was filled with carbon vapor, which is a much better conductor than the air, that the current passing through the vapor rendered it luminous, and that the arched form was caused by the upward rush of the heated surrounding air. The name "arch" or "arc" has remained, although the light takes a different shape when, as in modern arc-lamps, the two pieces of carbon are vertically placed, one above the other.

The voltaic arc may be produced between two electrodes of metal, but it differs from that between carbon terminals by a greater length for the same expenditure of energy, by its flaming character, and by a coloring due to the metal employed.

173. With a pressure of about 45 volts an arc can be produced between two pieces of prepared carbon, if they are first pressed together. The current, finding considerable resistance, heats the touching points to a white heat, hardly visible, however, because each point serves as a screen for the other. On separating the carbons, volatilization of the carbon takes place, filling the air space with a large quantity of incandescent carbon particles, offering so slight a resistance, that a comparatively low pressure will maintain the current. The positive carbon grows much hotter, gives off much more material and is therefore consumed more rapidly than the negative one, in the case of a direct current; it is hollowed out, while the negative carbon shows a sharp point. In the case of an alternating current both carbons show the same shape, slightly hollowed out, and they are consumed at equal rates.

Temperature and brilliancy

174. In this hollow or "crater" about 80 per cent of the total heat and light are generated, about 10 per cent in the negative carbon, and about 5 per cent in the incandescent air space. The temperature of the positive crater is estimated at 3500—4000° C, that of the negative point at 2250—3000° C. The brilliancy of carbon at this heat is 8000 times greater than that of platinum at 775° C. Liquid carbon has not been seen by any human eye. It seems that carbon at about 3500° C changes from the solid state through the liquid to the gaseous state. The globules seen on the carbon ends are due to melted silica or other impurities in the material.

175. The voltaic arc is the source of the most intense heat and brightest light which man can produce. This is due to an intense localization of both resistance and heating effect. The concentration of heat is favored by the poor thermal conductivity of carbon. The localization of resistance is aided by a thermo-electric effect consisting in a counter-electromotive force caused by the enormous difference of temperature in the two pencils.

The light of the arc most nearly approaches sunlight in color; it looks yellowish during the daytime; its blue or violet color at night is only apparent, and due to optical illusion. The human eye, being accustomed to the yellow artificial light of kerosene or gas lamps, and therefore unconsciously comparing the arc light with them, ascribes to it bluish tints.

Pressure

176. Of the 45 volts mentioned on page 229, about 39 are spent at the surface of the crater; the remaining volts maintain the arc. Consequently a potential difference of at least 39 volts is required for each arc lamp to set up volatilization, and generally about 50 volts are required to secure a steady light. At that pressure the proper distance for the two carbons from each other is about 3 millimeters.

When the distance is excessive, the negative carbon becomes blunt, and the arc flickers considerably, moving from one side to the other When not far enough apart the negative carbon tapers too much, the crater is formed imperfectly, and is screened too much by the negative carbon. reducing the illuminating power considerably.

Candle power

177. Records show that usually one horse-power is used for an ordinary 875 candle-power lamp using 10 amperes under a pressure of 50 volts. The remaining 246 watts (746—500) are lost in the various conversions, and from other causes described in preceding chapters. Such a lamp is usually spoken of as a 2000 nominal candle power lamp. Those used with 6·5 and 4 amperes are called 1200 and 600 nominal candle-power lamps. A "candle-power" equals the light given off by a spermaceti or paraffine candle of a fixed quality, size and form, varying in different countries. The British standard candle is a spermaceti candle seven-eights of an inch in diameter, weighing one-sixth pound, and burning at the rate of 120 grains per hour.

Because the crater is the part that gives the most light, the positive carbon is generally placed on top, so as to throw the greatest amount of the light downward. For this reason, also, the direct current is prefered to the alternating, and the negative carbon is generally a little thinner than the positive one, in order to screen the light as little as possible. For each type of lamp a candle power curve is established. showing the amount of light it will shed in various directions. See fig. 97. Globes of clear glass reduce the light by about 10 per cent., ground glass from 30 to 50 per cent.

The carbon

178. The carbons. in order to be perfect, must be very dense, uniform in structure, pure, and of low electrical resistance (from 0·15 to 0·175 ohm per foot). They are made of graphite mixed with pure carbon derived from the destructive distillation of gas-tar, bitumen, pitch or similar substances. After being ground and made into a paste with a syrup, rods are formed from $\frac{7}{16}$ to $\frac{5}{8}$ inches in thickness, and baked several times. Finally, a copper coating is put on by electroplating. The positive carbon is usually 12 inches long and has a core, which serves to keep the crater central. The negative carbons are 7 inches long.

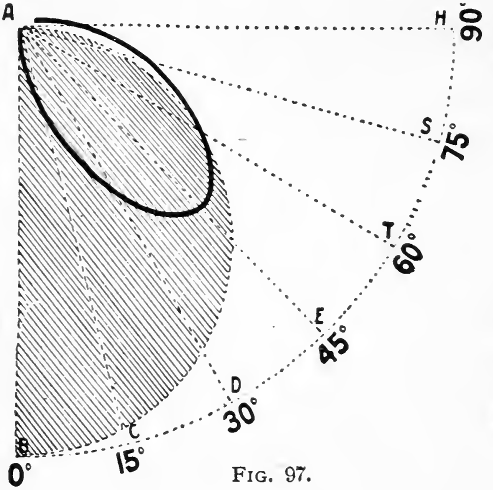


Fig. 97.

The lamps

179. Owing to the volatilization, previously described, and owing to some combustion, that is chemical union with the oxygen of the surrounding air, a mechanism is necessary which will press the carbons together at first, then separate them to a distance, *strike the arc*, in accordance with the amount of E. M. F. furnished, and finally *feed* the carbons together at a rate in proportion to their consumption. These several operations must be brought about electrically. In the most simple construction the action of striking the arc is controlled by the main or series coil, while the feeding is worked by a shunt coil. A lamp having both these coils is called *differential.* The coils must be perfectly adjusted so as to operate automatically as the effect of one preponderates over that of the other. In other lamp types a clock work, or a most ingenious combination of electrical and mechanical devices, regulates the operations. The lower carbon is generally fixed, and the upper one is controlled by the mechanism.

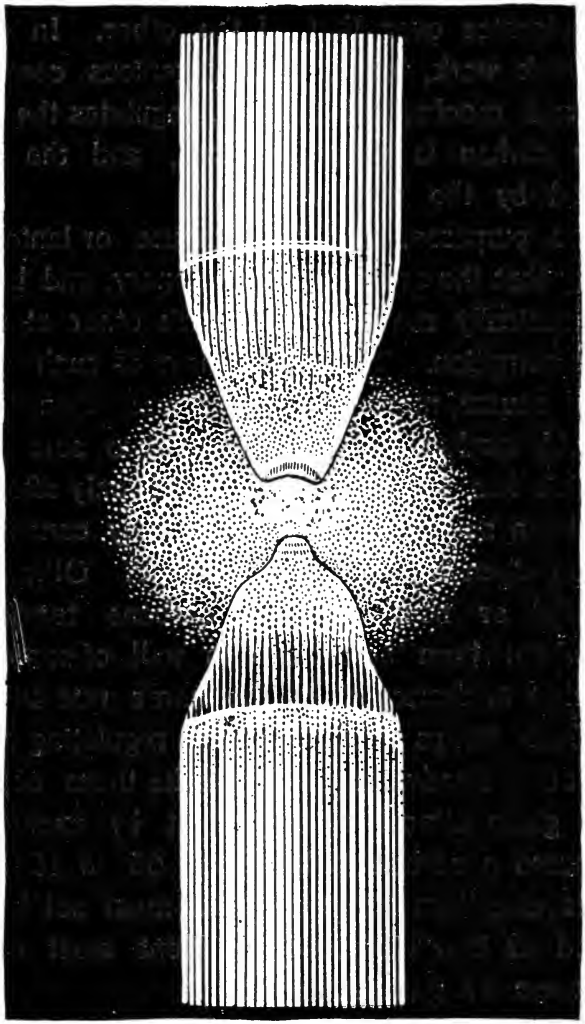
For some purposes, as for lighthouse or lantern work, it is necessary that the arc remains stationary, and both carbons must automatically move toward each other at their exact rates of consumption. The mechanism of such a *focussing* lamp is, of course, more complicated and expensive.

In a *double carbon* lamp there are two sets of carbons, one of which has its circuit completed only after the other pair have been so far consumed that they cannot meet any longer, even when the current is stopped. Other types have fixed parallel or nearly parallel carbons termed *candles,* some of which burn across a thin wall of some insulating material, that is destroyed at the same rate as the carbon pencils. Such lamps need little or no regulating mechanism, but have other disadvantages that make them objectionable.

A glass globe almost entirely tight by excluding nearly all air, causes a carbon to last from 65 to 150 hours, and the light is steadier; but the globe must not be hermetically sealed or it will explode. A vent must be provided for the excess of gas developed.

Regulating mechanism

180. Fig. 98 is a diagram illustrating a well-known form of regulating mechanism for a lamp designed for connection in series on a constant-current circuit. This type of lamp is much used for outdoor lighting. It has two electromagnets



THE ELECTRIC ARC.

(From photograph taken through smoked glass.)

Showing the positive carbon with its crater, and the lower negative carbon with its point.

controlling the feeding of the carbons. One magnet is wound with coarse wire and is connected in series with the arc, and the other magnet is wound with fine wire and connected in a shunt or by-path around the arc. The series magnet lifts the upper carbon to start the arc when current is first turned on, and its armature stays drawn down, as shown, during the entire operation. The shunt magnet regulates the feeding of the carbon; its armature being connected with the clutch through the balanced lever mechanism in such a way that as the power of the shunt magnet increases, the clutch and carbon will be lowered. In the operation of this lamp, as the carbons burn away and the resistance of the arc becomes greater, the current through the shunt magnet increases, causing it to feed down the carbon and keep the arc at the proper length. As the length of the arc decreases, its resistance decreases and the shunt magnet receives less current, so that the feeding is checked. When the clutch drops far enough to strike the plate immediately under it, it is loosened and allows the carbon rod to slip through. But as the arc is shortened, the shunt magnet is instantly weakened and the

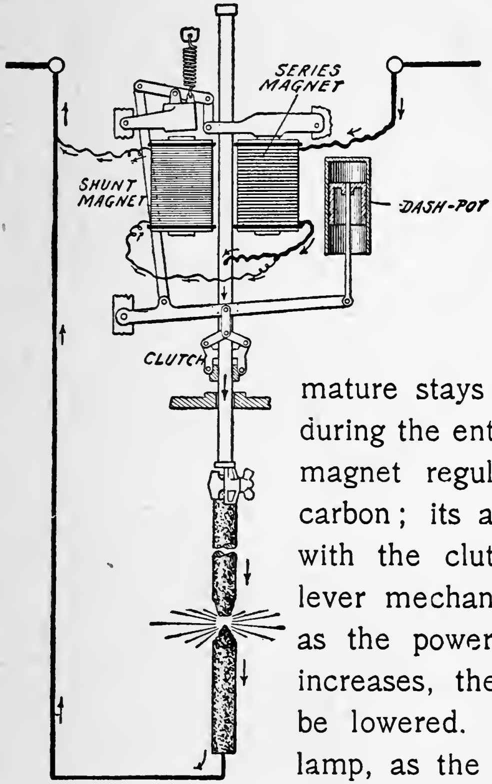


Fig. 98.

clutch lifted by the spring which is connected to the lever mechanism, so that the proper length of arc is thus maintained at all times.

Another form of arc lamp, shown in fig. 99, has a much simpler mechanism, requiring but a single electromagnet, which is in series with the arc. Such lamps as this must be connected in multiple arc across the mains of the system, the potential being constant while the current through each lamp may vary according to its resistance. As the arc becomes longer, the increased resistance cuts down the current through the magnet, which, becoming weakened, feeds down the carbon to maintain the proper length of arc. This is called a constant-potential lamp, and in lamps of this

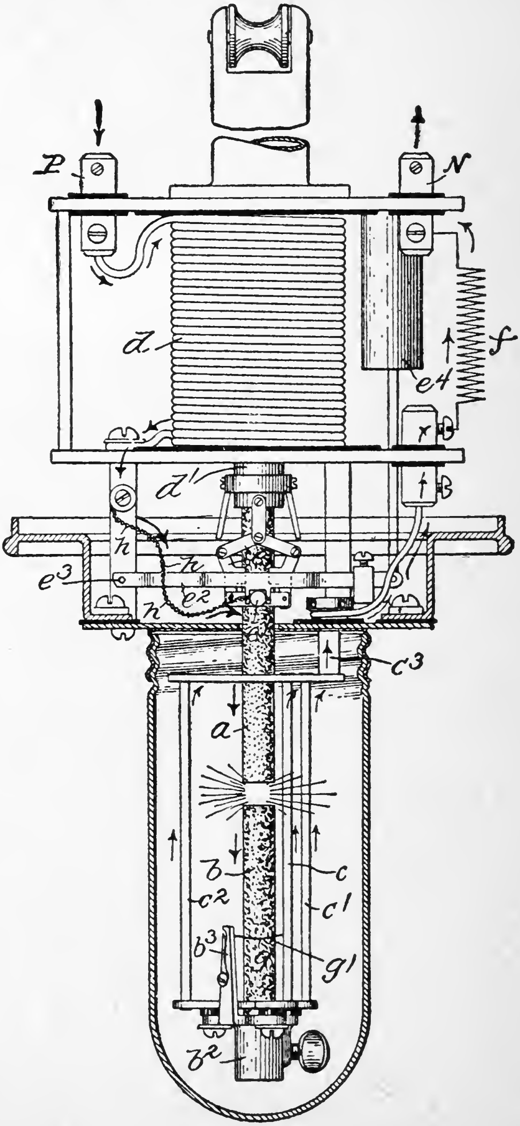


FIG. 99.

kind the arc is usually enclosed within a small glass globe which is nearly air-tight. The advantage of enclosing the arc is that the absence of fresh air—oxygen—prevents the carbons from burning away as fast as they otherwise would. If the arc is not enclosed the carbons of an ordinary lamp will be consumed in about eight hours, while an enclosed arc lamp will burn about 150 hours before new carbons are required. The enclosed arc, while steadier and more silent than the open arc, does not give so bright a light, and the light has more of a violet tinge. Enclosed arc lamps are at present generally constructed for connection in parallel on constant-potential circuits, such as incandescent lighting circuits, so that both arc and incandescent lamps may be used for indoor lighting on the same circuit. When the arc is enclosed the carbons burn flat at the ends as shown in fig. 99, since the crater formed wanders slowly over the surface of the positive electrode, leaving the ends fairly flat.

The circuit

181. On a *constant current* circuit, arc lamps may be used in series, and on a *constant pressure* circuit automatic cut-outs are often provided, especially on long lines, which open another path, of low resistance, in case the main circuit through a lamp is from any cause interrupted.

Where a number of series arc-light circuits are supplied from one station, an arrangement is needed by which any generator may supply any circuit. Generally there is a switchboard with a spring jack for every main wire, and a cord and plug for every dynamo.

Incandescent lamps

182. The first incandescent lamp, consisting of a thin stick of carbon brought to white heat in a vacuum, was made as early as 1845, but the difficulties in the way of making it a commercial success were so many that almost 35 years more passed, before Edison in America, and Swan and others in Europe succeeded in devising a substance that gave a brilliant light and could be produced at a reasonable price.

The principle

183. In § 60 the $I^2 R$ loss has been explained. The heat into which a part of the electrical energy is always converted in a conductor, was at an early period expected to furnish a new light, but no metal could be found that would not be dangerously near the melting point when incandescent, with the only exception of iridium which is too expensive to come under consideration in this respect. Moreover, the resistance of metals increases with rising temperature, while the resistance of carbon decreases. Carbon cannot be melted by any ordinary means and for these two reasons is especially fitted for the purpose; but it oxidizes readily when heated, and the great difficulty has been to exclude the free oxygen of the air from the bulb in a manner that was at once efficient and economical. The temperature developed in the incandescent filament is about 2000° *C*.

The filament

184. The filaments may be divided into two classes: first, those in which the original fibrous structure of the carbonaceous body is retained, as in the Edison filament, made of a kind of bamboo or of cotton thread; and second, those in which it is intentionally destroyed, the material being worked into a homogenous viscid mass, cellulose, and shaped by being squirted through a fine aperture, as in the filaments of Swan and other inventors.

The material is first carbonized in a solution of two parts of sulphuric acid to one part of water, then the acid is washed out in running water and the material is dried. It is then in a horny, transparent state. Often passing through a series of jewel dies which reduce it to a uniform gauge, it is wound on a frame, that is arranged to give the filaments the shape desired, with or without loops. A number of these frames are placed in a crucible and the empty spaces filled with powdered charcoal. The crucible is then sealed air-tight and brought to a white heat in a furnace. The charcoal absorbs any oxygen in the crucible, that would otherwise destroy the filaments The high temperature has the double effect of rendering the filament hard and durable, and also less porous so that it will not be liable to *occlude* (absorb) gases, which when heated would expand and cause minute fissures in the carbon. Then the filaments are cut to the desired length, fastened in pairs of clips connected with electric terminals, and immersed in coal gas or naphtha gas. *Flashes* of current sent through the filament heat the thinner parts more than the others, in consequence of which the carbon of the gas is deposited on the filament in proportion to the heat. The FLASHING is continued, until the filament shows a uniform luminosity.

The filament, when finished, is mounted on two short pieces of exceedingly thin platinum wire, which are sealed in a bit of glass. The ends of the wire, flattened, are bent around the filament and fixed with a carbonaceous cement, or in some other way. Though more expensive than gold, platinum is the only metal suitable for the purpose, because it happens to expand or contract with the varying temperature at almost exactly the same rate as glass. This glass is then sealed into the glass of the bulb. The metallic filament lamps are being used quite extensively in the last few years, even replacing arc lights and carbon filament lamps to a marked degree. Their cost is slightly greater than the carbon filament lamps but the increase in light and the decrease in power consumption offsets this. The metal filaments are made of fine tungsten or tantalum wire. The construction of the lamp is similar to the carbon lamp with the exception of a much firmer and much longer filament.

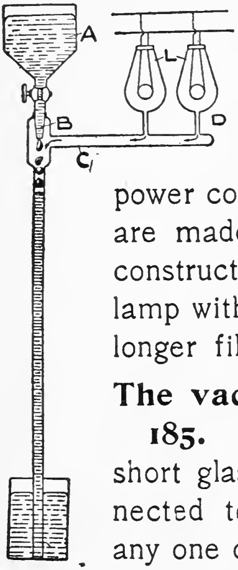


Fig. 100.

The vacuum

185. The bulb to be exhausted is provided with a short glass tube by means of which it can be connected to an air pump. The vacuum is created by any one of several forms of mercury pump. Fig. 100 illustrates the principle of the Sprengel pump, which may be considered typical. It consists of a barometer glass tube about 40 inches long, with a branch *C*, connected with the lamps *L* to be exhausted. The reservoir *A* is partly filled with mercury and so connected with the tube that the pinch-cock allows the metal to drop in small drops only. Each drop forms a piston and in rushing past the junction *C* carries before it a little air from the branch and lamps *L*. The diagram shows the minute quantities of air between the drops of mercury all the way down to the lower flask into which the mercury descends as fast as the column in the vertical tube tends to grow longer than 30 inches. When the air spaces between the mercury drops disappear, the bulb is exhausted and may be sealed off by fusing the small connecting tube *D* and drawing it out to a thread.

Base and socket

186. The exhausted bulb is next mounted in a brass *collar* or BASE fixed with cement, in which two free platinum wire ends are connected with two brass segments insulated from one another, The collar again fits into a holder or socket, in which the electrical contact is brought about in many different ways. In some types the base is screwed into the socket, contact taking place as soon as it is screwed in far enough. Some types have a switch in the socket, but they get out of order easily, which is natural when the smallness of the parts is considered, and the high temperature when the lamp is burning. Better have independent switches in convenient places.

Life of a lamp

187. The time the filament of an incandescent lamp will last varies considerably. It depends greatly on the quality of the filament and the degree of vacuum in the bulb, also upon the strength of the current. Experience teaches that a filament is not injured by a current strong enough to bring out its full luminosity, but a lamp will last longer if a comparatively feeble current is used. To insure a steady light, the pressure at the terminals of the lamps must be perfectly constant, because a slight variation in the pressure will cause a large variation in the luminosity. A 16-candle power lamp requiring a pressure of 110 volts, for instance, will give only 12-candle power at 105 volts, while at 115 volts it would show great brilliancy but burn out very rapidly, and the power consumed is considerably increased; the decrease in the life of the lamp is at a far more rapid rate than the increase of the voltage.

The efficiency of a lamp is generally expressed by the ratio or candle power yielded to watts absorbed. A new lamp usually has an efficiency of 1 ÷ 3·5 = 0·2857, but it deteriorates very soon, and it is a good lamp that then shows the ratio 1 ÷ 3·75. The continued efficiency of a lamp is of much more importance than a long *life,* and experiments have proved that the life of a lamp increases much more rapidly, than its efficiency decreases.

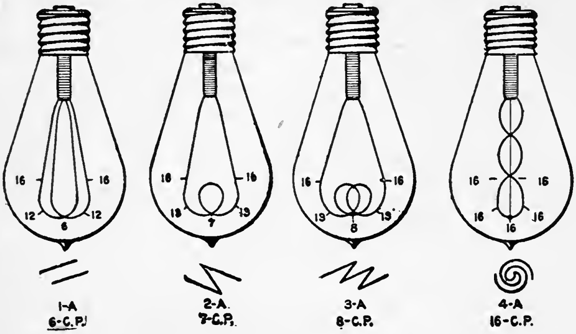


Fig. 101.

If a lamp that takes 2·5 watts per candle lasts for 150 hours, one that absorbs 3·0 w. p. c. will last 350 hours, one of 3·5 w. p. c. lives 700 hours, and one of 4·0 w. p. c. 1000 hours.

Fig. 101 shows four incandescent lamps, together with the appearance of the filament from the point, and with the luminosity in different directions, expressed in candle powers.

Fig. 102 illustrates the new "Economical" lamp. By a turn of the bulb either the small filament with 1 c. p. or the large one with 16 c. p. may be turned on. Fig. 103 represents the same lamp arranged so that a pull of one or two cords will switch in one filament or the other.

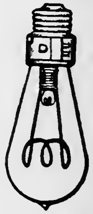


Fig. 102.

Fig. 103.

Rating of lamps

188. After the lamps have been perfectly mounted they are tested with regard to candle power, pressure and current and slips of paper showing the illuminating power.

pressure and watt consumption are pasted on the bulb. There are many different rated lamps in the market ranging from 1 to 150 candle power. Usually 16 c. p. lamps requiring from 50 to 60 watts are employed. 110 volts, 55 watt and 16 c. p. lamps require a current of 0·5 ampere. Lamps are usually made for 50, 60, 110 and 220 volts pressure.

Incandescent lamps may be used for both direct and alternate currents. For example, when supplied with 50 volts direct current, a lamp will have the same illuminating power as when supplied with 50 volts alternate current.

Connections for lamps

189. Incandescent lamps may be operated upon series or parallel circuits, but the latter have been found to give more satisfaction.

When connected in series, it is impossible to cut out of circuit one of the lamps, as by this operation the current is cut off from all the lamps of the circuit. If it is desired to cut off a lamp in a series circuit, the lamp must be short circuited, and special switches have been introduced in the market for this operation. When connected in a parallel circuit every lamp is entirely independent of the current flowing through other lamps of the same circuit, the current flowing through it depending only upon the resistance of the lamp and the pressure at its terminals. Any lamp of a parallel circuit may be cut out of circuit by a simple operation of the switch in the socket of the lamp and without interfering with the other lamps. (See § 155).

Drop in mains

190. When lamps are connected to long mains leading from the central station there is always a loss of pressure in the mains, called the "drop," equalling the product of the current and the resistance of the wire. (See § 58).

It is not advisable to allow the drop to be greater than twenty per cent of the dynamo pressure when all lamps are turned on, as it is very difficult to regulate the pressure of the dynamo when the drop is too great. For this reason, and also to save the cost of copper in mains it is advisable to transmit the current at a very high voltage and to reduce the voltage to the necessary value at the center of distribution. This may be accomplished by using an alternate current and transformers or rotary converters as described in § 128 and 141,

Mercury vapor lamp

191. The mercury vapor lamp (see fig. 104), consists of a long glass tube (a) about an inch in diameter. Mercury is placed in an expansion (b) at the lower end of the tube, from which the air has been partly exhausted. Two platinum terminals (c_1 c_2) are sealed into the tube, one on each end of it. The lamp may be operated on a 110 or 115-volt circuit, and an induction coil is provided to start the lamp by supplying it temporarily with high voltage current. This current instantly vaporizes a part of the mercury and the whole tube becomes filled with mercury vapors. These are brought to incandescence by the current passing through them, thus producing light of a pale blue-green tint. The light contains no red rays, and casts no sharp shadows. It is very favorable for the eyes, causing but little fatigue, and has been used in draughting rooms to a great extent. It is also used for photographic work and for making blue prints. The efficiency of this lamp is about five times

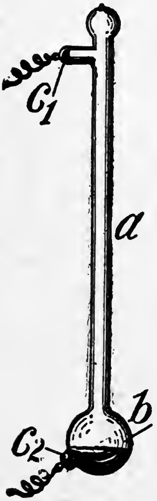


FIG. 104.

that of ordinary incandescent lamps, being from 0·5 to 0·25 watt per c. p. As there is nothing in the lamp which could wear, the lamp theoretically is everlasting and shows after a use of 2000 hours but slight decrease in efficiency. The mercury vapor lamp was invented by Peter Cooper Hewitt and first exhibited in April, 1901.

Measurements of illuminating power

192. Illuminating power of lamps is measured by special apparatus called photometers. The simplest apparatus is the original BUNSEN photometer (named after its inventor) shown in diagram in fig. 105. A standard candle described in § 177 is placed in *A*. The electric lamp whose candle power is to be measured in *B*. *C* is a movable stand with two screens made of thin transparent paper on which grease stars a_1 a_2 have been drawn and placed at a sharp angle to each other. *D* is a long scale. When in use this photometer is usually enclosed in a perfectly dark room and the light of the candle *A* and the lamp *B* so screened as to fall on the grease stars a_1 and a_2 only. Then the screen *C* is moved on the scale until both of the grease stars a_1 and a_2 are equally illuminated. When both stars are equally illuminated then the candle power of the candle *A* and lamp *B* are related to each other *in ratio of the squares of the distances measured from the screen to the candle and lamp respectively,* because the light varies inversely as the square of the distance.

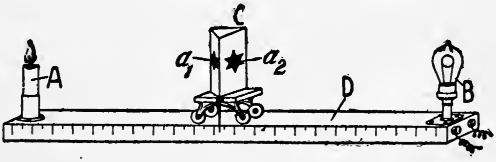


FIG. 105.

The candle foot

193. The intensity of illumination of a surface by a lamp fixed above it is inversely proportional to the square of the distance from the lamp to the illuminated surface. The unit for measuring illumination of lamps is the intensity of illumination which a lamp of one candle gives to a perpendicular surface placed at a distance of one foot. This illumination is called a *candle foot.*

RULE 45. — The illumination produced on a perpendicular surface by a lamp equals the candle power of the lamp divided by the square of the distance from the lamp to the surface.

Thus a 16 c. p. incandescent lamp being placed 4 feet from a sheet of cardboard gives it an illumination of $\frac{16}{4^2} = \frac{16}{16} = 1$ candle foot.

The illumination for reading should be not less than 2 or 3 candle feet and the light should be placed so as not to meet the eyes. The average illumination of light rooms by daylight is about 35 candle feet.

EXAMPLE 70.

10 16 c. p. incandescent lamps are placed above a writing desk at a distance of 4 feet. What. is the illumination of the desk ?

Total c. p. of lamps $= 10 \times 16 = 160$.

$$\frac{160}{4^2} = \frac{160}{16} = 10 \text{ candle feet. Ans.}$$

Questions and Answers.

Q. What size of copper feeders is required for ten 110 volt and 55 watt lamps connected in parallel, their center of distribution being 100 feet from a dynamo, generating 115 volts. Pressure at center of distribution 111 volts.

A. Current for one lamp $= \frac{55}{110} = 0{\cdot}5$ ampere.

Current to be transmitted to center of distribution $= 10 \times 0{\cdot}5 = 5$ ampere.

Drop in mains $= 115 - 111 = 4$ volts.

$$\text{Circular mils} = \frac{10{\cdot}79 \times 100 \times 2 \times 5}{4} =$$

$$= \frac{10{,}790}{4} = 2697{\cdot}5 \text{ c. m.} \quad \text{Ans.}$$

Q. A current of 8·5 amperes flows through an arc lamp where the fall of potential is 50·5 volts. How many watts are expended in the lamp? How many H. P.?

A. Watts expended $= 8{\cdot}5$ (amp.) $\times 50{\cdot}5$ (volts) $= 429{\cdot}25$.

H. P. expended $= \frac{429{\cdot}25}{746} = 0{\cdot}58$ H. P. (approx.).

Q. How many watts are lost in heat in the preceding example when only 12 per cent. of the energy supplied appears as light?

A. 88 per cent, of 429.25 is lost in heat.

$$\frac{429{\cdot}25}{100} \times 88 = 377.74 \text{ watts.}$$

The telegraph

194. The earliest experiments with transmitting signals through wires were made as long ago as 1774 by LESAGE in Geneva, who invented a system of transmitting messages, which were read by observing the divergence of two pith-balls at one end of a wire, when a charge of electricity was sent into the other end. Many other inventors have worked on the problems of telegraphy, especially AMPERE, (1821) CROOKE and WHEATSTONE (1837) until MORSE (1837) succeeded in constructing a telegraph system in which by the attraction of an armature by an electro-magnet, marks were made upon a moving strip of paper. In 1844, his experimental line connected the city of Washington with Baltimore. In 1845 this line was opened to public traffic and after a year of successful operation, the construction of Morse's system of telegraph lines was undertaken in almost all parts of the civilized world.

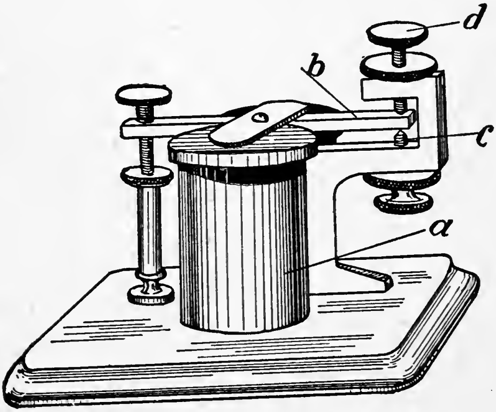


FIG. 106.

The Morse telegraph system contains the following parts:

1. The Key.
2. The Battery.
3. The Line.
4. The Morse instrument.

The Morse instrument

195. The sounder or the Morse (see fig. 106), named after its inventor, is the most widely used apparatus in telegraphy. It consists of an electromagnet *a* which when magnetized by a current passing through its coils for a short length of time, attracts an armature screwed on lever *b*, a spring drawing the lever and the armature into their previous position when the current is stopped; at this time the lever *b* makes a click when striking against screw *d*; another click is heard when the armature is attracted and when it strikes the screw *c*. This apparatus may be arranged to serve either as a *sounder* or as an *embosser* or an *ink-writer*.

THE MORSE ALPHABET.

A	B	C	D	E	F	G	H	I	J
·—	—···	·· ·	—··	·	·—·	——·	····	··	—·—·
K	L	M	N	O	P	Q	R	S	T
—·—	———	——	—·	· ·	·····	··—·	· ··	···	—
U	V	W	X	Y	Z	&	1		
··—	···—	·——	·—··	·· ··	··· ·	· ···	·——·		
2	3	4	5	6	7				
··—··	···—·	····—	———	······	——··				
8	9	0	Comma (,)	Semicolon (;)	Colon (:)				
—····	—··—	———	·—·—	··· ··	—·—··				
Colon Dash (:—)	Hyphen (–)	Period (.)	Interrogation (?)						
—·— ·—··	···· ·—··	··——··	—··—·						
Exclamation (!)	Dash (——)	Capitalized letter	Paragraph (¶)						
———·	—·· ·—··	·· · ·—··	————						
Dollars ($)	cents (c)	Pound Sterling (£)							
··· ·—··	·· ·	····· ·—··							

Fig. 107.

When used as a *sounder* it gives the operator the telegraphed letters in a special Morse-alphabet, composed of *dots* and *dashes.* (See fig. 107.) At each attraction of the armature, two clicks are heard, and the operator knows that a *dot* is signalled when the two clicks follow immediately after one another; when a *dash* is signalled the interval between the two clicks is longer.

When used as an *embosser,* it is arranged so as to print dots and dashes on a strip of paper, which by means of an ordinary clockwork is drawn under the needle of the instrument. The *ink-writer* pushes a little wheel against the paper when its armature is attracted by the electro-magnet.

The key

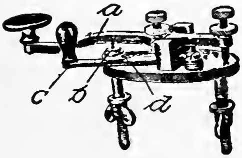


FIG. 108.

196. The key (fig. 108) consists of a lever *a* which being pivoted may move up and down through a small range and strike a contact *b* when the button on one end of the lever is pressed down by the operator's hand. A small spring under the lever tends to push it to the upper end of its stroke when the operator's finger ceases to press the button down.

When the key is in a circuit, the current enters it at the binding post, passes through the legs and the pivot into the lever, and when the lever is depressed and thus a connection with the other binding post at *b* is established, the current leaves the key to pass into the line. Thus circuit may be made or broken at will by depressing or raising the lever *a*.

When the key is not in use, the circuit is kept closed by a switch lever *c* mounted upon the same base plate as the key, and adapted to wedge in under a flat contact spring *d* mounted at the side of the lower contact point and electrically connected with it.

When it is desired to transmit a message, the circuit is opened by pressing the lever to one side and the key is manipulated at intervals necessary to transmit the signs of the Morse alphabet.

The recording register

197. The recording register consists of a clockwork, which being enclosed in a case, is so arranged as to draw slowly, a long strip of paper between its rollers and under an electromagnetic writing apparatus, a long lever or *marker* of which, is moved by the armature of the receiving electromagnet. The sharp point or the writing wheel is held down upon the moving strip of paper as long as the circuit in the apparatus is closed and its magnets excited. When the circuit is broken the marker is lifted off the paper. Thus dots are printed when the circuit is closed for a moment only, and dashes when the circuit is closed for a short length of time

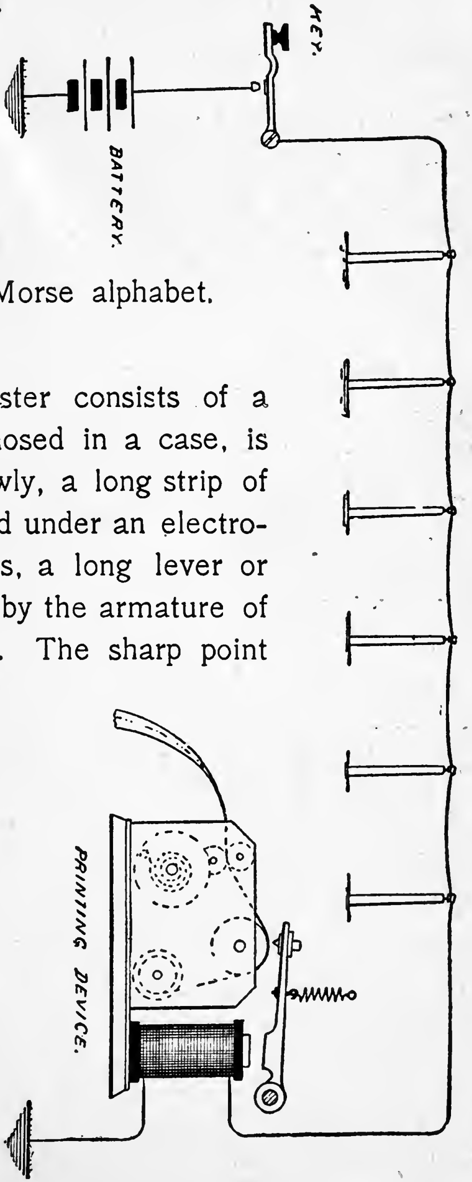


FIG. 109.

so as to allow the rollers to move the paper under the point of the marker.

The recording register is shown in fig. 109 which represents a Morse transmitting station, receiving station and line.

The telegraph line

198. The current used in the telegraphic transmission of messages — its average being about forty milliamperes — allows the use of the earth for one part of the circuit (see fig. 109). The other part of the circuit consists ordinarily of a galvanized iron wire supported on wooden poles and insulated from them by glass or porcelain insulators. Wires for telegraph lines are usually No. 8 to No. 6 B. W. G., but the size of the wire is often increased according to the length and the importance of the lines in order to prevent frequent faults in them caused by snow, wind, etc.

The relay

199. The *relay* or *repeater* is an instrument which is frequently used in working over long lines, where there are a number of instruments on a common circuit and when the current is not strong enough to operate the recording register.

The relay, a diagram of which is shown in fig. 110, consists of an electromagnet *a* having a lightly pivoted armature *b*, the movement of which is controlled by a little spring *c* which, when attracted, closes the local circuit, consisting of battery *d* and the recording register *e*.

The armature of the relay always works regardless of which direction the current flows and by placing many turns of fine wire on their magnet coils, relays are made so sensitive as to be operated satisfactorily with currents even smaller than 10 milliamperes.

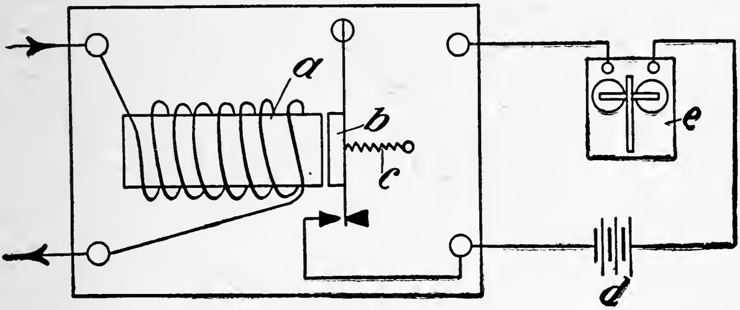


FIG. 110.

Open and closed circuits

200. The so-called OPEN CIRCUIT working means the battery is out of circuit when the line is in rest. The open circuit working is used on almost all European lines and has the advantage of not using the battery when messages are not being sent.

In the CLOSED CIRCUIT working, used among American telegraph companies, the current continues to flow through the line when messages are not being sent, but it is interrupted by the key of the operator when sending signals.

This system allows the connection of a number of isolated stations on a single circuit, each of which can communicate with all the others by opening the circuit. A further advantage of this system is that every failure in the line announces itself by stopping the current.

Faults in lines

201. The faults occurring most frequently in telegraph lines, are caused by one of the following reasons: either the insulator breaks and causes a short circuit, allowing the current to pass to the earth before reaching the receiving station, or the wire itself breaks and falling on the ground establishes a short circuit. Insulation *faults* in stations are also frequently the cause of short circuits.

Multiplex telegraphy

202. For reasons of economy, in long and expensive lines, special arrangements have been made which allow the sending of more than one message from one station to another. If it is possible to send two messages at one time from one end of the line to the other, the line is said to be *diplexed.* If one message may be sent from each end at the same time, the line is said to be *duplexed.* When four messages may be sent at once, two in each direction, the line is said to be *quadruplexed.* The last system is a combination of the two preceding ones.

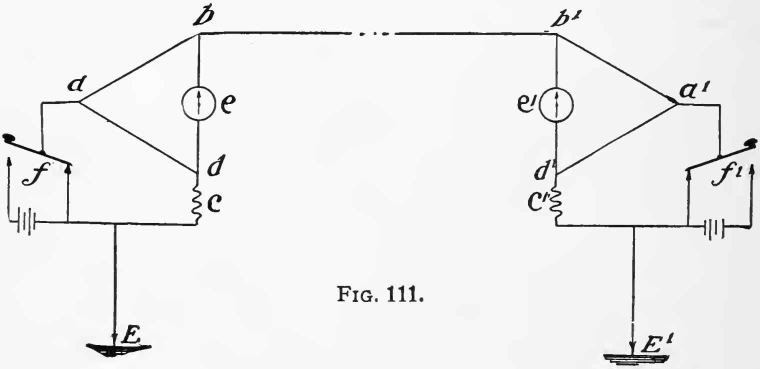


FIG. 111.

Duplex telegraphy

203. The commonly used method of duplex working is the so-called *bridge-method.* The diagram in fig. 111 shows a duplex station working with the bridge method.

The circuit divides at *a* (a^1) into two branches, one of which connects at *b* (b^1) to the line, the other through a resistance *c* (c^1) to earth. When the ratio between the resistances in the sections of the circuit *a b* and *a d* equals the ratio of the resistances of the line and of *c*, then no current may pass through *e* (compare § 92) and *e* does not indicate any currents sent from *a*, but e^1 will show it, for the current passing through the line and arriving at b^1 will divide into the two branches b^1 a^1 flowing over c^1 to earth and the other part flowing over b^1 e^1 d^1 and signalling in the apparatus e^1. Even when the operator at the other end depresses the key f^1, the apparatus e^1 will not cease to give signals, and the apparatus *e* will give signals even when the current in the line is stopped by an equal current sent from the opposite direction, because the current from *a b* will then flow through *e* as if it had been sent from the other station.

Polarized relay

204. A relay possessing a permanently magnetized steel armature is called a *polarized relay*, (see fig. 112). When there is no current passing through the coils of the electromagnet, the magnetized armature will stand between the poles of the electromagnet, being restrained by two springs. When a current flows in one direction the armature will be attracted by one pole; and when the poles of the electromagnet are reversed by a current flowing in another direction it will move to the other pole. It is possible to send a current toward a non-polarized relay, over the line

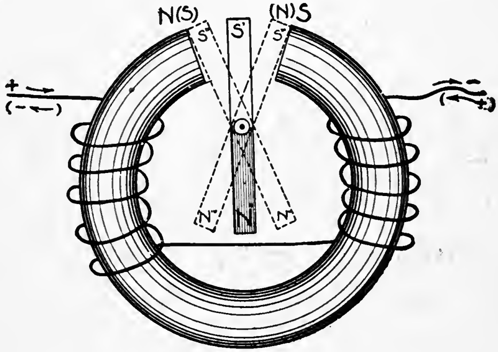


FIG. 112.

which is used for a polarized relay, without interfering with the working of the latter.

Diplex telegraphy

205. In this method, it is necessary to employ one set of instruments which only work with a current sent in one direction, and another set which works when a current sent in any direction exceeds a certain strength; therefore, polarized relays (see § 204) which respond only to currents in one direction, and adjusted non-polarized relays which respond to currents above a fixed minimum are used. There are two keys: one reversing the current for any direction and another which is so adjusted as to send weak or strong currents in one direction only. Two currents are used in diplex telegraphy. One being quite weak, is reversed when sending signals and thus operates a polarized relay. The other, a stronger current, is increased and decreased when sending signals to work a non-polarized relay. The current is increased and decreased by a special key which alternately connects into the circuit a large and a small battery.

Automatic and autographic telegraphy

206. For sending quick messages such as stock quotations, press dispatches etc., machines are sometimes used instead of hand. The receiving stations then, consist of a machine receiver, which prints the messages in the English alphabet directly, and this operation is known as *automatic telegraphy.*

Machines have been devised to transmit writings and sketches exactly as they were written or drawn. Most of these machines are very complicated and being too expensive and easily put out of order, are not in practical use. Machines reproducing writing are called *autographic telegraphs*.

Submarine cables

207. Cyrus W. Field was the first man who entertained and financed the idea of laying a cable across the ocean. After several unsuccessful attempts, in 1858 he succeeded in laying a line from Newfoundland to Ireland. This cable, being too weak, was later replaced by another of a better construction, and the laying of it was completed in 1866 when it was put into operation. Since then, a new cable has been laid almost every year, all forming at the present time a complete network, connecting in conjunction with the overland telegraphs, almost all parts of the civilized world.

Submarine cables are made with several separate conductors instead of only one, the different terminals of which, connect with different lines on the shore. The single conductors are made of three or seven copper wires, in order to do away with the easy breaking of the cables The covering is of hemp or jute impregnated with tar, asphalt, or similar compound, spun around the insulated core to serve as a protection for the cable against the pressure of the iron wire, which forms the armor of the cable.

Working on submarine cables

208. The ordinary Morse telegraph is not suited for use in submarine telegraphy; therefore, a delicate instrument designed by Lord Kelvin is used. It formerly consisted of a galvanometer of very high resistance, having on its magnets a small mirror. At a considerable distance and opposite to the galvanometer, a scale was placed at the center of which, was a small vertical slit. The rays of a lamp behind the slit, concentrated by a lens, were allowed to fall upon the mirror and reflect from it upon the scale. The dots and dashes of the Morse alphabet were indicated by the movement of the reflected spot, to right or left of the center of the scale.

Later, Kelvin's *syphon recorder* was introduced and it has been constantly employed since then. It consists of a flat coil of very thin wire, which is in circuit with the line and is suspended on silk fibres between the poles of a powerful magnet. When there is a current passing through the coil, it tries to set itself with its plane, perpendicular to the line joining the poles of the electromagnet. The coil communicates its motions to a very fine glass syphon, one end of which dips into a vessel of ink; the other, when a current passes through the coil, draws a wavy line on a ribbon of paper, which is moved under it by clockwork. This wavy line is a perfect record of the message, in Morse alphabet; its lines in one direction corresponding to the dots, and those in the other direction to the dashes.

The telephone

209. In 1861, Prof. Philip Reis of Friedrichsdorf, Germany, was the first scientist whose experiments with the telephone proved a success. In his imperfect instrument the sound waves were caused to act upon a point of loose contact in a circuit, and thus to vary the resistance of the circuit The simplest telephone transmitted music and speech, imperfectly though, owing to the lightness of the contact employed. Later inventions which made the telephone practical, were those of Alexander Graham Bell (1876) and Dr. Elisha Gray.

The first practical telephone constructed by Bell and exhibited at the Philadelphia Exposition in 1876 is shown in fig. 113. It consisted of two similiar apparatus, the *transmitter* being used to talk into and the *receiver* reproducing the sounds. Each of these two instruments consisted of a rod magnet *m,* around which, fine wire was wound and a *Diaphragm* or disk *d,* made of thin iron and placed in the field of the magnet. Each apparatus was provided with a special *mouthpiece,* of such a shape as to gather the largest possible amount of sound and concentrate it upon the diaphragm. There was no battery used in this circuit, the ends of the magnet coils being first connected with two wires, later with only one wire, while the two other ends were grounded as shown in fig. 113.

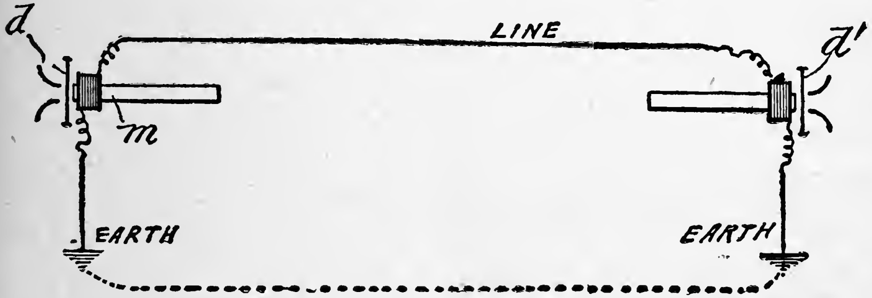


FIG. 113.

The working of this telephone may be explained in the following way: Many magnetic lines of force of the rod magnet *m,* pass the coil, and some of them enter the diaphragm *d,* pass through it and return toward the opposite pole. When the speaker's voice causes the diaphragm to vibrate, however slight the vibration may be, a larger amount of magnetic lines of force enters the diaphragm when it

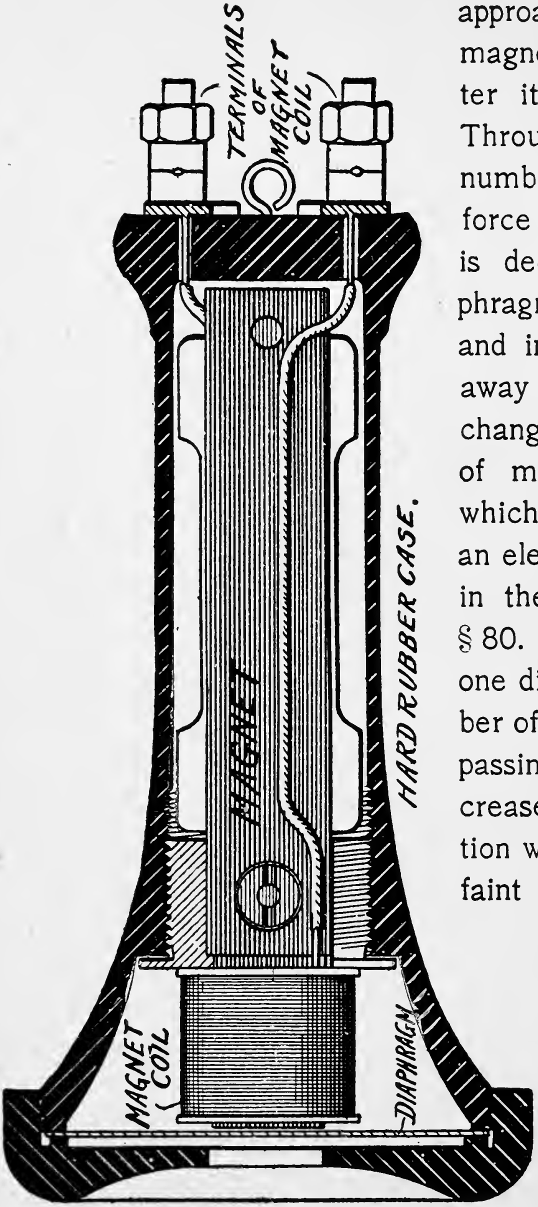


FIG. 114.

approaches the pole of the magnet, while less lines enter it when it moves away. Through this operation, the number of magnetic lines of force passing through the coil is decreased when the diaphragm approaches the pole and increased when it moves away from it. When these changes occur in the number of magnetic lines of force, which pass through the coil, an electric pressure is set up in the coil, as explained in § 80. The current flows in one direction, when the number of magnetic lines of force passing through the coil increases, and in another direction when it decreases. This faint current transmitted to the receiving apparatus increases or decreases the strength of its magnet, thus altering the amount of attraction the magnet exerts upon the diaphragm *d.* The diaphragm of the receiver is thus set into vibrations which correspond to those of the diaphragm of the transmitter and result in producing sound-waves like those which act upon the diaphragm of the transmitter.

The receiver

210. Fig. 114 shows the improved receiver, which is now in general use. Like its old type, it consists of a permanent magnet equipped with a coil and a diaphragm made of thin varnished iron, which are enclosed in a hard-rubber case for protection from variations of temperature, moisture, etc.

There are various types of receivers on the market, most of them differing in shape only, and all combining the essential features of permanent magnets, bearing coils on their poles and a thin iron diaphragm destined to transform into sound-waves the impulses brought in current form along the line from the transmitter.

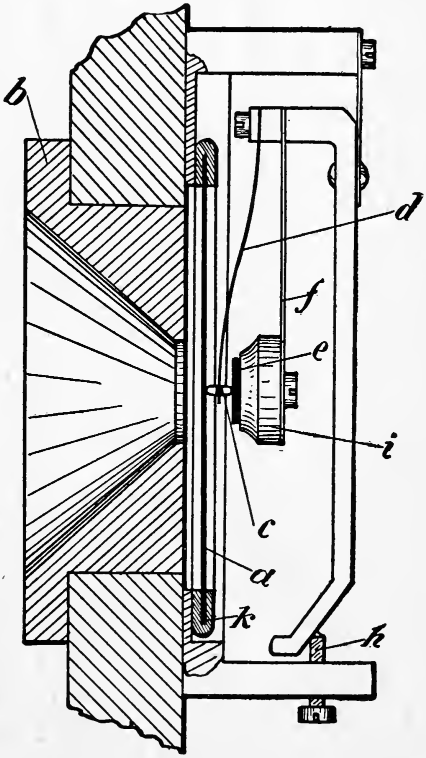


FIG. 115.

The transmitter

211. The transmitter constructed by Bell was not powerful enough to transmit electrical impulses satisfactorily over long distances ; a more powerful current was needed to overcome all obstacles in the line.

Berliner, Hunning, Edison and Blake, have designed transmitters based on the theory of varying pressure, which transmit electrical impulses more effectively. Fig. 115 shows a section of the Blake transmitter.

In this instrument the diaphragm *a*, surrounded by a rubber ring *k*, is fastened behind the aperture of the mouthpiece *b*. A short piece of platinum wire *c*, fixed to a fine spring *d*, touches the back of the diaphragm with one end, the other establishing a loose contact with the polished surface of a carbon button *e*, fastened to a spring *f*. The contact of the platinum wire and the carbon button may be adjusted by a screw *h*. Electrical impulses beating against the diaphragm, press to a greater or lesser degree the platinum wire *c*, against the carbon button *e*, thus varying the resistance of the contact. When this transmitter is connected into a circuit, the current of a battery passes through *d*, *c*, to *e* and *f* and then to the coil of a receiver.

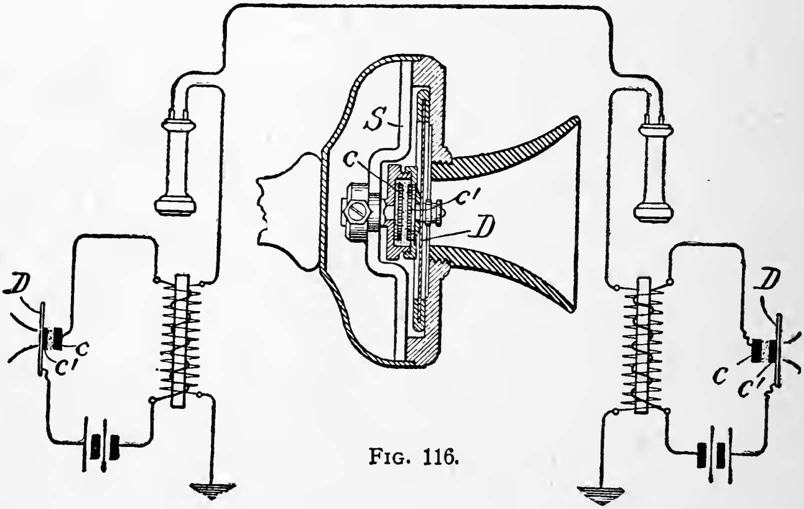


Fig. 116.

Being compelled to overcome a greater or a lesser resistance between *c* and *e*, the strength of the magnet of the receiver decreases or increases, thus producing the original sounds as described in § 209.

There are many different systems of transmitters using granules (one of which is shown in the center of fig. 116) or small globes of carbon as a means for establishing and varying the contact. The Berliner and Ericson types are the most widely known.

Microphones

212. A device for rendering faint or distant sounds distinctly audible, is called a *microphone.* The principle of the microphone is shown in fig. 117. It consists of a stick of carbon *a*, which being cut to sharp points on both ends, is held loosely, between two blocks of carbon *b* and *c,* which are fastened to a thin pine-wood board *d.* The microphone illustrated is in circuit with battery *B* and receiver *R.* When the board *d,* is also brought to vibration, thus establishing a more or less perfect contact of carbon stick *a* with the carbon blocks *b* and *c,* and offering the current passing through these contacts more or less resistance, the receiver *R* will reproduce the faintest sounds. Transmitters using microphones are called *microphone transmitters.*

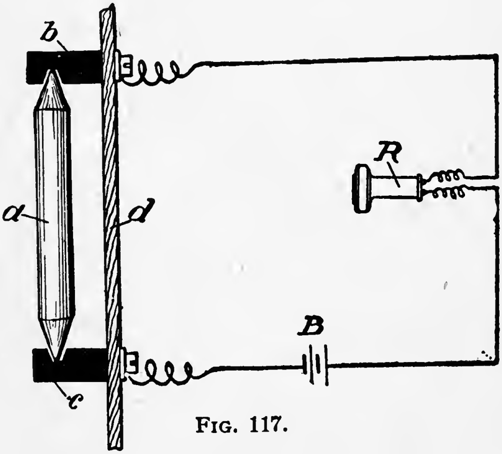


FIG. 117.

The telephone induction coil

213. In order to make the microphone transmitter, which may be operated usually with one or two battery cells, suitable for work over long lines, *electromagnetic induction* is used to strengthen the effect of the transmitter. For this purpose, especially designed induction coils are used in connection with the transmitters, the effect of which, is to do away with the scratching sound caused by the carbon particles of the transmitter. A section of such an *induction coil* is shown in fig. 118. The core *a*, of the induction coil, is made up of pieces of soft iron wire inserted into *b*, a tube of insulating material. The primary winding *c,* is of coarse wire, the secondary *d*, of thin wire as described in § 82. The primary coil is then connected in series with the transmitter and battery and the secondary coil in series with the line, as shown in fig. 116.

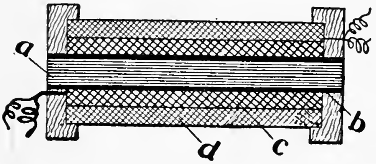


FIG. 118.

The magneto-generator and the bell

214. The magneto-generator consists of a number of permanent horseshoe magnets, which are so arranged that an armature mounted on a crank, can revolve between the magnet poles, thus producing an alternate current which is sent toward the bell. (see § 81.)

The bell consists of a polarized magnet having two poles and an armature, which is pivoted in its center, so as to allow it to sway from side to side as it is alternately attracted by the magnet-poles. The current from the magneto-generator, being an alternate current, causes the armature to be attracted by each pole successively, the rod or clapper vibrating then with great rapidity and striking the two gongs above it one after another

Complete subscriber sets

215. A complete telephone set, two of which may be used for connecting two distant places, is shown in diagram in fig. 119. This set consists of a transmitter, induction coil, battery, receiver, a bell and the magneto-generator.

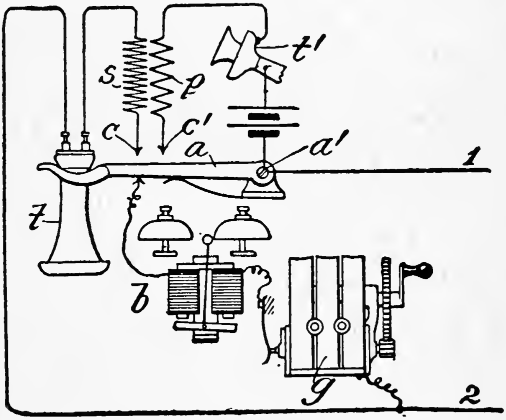


FIG. 119.

The telephone switch lever a, is pivoted at one end a', the other end being formed into a hook to support the telephone receiver t, when not in use. This switch lever a, is provided with a spring which tends to hold it in its elevated position, and in which it touches the two contact springs c c'. When the receiver is hung on the hook, its weight overcomes the tension of the spring, and the switch lever touches a contact, thus completing the circuit from line 1 to a' through the polarized bell b, magneto-generator g to line 2. When the lever is in the position just described, the bell b, of this station will ring when the crank of the magneto-generator is turned on the other point.

By lifting the receiver f, the lever a is brought into contact with the springs c and c' thus completing the two circuits: The one consisting of the microphone transmitter *t'*, local battery and primary windings *p*, of induction coil: The other of line *1*, secondary windings *s*, of induction coil receiver *t*, and line *2*.

The local battery is always cut out of circuit when the telephone is not in use and when the receiver rests on the hook. When a signalling current is sent from the other end of the line, the bell is rung; and, in taking the receiver from its hook to answer the call, the circuits are automatically changed — the bell and the magneto-generator being cut out of circuit and the transmitter, local battery, receiver and induction coil brought into circuit.

When it is desired to call up the other point of the line, the crank of the magneto-generator is turned while the receiver rests on the hook, and then the receiver is taken off the hook to listen for the answer of the station called.

The bell is sometimes connected in parallel with the magneto-generator, or *bridged*.

Central exchange

216. In cities, the lines of all the users of telephones, are connected and lead into a common center known as the *central exchange*, and there to a *switchboard*, each line having its own number. The subscriber, when wanting to speak to another, calls by means of his magneto-generator the central exchange, which connects him with the desired number, having signalled it with the magneto-generator.

The telephone switchboard

217. The switchboard is the means by which the telephone operator quickly connects the subscribers. As there is almost always a very large number of lines connecting with a common switchboard, they are generally very complicated.

Fig. 120 shows a simple ten-line switchoard; As may be seen, the switchboard consists of two distinct parts, one the *vertical* board with a series of *drop shutters* or *drops,* and a series of round apertures lined with metal with an apparatus *jack* (spring jack) behind the board, and a *horizontal* board upon which appear a row of upright instruments, the *plugs*, and sometimes a row o short levers.

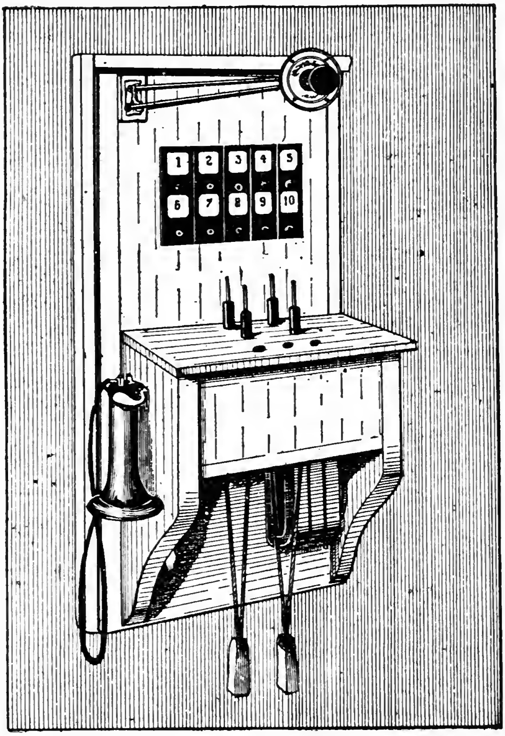


Fig. 120.

The jack and plug

218. The *jack* is an (see *A* fig. 121) arrangement by means of which, the connection of two subscribers may be made, by inserting the *plug B* into its aperture, so that it comes into contact with the line by touching the spring *a.* The forward end of the spring *a*, rests in its normal position on a pin *b*, which being safely insulated from the base *c*, connects with the wire leading through the coil of the drop to the ground. Normally, therefore, the line wire is connected to the ground. When the plug is inserted into the aperture of the jack, it disconnects the line from the ground by lifting the spring *a* from the pin *b* and establishes a connection of the other line to the jack where another plug, connected with the former by a flexible cord *d*, is also inserted.

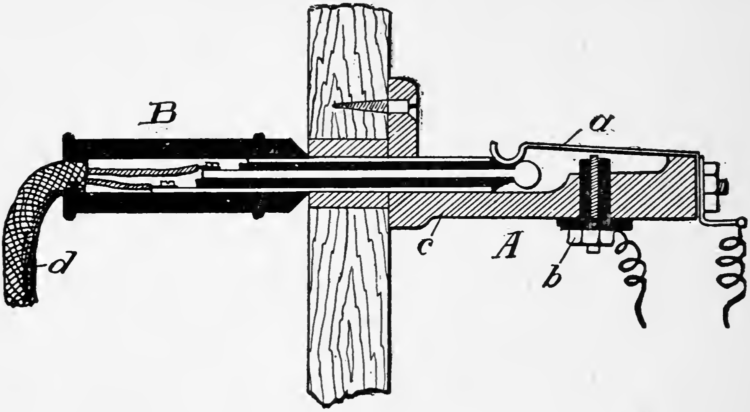


FIG. 121.

The drop

219. The drop (see fig. 122) is an apparatus intended to attract the attention of the operator when a subscriber wishes a connection. The electromagnet *a*, is mounted on the back of the switchboard's front plate, in which an aperture

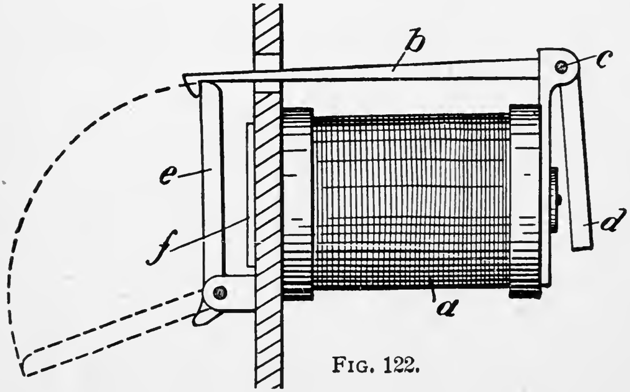


FIG. 122.

has been left, to allow a rod *b* pivoted in *c* and connected with the armature *d* of the electromagnet, to move up about one quarter of an inch. The rod *b*, is provided on its forward end, with a hook which holds the drop shutter *e* in its raised position. When a current from the magneto-generator of a subscriber passes through the coil of the electromagnet *a*, the armature *d* is attracted, thus lifting the rod *b*. The drop shutter *e*, falls down (see dotted position of shutter) and displays to the operator the number attached at *f*, by which the line in designated.

Operation of switchboards

220. Fig. 123 shows a diagram of a *grounded* or *common-return* switchboard. Keys *a*, *b*, *c*, are the *operating keys*, *a* and *c*, being the *ringing keys*, and *b* the *listening key*. The plugs *e* and *d*, connect by their flexible conducting cords with the ringing keys *c* and *a* respectively. Each of the keys has two contacts *1* and *2* which enable it to be in connection with either of two circuits. The switchboard shows the magneto-generator *g*, the operator's telephone set *f*, the drop *k*, jack *j*, and clear-out-drop *i*. When the subscriber whose line connects to jack *j*, desires a connection, the current of his magneto-generator passes through line, through jack *j*, and coil of the drop *k*, to ground, thus releasing the shutter of the drop and exposing the number of the subscriber's line. The operator inserts plug *e* into the same numbered jack *j*, depressing at the same time the listening key *b*, thus connecting his own telephone set *f*, in circuit with line. By these operations, the operator is enabled to converse with the subscriber, the circuit being complete through the line wire, the jack *j*, the plug *e*, and its cord, to contact *1* of key *c* and thence through spring of key *b* to the telephone set *f*, which contains a receiver, a transmitter, induction coil and battery, and ends in the ground connection, like all subscriber sets. When the subscriber has told the operator the number with which he wishes to connect, the operator inserts plug *d* into the jack of the desired number, depressing at the same time

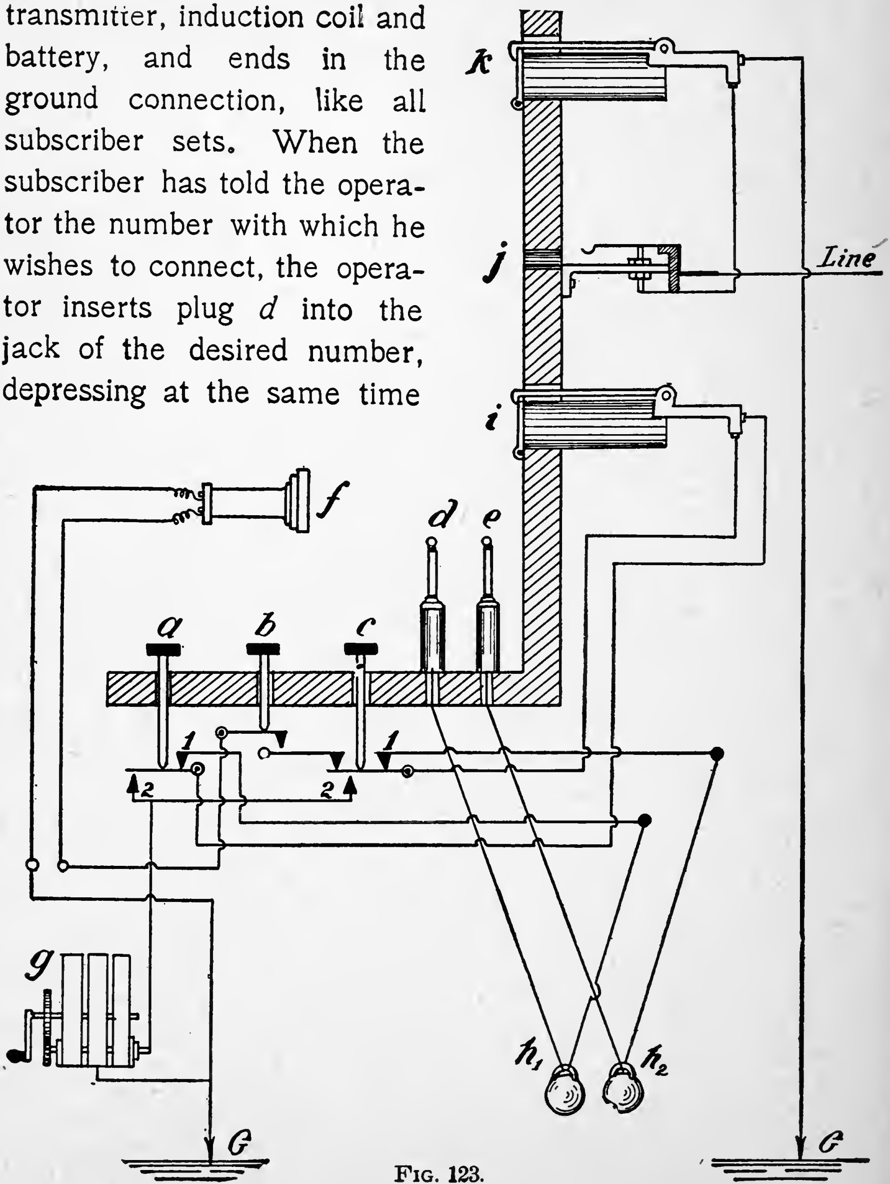


FIG. 123.

the ringing key *a,* thus throwing into circuit his own magneto-generator *g,* whose handle he turns. Thus a circuit is established from the ground in the exchange, through the magneto-generator *g,* the contact *2* of key *a*, cord and plug *d* and through the jack with the desired line, and subscriber's apparatus, the bell of which is rung. Then the two subscribers may converse, being connected across the clearing-out drop *i,* whose shutter falls, when the subscribers having finished their conversation "ring off" by means of their magneto-generators. Then the operators releases the plugs *e* and *d,* from the jacks of the two subscribers, the pulley weights h_1 and h_2 bringing them back into the position shown in the cut. The grounded circuit switchboard has practically passed out of existence and, while a few of them may be in use, they are not manufactured at present.

Common battery telephone system

221. The various faults, formerly found in telephone lines, were generally caused by *faults* in the subscriber's battery or magneto-generator.

The magneto-generator being the most expensive instrument in the subscriber's set, and easily put out of order, attemps were made as long ago as 1878 to do away with it, also dispensing with the battery; and to supply the current necessary to transmit speech and to ring the bells from a common battery located at the central exchange. This system developed rapidly and at present is used in almost all large exchanges.

In the so-called *central energy,* or *common battery system,* the current is generated at the central exchange and supplied to storage batteries which, having an extremely low internal resistance and being able to maintain a constant E. M. F. for a considerable length of time, are well fitted for use in telephone work. From the secondary batteries, the current is sent over the switchboard to the subscribers. Thus the current of all subscribers is brought under control of the operator at the switchboard, the cost of frequent inspection of the subscriber's sets is greatly reduced, and the cost of repairs and renewals of batteries practically annihilated.

Automatic telephone system

222. The mistakes made by operators when connecting and disconnecting the lines of subscribers at the central exchange and the high cost of the operator's labor, induced many to consider the problem of operating central switchboards automatically; in other words, to make it possible for every subscriber to establish and break the connection with the number desired without the intervention of the central exchange. The earliest machines for this purpose were invented in 1879 by Messrs. Connolly and McTighe, at Washington, D. C. Being very complicated and therefore not practical, these machines have never been used. In 1891 Strowger developed another machine which met with a similar fate, but Keith and Erickson finally improved the original Strowger machines and with these improvements they have been put into successful operation. To go into details of construction of the apparatus involved is beyond the scope of this book, therefore a mere mention is made in reference to the automatic telephone.

In the automatic system the central switches are governed in their action by the subscriber who desires connection or disconnection as the case may be. The preliminary action of calling for the number of the party sought is done by operating the dial on the telephone. In this way the subscriber makes his own connection with any one desired. In the same way the subscriber is able to disconnect himself from the line.

Questions and Answers.

Q. What is a pole-changer?

A. A key for sending telegraphic signals by reversing the current.

Q. What is a telegraphophone?

A. An apparatus which, by means of an electromagnet whose coils are in circuit with the subscriber's telephone set, registers spoken words on a moving strip of steel, so that they may be reproduced by means of a simple receiver, under whose magnets, the strip is moved.

Q. A common telephone switchboard consists of what apparatus? For what purpose do these apparatus serve?

A. The drops or lamps serving to attract the operator's attention to the number of subscriber who wishes connection.

Spring jacks and plugs, by means of which, connection between two subscribers is established.

Clear-out-drops, or lamps announcing to the operator that the subscribers have finished their conversation.

Operating keys. The ringing keys being used to call subscribers by ringing the bells of their sets, the listening keys being used to bring the operator's set into circuit for communication and connection of the switchboard operator with the subscriber.

Q. An operator's set consists of what apparatus?

A. Of receiver, transmitter, battery and induction coil.

CHAPTER XIV.— WIRELESS TELEGRAPHY.

Ether

223. The earth is surrounded by air; an atmosphere which is supposed to extend about twenty miles above its surface, forming a hollow ball, the smaller or inside diameter of which, is that of the earth, the larger or outer diameter equalling that of the earth, plus about forty miles. It is said that the distance between the earth and the sun is more than ninety million miles and it is generally accepted, that between the sun and the atmospheric globe described above, there exists some unknown substance, which scientists call the *ether*. It is supposed that the ether is a fluid medium existing in all space, permeating the denser atmosphere, passing through all substances, gases. liquids, and solid bodies, just as light penetrates a plate of transparent glass. Even the molecules of metals and minerals are not impervious to this invisible, ever present, mysterious, liquid substance.

Waves

224. Undulations of fluid or semi-fluid surfaces, commonly known as *waves,* are known and understood by everyone. When striking the smooth surface of a pond with a stone or stick, *waves* are set up, which rapidly transmit their motion to the remaining part of the surface of standing water, causing it to *wave*. Thus produced, they extend in all directions from the point of generation until they are broken by some object floating on the water or by the banks, or if the pond be very large they become by friction smaller and less visible until they entirely disappear.

Imagine fig. 124, were a section of the undulating surface of water, which, when in rest, is represented by the line *M*. The distance between the highest points of a wave *A*, is called its *length*. The distance *B*, between the highest and the lowest point of a wave is called its *amplitude*. The line *M*, which divides the amplitude *B*, into two equal parts is called the *axis of the wave*.

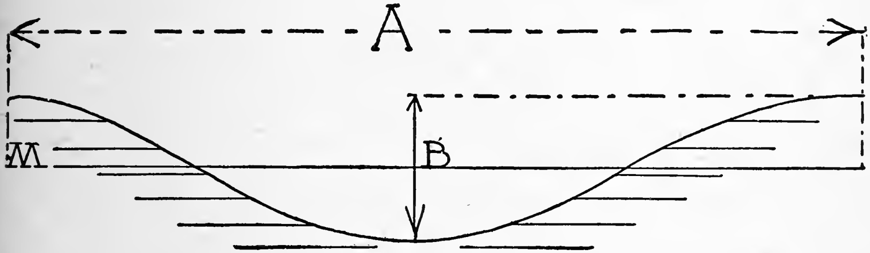


FIG. 124.

Interference of waves

225. If two points of the surface of the water in a pond were struck simultaneously, the waves extending from these points, would meet with each other and break. This meeting and breaking is called *the interference of waves*. The wave length and amplitude depends upon the strength of the blow upon the surface of the water.

When waves are set up, the particles of water are caused to vibrate along a line perpendicular to the surface, assuming their former position, when the waves subside.

Transverse and longitudinal vibrations

226. Fig. 125 represents a pulley *A*, over which, lies a thin wire *B*, one end of which, is connected to a circular piece of wood *C*, (called a floater,) the other, to a weight *D*, which however high or low the floater *C* may swing, keeps the wire *B*, strained. By dropping the floater on the surface of water, *M*, waves are produced which cause the floater to swing up and down along a line perpendicular to the surface, *N–O*, which line in this example is represented by the strained wire *B*. The weight *D*, moving up or down will indicate precisely the height of the waves set up.

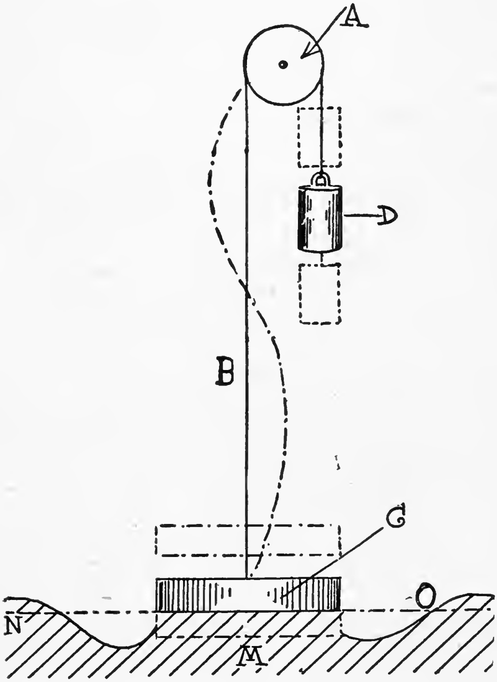


Fig. 125.

Such vibration described in the example above, where the particles swing perpendicular to the direction of the waves, is called *transverse vibration,* and is represented in the above example by the swinging floater in its relation to the waves set up, by dropping on the surface of the water.

The wire *B*, by striking it at a point with the finger may be brought into vibration like a string of a violin. Then the floater *C*, will swing along the direction of waves set up in the wire. Such vibration, which causes particles to swing along the line of the direction of waves, is called *longitudinal vibration.*

Ether waves

227. Heat and light are supposed to extend from their respective sources, through the ether, toward other bodies which they heat or light by means of the transverse waves they produce in the ether. Heat sets up waves in the ether, and their presence may be demonstrated by holding the hand toward a heated object ; yet no heat will be felt when an iron or wooden plate is interposed between the hand and the heated object, a proof that the waves are deflected. Heat waves are longer than light waves, hence it is believed that the latter are merely heat waves of shorter length, as may be demonstrated by the friction of two substances which first give off heat and then light.

Like the surface of the water disturbed by the dropping of a stone, according to their length and amplitude, the ether transmits either heat or light waves, in all directions.

The frequency and length of ether waves varies. It is estimated, for instance, that light has a velocity of about 185,000 miles per second.

The immense velocity of the waves may be more clearly understood when it is considered that their velocity in one second equals a little more than seven times the circumference of the earth, or that these waves would travel a little more than seven times around the earth in one second.

Ether waves due to electromagnetic disturbances

228. The first experiments and researches regarding waves produced in the ether by electromagnetic disturbances, were made in 1865 by Clerk Maxwell, who constructed mechanical models to demonstrate electrical actions. Later, his models were improved by Professors Fitzgerald and Oliver Lodge, who thoroughly studied the experiments of former scientists and prepared a series of important papers upon the results obtained. Prof. Lodge was the first who explained the actions of a Leyden jar by means of a hydraulic model. Even earlier, as far back as 1842, an American, Joseph Henry, suggested that the discharge of a Leyden jar might be of an oscillatory character. In 1847, Helmholtz stated the same supposition, which was proved to be true by the mathematical demonstration of Lord Kelvin in 1853 and by experiments of Feddersen in 1859.

The syntonizing, or tuning together of the oscillator and resonator, may be compared to the adjusting of two tuning forks. The vibration of one fork produces sound waves, which in turn cause the other fork to vibrate.

Professor Hertz, in 1888, actually produced electromagnetic waves in the ether by an apparatus, a diagram of which, is shown in fig. 126

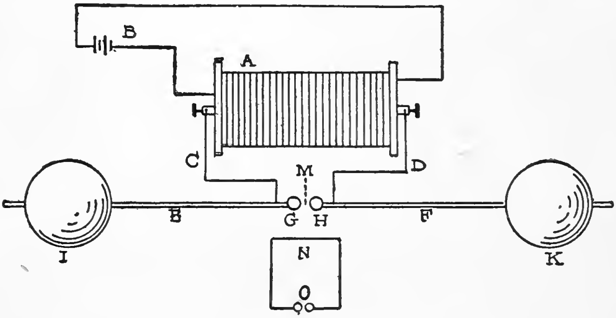


Fig. 126.

The apparatus consists of an induction coil *A*, to which a current is supplied by a powerful battery, *B*, in a manner similiar to that shown in dealing with Ruhmkorff's induction coils (see § 82). The secondary windings of this induction coil are connected with the so-called *oscillator*, by wires *C* and *D*, which consist of two brass rods *E* and *F*, terminating in small brass balls *G* and *H*. Large balls *I* and *K*, are so adjusted as to slide on rods *E* and *F*, respectively. The air space *M*, called the air gap, between the balls *G* and *H*, may be enlarged or diminished by moving the rods *E* and *F*. The *resonator N*, consists of either a wire rectangle or circle which terminates in two small brass balls, so that a small air gap *O*, is left between them. The oscillator may be brought in tune with the resonator by altering the positions of balls *I* and *K*.

When a momentary current is sent through the primary windings of coil *A*, the current induced in the secondary windings produces a spark across the air gap *M*. This spark however, which has the appearance of a single flash, is in reality flying back and forth of the discharge between the small balls *G* and *H*, with intense rapidity. By this discharge a vibration is set up in the ether which by friction slowly dies away, similar to the waves on the water surface described in § 224.

The electromagnetic waves set up in the ether by a spark passing over the gap *M*, extend in all directions; but principally at right angles to a line that would connect the centers of the balls *G* and *H*. When the ether waves extending from gap *M*, pass through the resonator, electrical vibrations are also set up in the wire of the resonator which create a current in the wire and small sparks passing over the gap *O*, of the resonator are visible. No sparks, however, will be observed when the two apparatus, the oscillator and the resonator are not in perfect harmony; then the waves coming from gap *M*, *interfere* with the electrical vibrations set up in the resonator and disturb them. Compare the interference of waves described in § 225.

Bjerknes succeeded in obtaining curves showing the rapid subsidence of electromagnetic waves in the ether, by means of calculations based on the readings of an electrometer inserted between the balls of the resonator *N*.

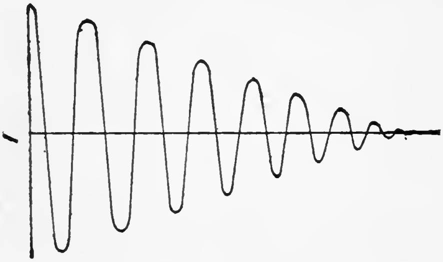


Fig. 127.

Fig. 127, shows the extremely rapid subsidence of electromagnetic waves, when the oscillator and the resonator are not in tune.

Perfect electromagnetic waves set up when the two instruments were tuned to *syntonism,* and when a ring shaped resonator was used are shown in fig. 128.

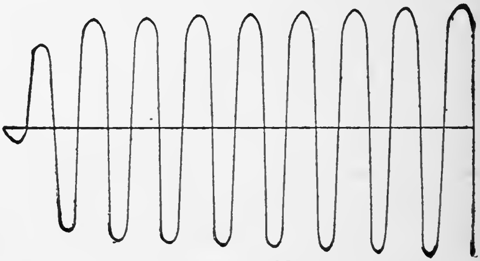


Fig. 128.

The coherer

229. The resonator has proved to be of no use for detection of electromagnetic waves sent over long distances. It was replaced by the so-called *coherer,* developed by Prof. Hughes,which after some improvements by Guglielmo Marconi is now used in wireless telegraphy. The Marconi coherer fig. 129, consists of a small glass tube *A,* about one-eight of an inch in diameter and $1\frac{1}{2}$ inches long, from which the air has been exhausted by means of a mercury pump described in § 185. Two silver poles *B* and *C,* are fitted into the tube so that a gap of about $1\frac{1}{16}$ of an inch

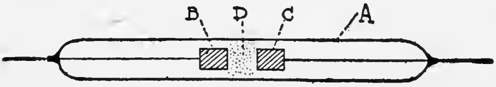


Fig. 129.

in length is formed between them. The gap *D,* is filled with granulated filings of an alloy of 96 parts of nickel and four parts of silver worked up with the merest trace of mercury. The electrical resistance between poles *B* and *C,* amounts to several thousand ohms, but when waves of a properly tuned oscillator pass through the tube, the filings are electromagnetically attracted to each other, thus forming a conductor, of very few ohms resistance, between the silver poles.

When the filings stick together by electromagnetic waves passing through the tube, they are said to *cohere.* Marconi's coherer is able to detect the merest trace of electromagnetic waves, is not liable to get out of order, and may be easily replaced when defective.

Wireless telegraphy

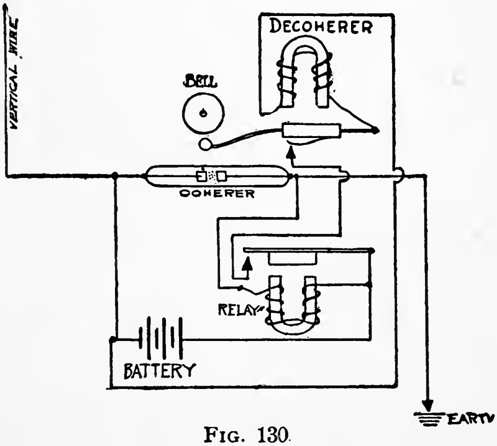


Fig. 130.

230. Fig. 130 shows the first receiving station for electromagnetic or *Hertzian* waves, which was constructed by Professor Popoff. When an electromagnetic wave strikes the vertical wire, it is conducted into the coherer, causing the filings to *cohere,* and thus reducing the enormous resistance between its silver poles. A current from a battery is enabled to flow through the coherer, and then through the external circuit, where it energizes the magnets of a telegraph relay, thereby closing another circuit (not shown in illustration) containing a telegraphic recorder and battery. As soon as the relay is energized, the circuit of an electric bell is closed, its magnets also energized, and the bell-hammer striking against the coherer jars the filings apart, or decoheres them. If the waves are continuous they again cause cohesion and a working of the telegraphic recorder.

This and the transmitting system was improved upon by Signor Guglielmo Marconi, who laid the first foundations for the practical use of wireless telegraphy.

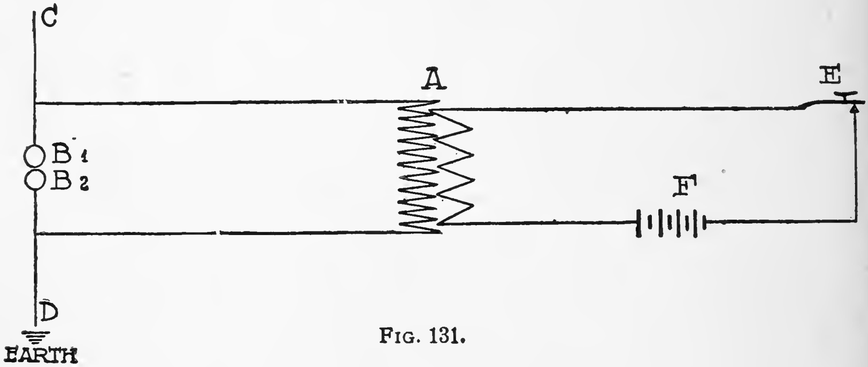


FIG. 131.

Marconi's transmitting station in its earliest form, (see fig. 131), consisted of an induction coil *A*, whose secondary coil terminals were connected with two small spheres B_1 and B_2, which were separated from each other by a small air gap. Sphere B_1 was then connected with a long vertical wire, *C*, the sphere B_2, being connected with the earth by wire *D*; When the Morse key *E*, was depressed, the current of battery *F*, flowed through the primary windings of induction coil *A*, inducing a secondary current which flowed to spheres B_1 and B_2, maintaining a stream of sparks between them, as long as the key *E*, was pressed down. Thus produced, sparks set up electromagnetic waves, which extended in all directions in a form of wave shown in fig.

128, which may be detected anywhere by means of a receiving station, the simplest form of which, was shown in fig. 130. These transmitting stations, however, do not answer the purpose very well, for which they were intended and the secrecy of messages transmitted through them, may not be guaranteed, as any receiving station placed anywhere, will detect the electromagnetic waves sent by them.

When it is desired to send waves in only one direction, an oscillator designed by Professor Righi, of Bologna, former teacher of Marconi, is used (see fig. 132), in connection with a parabolic reflector. (See fig, 133.) This reflector concentrates the waves in the required direction.

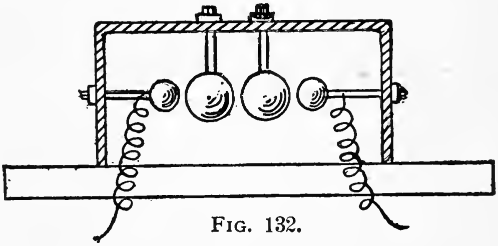


Fig. 132.

When it is desired that the receiving station register only the waves coming from a certain direction, then the coherer is placed in the focus of a parabolic mirror which faces the direction. The arrangement is the same as in fig. 133, the oscillator being replaced by the coherer. Reflectors may not be used for transmitting messages over long distances. Experiments in which they were used were made over a distance not exceeding two miles.

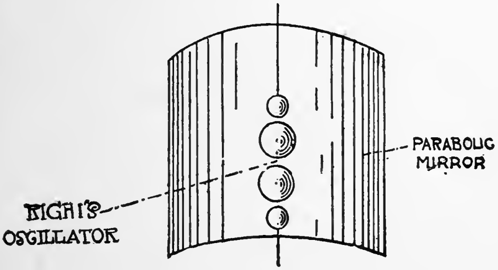


Fig. 133.

As shown in fig. 130 and fig. 131, a long vertical wire is used in connection with the transmitting and receiving stations. The effect of this long vertical wire is to increase the length of the electromagnetic waves set up in the ether, and thus enhance their power of penetrating obstacles, obstructing all waves of shorter length. It is supposed that the wave length equals about four times the length of the vertical wire employed. The vertical wires are generally suspended from high poles or wooden towers, the height varying according to the distance over which the signals are to be transmitted. Generally they are 150 feet high. Such a vertical wire is called "antenna."

Marconi's Syntonic System of Wireless Telegraphy

231. The fundamental systems of wireless telegraphy described in the foregoing § 230 may not be used for practical work because of the interference of simultaneous messages from different stations, every one of which sets the telegraphic recorders of all surrounding stations in motion. It also has been found that the receiving stations are affected by atmospheric disturbances and on such occasions, it was almost impossible to decipher the messages. To remedy this defect it was necessary to construct the two stations with a syntonized transmitter and receiver, so that the receiver would respond only to the impulses which are intended for it, and not be affected by the communications of other surrounding stations. Yet by syntonizing the two apparatus the strength of the electromagnetic waves

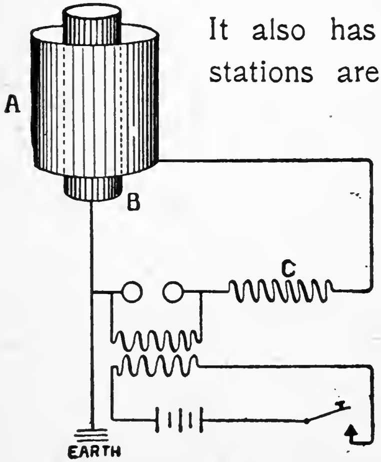


FIG. 134.

were weakened. Marconi constructed a transmitting station fig. 134, in the circuit of which there are two hollow cylinders *A* and *B,* one of which is inserted into the other and the inner cylinder *B,* being connected with earth, they act as a condenser. The effect of this earthed inner cylinder is to increase the capacity of the oscillator. Later an induction coil was added into the circuit between the spark gap and the cylinders (so-called radiators). With. this arrangement the oscillation period of the receiving cylinder could be made so as to correspond with a single transmitter so that it would be affected by the waves coming from this transmitter only.

This problem of perfect syntonizing two stations without affecting the strength and length of the waves has not yet been satisfactorily solved.

Different systems of wireless telegraphy

232. Many different arrangements of apparatus have been designed for successful transmission of messages through the atmosphere; however, though the principle of wireless telegraphy specified in Marconi's patents — the production and detection of electromagnetic waves — is the foundation of all systems, it is quite important to know the characteristics of the most successful constructions.

Fig. 135 shows the new arrangement of Marconi's stations. The transmitting station contains three separate circuits the first of which, consists of battery *A*, key *B,* and primary windings of induction coil *C.*

The second circuit consists of secondary windings *D,* of the induction coil, gap *E,* condenser *F*, (to make the oscillations more powerful) and the primary windings *G,* of a transformer which transmits the oscillation to the third circuit, consisting of the secondary transformer coil *H,* one end of which, is connected to earth, the radiator *I,* with sliding contact *K,* (by means of which the inductance of the radiator may be varied) and the vertical wire *L.*

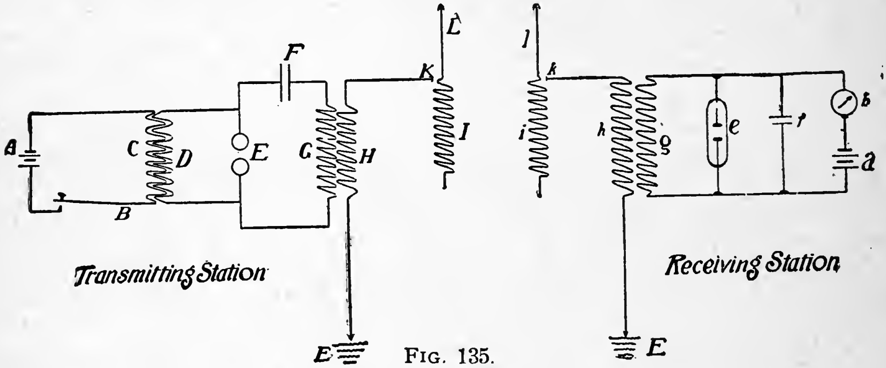


FIG. 135.

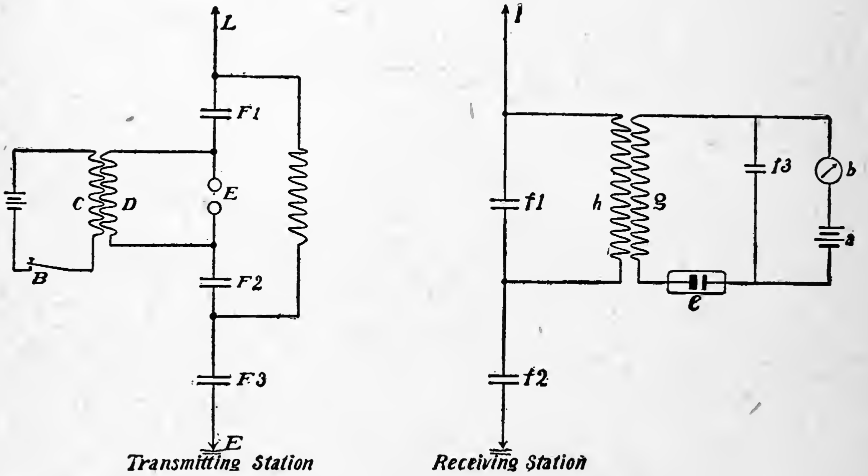


FIG. 136.

The receiving station contains two separate circuits. one of which, consists of the vertical wire *l,* with the radiator *i,* sliding contact *k,* and primary coil *h,* of the transformer; the second, consisting of secondary coil *g,* of transformer, the coherer *e,* parallel with condenser *f,* and battery *a,* in series with the telegraph recorder *b.*

Fig. 136 shows a diagram of the arrangement of stations designed by Professors Lodge and Muirhead.

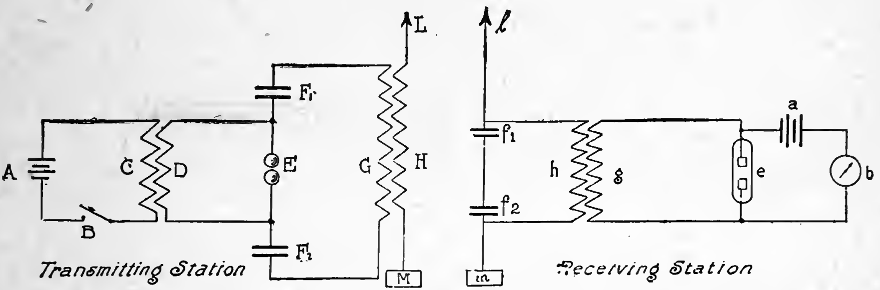


Fig. 137.

The apparatus of the different systems are named with same letters like those of fig. 135. The difference in the arrangement of the systems may be clearly seen from the diagrams. Fig. 137 shows diagram of stations designed by Professor Dr. Ferdinand Braun.

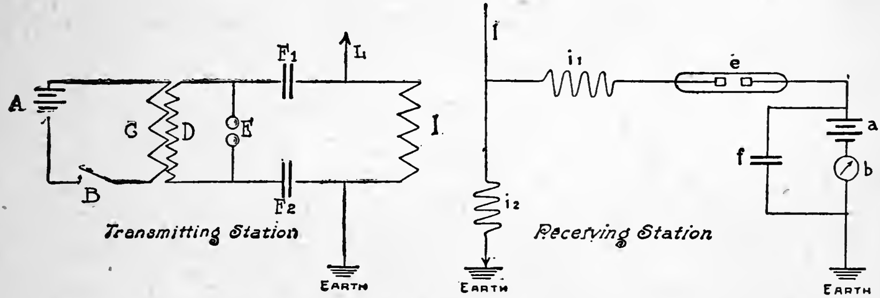


Fig. 138.

These stations show instead of the usual connection with earth a well insulated *capacity plate,* *M* (*m*). Fig. 138 shows the Slaby–Arco system. Fig 139, shows the Lee de Forest–Smythe system.

This arrangement differs considerably from all others. No condensers are used, and no induction coil. The current is supplied by alternator *N*, the key *B*, being in the secondary circuit.

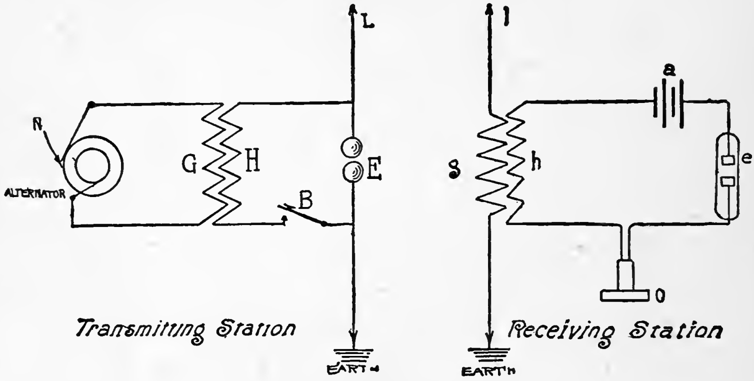


FIG. 139.

The receiving station shows instead of the telegraphic recorder, a telephone *O*, by which the operator hears the signals telegraphed, whose waves affected the coherer.

Questions and Answers.

Q. Describe a portable apparatus for military services?

A. Both, receiving and transmitting stations are placed in a car, on the roof of which is a movable cylinder, instead of the vertical wire. A 25 centimeter spark coil is used, taking about 100 watts. The current is supplied by accumulators, which may be recharged by a dynamo placed in the car. The earth connection is established by a bare wire-net, which is laid on the ground when signalling. This arrangement may be successfully operated over distances of 30 miles.

CHAPTER XV.

ELECTROPLATING AND ELECTRO-METALLURGY

Electrolysis

233. As far back as 1801, Wollaston observed that a strip of silver when connected with another more positive metal and immersed in a solution of copper salts became covered with pure copper, and in 1840, Elkington successfully completed his experiments of coating metals with a thin film of silver and gold, thus introducing *electroplating,* into commercial use. Yet, practically electroplating came into common use only a few years ago.

Electroplating is the process of coating metal articles with thin films of other metals which are obtained by electrolysis from the solution of their salts. (Compare § 45.) The articles which are to be plated are usually made of metals such as Britannia, brass and German silver, the coating being usually of gold, silver or nickel.

Silver plating

234. Silver plating is the most important branch of electroplating. The salts used in this process are chloride of silver, nitrate of silver and cyanide of silver. A standard solution for silver plating may be made in the following way: mix three ounces of silver chloride with water until a thin paste is made; then dissolve nine to twelve ounces of 98 per cent potassium cyanide in a gallon of water; after doing this add the silver chloride paste to the solution, meanwhile stirring constantly. The solution should be filtered before being used. In case a smaller quantity of the bath is required, the chemicals must be mixed so as to remain in the proportions, above specified. Great care must be taken to keep the proper ratio of current, silver and cyanide; a weak current requiring more, a strong current less of cyanide. Free cyanide lessens the resistance of the solution; too much of it causes a brownish color to appear on the plated articles, while an insufficient quantity of cyanide renders the plating irregular.

Vats for silver plating

235. For commercial silver plating, the vats are usually six feet long, three feet wide and two feet deep, generally made of wood, or if of iron, they are lined on the inside with wood. Fig. 140, shows such a vat, containing a solution in which a silver plate is immersed, and connected with the positive pole of the battery, thus serving as the anode, while the articles to be plated such as knives, forks, spoons, etc., serve as the cathodes, and hang on looped pieces of insulated wire which are electrically connected to a copper tube, laid across the vat and connected with the negative pole of the battery.

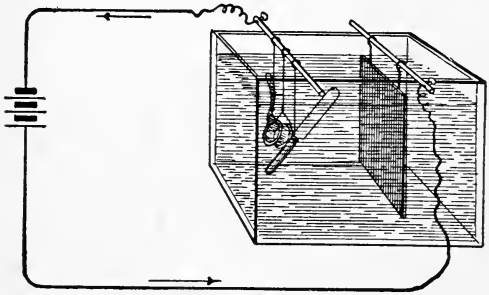


FIG. 140.

When a current is sent through this vat, pure silver is deposited on the cathodes, while an equal amount of silver is dissolved, and taken away from the silver anodes, thus rendering the solution always serviceable. In these vats, the silver anodes, only, must be changed when dissolved too much; the solution does not require any change for a number of years.

Nickel plating

235. Articles, mostly machine parts, made of steel, iron, copper or brass, are usually nickel plated because of the hardness and durability of the nickel coating, which prevent the articles from oxidizing.

The nickel plating bath is usually composed of the double sulphate of nickel and ammonia. The double salt is dissolved by boiling twelve to fourteen ounces of it in a gallon of water, and this solution is then diluted with water until a hydrometer placed in it stands at 6·5° to 7° Beaume.

The nickel plating vats are usually made of wood and lined with lead. Carefully polished articles are dipped in a hot solution of lye and water, and then in an acid solution as described in § 241; they are then hung in the bath, as are the articles to be silver plated, and thus act as the cathodes; the anodes being plates of nickel. To improve the quality of the nickel deposit, an addition of 0·125 ounce of benzoic acid per gallon of solution is recommended. The current for nickel plating should be of moderate strength, from 0·5 to 0 8 ampere for every fifteen square inches of the article, the voltage varying, from three to six volts being the most suitable.

Copper plating

237. Copper plating is mostly used for the purpose of giving iron articles a bronze finish, or to prepare articles for silver plating. The formula most commonly used at present is: To each gallon of water add five ounces of copper carbonate, two ounces of potassium carbonate, and ten ounces of potassium cyanide. The vats are of the same construction as those used in nickel plating, the anode being in this case a plate of copper. Before plating, the articles are cleaned with the solution described in § 241.

Gold plating

238. The operation of gold plating does not differ much from that of silver plating. The bath is usually made of a solution of the double cyanide of gold and potassium in water, the solution being prepared in the same way as for silver plating. (See § 234.) Baths for hot gilding should contain from ten to twenty grains of gold per quart of solution and a considerable excess of cyanide; baths for cold gilding requiring from 60 to 250 grains of gold for each quart of solution.

Current and pressure for plating

239. The current for plating may be furnished by a battery or by a dynamo generating a current at a low pressure. Resistances, in circuit with the coils of the dynamo-magnets, permit the adjustment of the pressure to suit the purpose. Too great a current renders the articles gray or brown and rough, while a small current plates well; but if too small, it makes the operation of plating too slow. It was proved by experiment that the most serviceable current for silver plating is about one ampere for each sixty square inches of the surface of articles to be plated. The vats may be connected both in series or in parallel.

Preparation of articles for plating

240. Before submerging the articles to be plated in the depositing vat, they must be properly cleaned, and free from grease and oxides, which would cause the silver deposit to peel off. For this purpose, all articles must be polished and thus all scratches removed. They are then dipped in a warm bath, consisting of a solution of caustic potash or soda in water. This cleansing solution may be prepared by dissolving commercial lye in water, and may be used for a great length of time.

After the articles have been in this solution for awhile they are dipped in a bath of diluted acid, which renders their surface smooth, and then after having been carefully washed in running water, they are placed in the depositing vat. Great care must be taken not to touch any part of the articles to be plated with the fingers as they may thereby be made greasy, in which case they would not plate properly.

Cleaning solutions

241. The cleaning of articles before plating is done by means of solutions of acids, varying with the different materials of which the articles are composed. The solutions in general use are as follows:

For copper and brass, 100 parts water, 50 parts nitric acid, 100 parts sulphuric acid, two parts hydrochloric acid ;

For zinc, 100 parts water and 10 parts of sulphuric acid ;

For silver, 100 parts water and 10 parts nitric acid ;

For cast iron, 100 parts water, four parts nitric acid, 12 parts sulphuric acid, and two parts hydrochloric acid;

For wrought iron, 100 parts water, two parts nitric acid eight parts sulphuric acid, and two parts hydrochloric acid.

Finishing of plated articles

242. After having been plated the articles must go through a series of processes, namely, scratching, buffing and polishing, which are usually done by three different wheels, which rotate with great rapidity; one made of brass-wire, one of leather, and the other of canvas. Sometimes the articles are polished with the hand by means of steel or agate tools.

Electrotyping

243. Electrotyping which is now used in almost all large printing offices is the process of reproducing type and wood cuts by means of copper plating. First an *impression* of the type to be electrotyped is made on wax or soft paper pulp, which is done by pressing the wax upon the type. Then this impression is coated with fine plumbago so as to make it a conductor; it is then hung in a copper plating vat, as described in § 237, where copper is deposited upon the mould. The thickness of this deposit varies according to the requirements of the type. The shell is then trimmed and backed up by a filling of melted type metal which is poured upon the back of the shell. Electrotyping has a great advantage in that it permits the setting up of large volumes with only a small font of type, which is always distributed after they have been electrotyped.

Electrolytic refining of copper

244. Refining copper is the most important application of *electrometallurgy.* Crude copper, the product of smelting ores in ovens, usually contains many impurities, such as silver, gold, iron and lead, which greatly affect its conductivity; There are about five per cent of such impurities in crude copper. By electrolysis these impurities may be easily separated from the copper, and thus *electrolytic copper* produced, which contains only such a small quantity of other metals that it has a conductivity almost as high as (98 per cent) pure copper. Therefore almost all wires for electric work, as electric lighting, wires for winding armatures and magnets of dynamo-electric machines, and coils of measuring instruments are made of electrolytic copper.

The copper to be refined is cast into large and thick plates, which are then hung in large electrolytic vats to serve as anodes, constructed as those described in § 237. Cathodes are thin sheets of pure electrolytic copper, which are arranged so as to be in alternate rows with the anodes. The electrolytic solution consists of copper sulphate (blue vitrol) with a trace of sulphuric acid, dilluted in water. The copper dissolving from the anodes replaces the copper from the solution which deposits on the cathodes to form thick plates of almost pure copper, which may be worked into bars or drawn into wires, so as to serve their purpose.

The impurities contained in the copper of the anodes generally form salts with the electrolytic solution, and settle down on the bottom of the cells — this mud is called *sludge*. The silver and gold is then recovered from the sludge by smelting in ovens. Electrometallurgy is the cheapest method of separating gold and silver from copper. The largest electrolytic refineries are in this country, principally in the West, those in Montana being the most important.

Current and pressure.

245. The arrangement of the copper plates in electrolytic vats differs. In some cases they are connected in parallel ; in other instances in series ; the latter arrangement being more often met with, because it is more practical and does not require so many contacts as the former. Yet in the series connection, the leakage of current amounts to about 15 to 18 per cent.

The pressure required, varies from 0·2 to 0·4 volt for each cell, the current from 10 to 16 amperes for each square foot of the plates. From 8 to 10 pounds of copper are usually deposited per kilowatt hour at a pressure of about 0·3 volt; the cost of the process of manufacture amounting to about 0·7 cent for a pound of refined copper.

In general, the pressure should be as low as possible, while a current of high intensity is needed. Too great pressure also causes the impurities to deposit on the cathodes, thus rendering the deposit unsuitable for fine electrical work.

Refining of silver

246. When silver is to be recovered from copper, plates are cut of copper containing silver impurities, and used as anodes. Cathodes are thin silver plates slightly oiled. The electrolytic bath consists of a one per cent solution of nitric acid in water. The current causes formation of nitrates of copper and silver, by which action, copper and silver from the anodes are dissolved. From these formations silver is deposited on the cathodes, leaving the copper in the solution. Trays, placed under the cathodes serve to catch the silver deposit, which in the Moebius process is continually removed from the cathodes by means of brushes which, mechanically driven, sweep over them.

Reduction of aluminum

247. The process of reduction of aluminum from its compounds was discovered by Hall (1886) in the United States and almost at the same time by Heroult in France; but aluminum cannot be gained from its salts by simple electrolysis of solutions of its salts in water, because the recovered metal immediately oxidizes after being deposited on the cathodes. In Hall's process which is used now in the Niagara Fall's refineries, the vats are made of iron and lined on the inside with carbon plates, which at the same time serve as cathodes, the anodes consisting of large carbon cylinders. The bath consists of molten cryolite brought to a temperature of about 1,600° to 1,800° Fahr. The aluminum oxide separates into aluminum and oxygen; the oxygen passes to the anode, combining with its carbon into carbonic acid; (carbon dioxide) The aluminum settling at the bottom of the vats is tapped off at regular intervals. The current used, generally has an intensity of 5000 amperes, 7 to 8 volts pressure being sufficient. This current reduces one pound of aluminum for every 10 kilowatt-hours.

Electric smelting

248. That large electric arcs and their intense heat (see § 172, 173, 174) may be used for chemical purposes was made known by the experiments of Depretz as long ago as 1848; yet their practical use for this purpose was not made until 1880 when Sir William Siemens published an interesting paper regarding his own experiments.

In electric smelting the heat of the arc is utilized, by placing the ores to be melted between two great carbon electrodes in furnaces, built of fire-brick and lined with carbon. Electric smelting is used in the manufacture of *calcium carbide, carborundum* and for other purposes.

Calcium carbide

249. Calcium carbide, which is now widely used in generating *acetylene gas,* was discovered by Moissan, a Frenchman, in 1892, and almost simultaneously by Thomas Wilson in the United States.

In manufacturing calcium carbide, electric furnaces are filled with a mixture of burnt lime (calcium oxide) and pulverized coke or anthracite coal, this mass being heated to about 3000° by an electric arc. The calcium oxide combines at this temperature, with the carbon in the coke or coal; the result of this combination being calcium carbide and carbonic oxide. The carbonic oxide passes away as gas and the calcium carbide after being allowed to cool off, is removed, ready for use. The calcium carbide is a gray hard crystallic mass, which when in contact with water gives off a gas of peculiar smell,—the now widely used acetylene. The largest calcium carbide works are those of the carbide company at Niagara Falls, where large furnaces are used, into which material is fed at one side, and the calcium carbide taken out at the other.

Carborundum

250. *Carborundum* (silicon carbide) is also a product of the electric furnace, and is made by smelting a mixture of powdered carbon and sand. The result of this smelting is a mass of very hard black crystals, which are then worked up as grinding stones or other articles for similar use

Electric welding

251. The heat developed by large electric currents, overcoming resistances, is utilized for many purposes, the most important being that of *electric welding,* an invention of Prof. Elihu Thomson.

It was not before the year 1889 that electric welding was so improved as to be commercially valuable.

The metals are carefully cleaned, and placed in especially constructed welders with the surfaces which are to be welded together, touching each other. Then an alternate current of great intensity is passed through them, which brings the metals at the point of contact — the point of highest resistance — to the necessary heat; a mechanical pressure being applied at the same time, to press the metals together. By this process many metals can be welded; even those metals which cannot be welded by any other method.

Rail welding

252. Electric welding is also used in electric railway work, to unite the joints of two rails, which, before this process of welding was developed, were bolted together. By welding the rails together expensive railway *bonds* may be dispensed with; it also does away with the roughness in the track and the expense of repairing the rail-joints.

Electric welders for rail welding are usually mounted on special cars, so as to move freely on the track. The current at 500 volt pressure is taken from the trolley and converted by means of a rotary converter, into an alternate current (of about 300 volts pressure) which is supplied to the welder. The rails are pressed against each other, while heating and cooling, with a force of about 35 tons. The current used is as high as 25,000 amperes.

Electric heating apparatus

253. It has been explained in paragraphs 61 and 62 that heat is generated by a current overcoming resistance. By passing through wires of high resistance, the current is made to generate heat. which is then used for different purposes, the more important uses being heating and cooking. Small heaters, usually installed in electric cars, consist of coils of insulated wire which offer a high resistance to the current. Electric kettles are now manufactured, having an electric heater of simple construction in their bases; also electric flat-irons and curling-irons. They may be connected by a plug to the socket of an incandescent lamp. All electric heating apparatus are very desirable, because they do not vitiate the atmosphere. On account of their cleanliness, and the ease of handling and transporting them, they are especially convenient. They are not, however, liable to come into general use, on account of the expense of the electric current consumed by them. Assuming the cost of the electric current to be 10c for every kw. hour, and the efficiency of the heater 65 per cent, then the cost of heating a gallon of water from 10° to 100° C, would be about 5·72 cents. The cost of heating rooms by electric heaters, in comparison with the use of coal, is enormous; the cost of coal being less than 20 per cent of the cost of electricity.

It is doubtful if electricity will even supersede coal for general purposes, unless it can be generated directly from fuel, without the intervention of steam engines.

CHAPTER XVI.— X-RAYS AND RADIUM.

Electric discharges in partial vacuum

254. When an alternating current of high frequency is sent through a glass tube, from which the air has been partially exhausted, many beautiful luminous effects may be observed. For testing these effects *vacuum tubes* or *Geissler tubes* are usually employed. These tubes consist of thin glass blown into different shapes and are provided with two platinum electrodes, which are fused into the glass walls. Geissler tubes are only partially exhausted by a mercury pump, such as that described in § 185. These tubes may be worked with an induction coil, producing sparks about one half an inch long.

The spark passes through entirely unexhausted tubes without producing any light effect. Yet a spark through partially exhausted tubes produces a peculiar, pale, tinted light which has a nebulous appearance. The cathode shows a bluish or violet light which as it extends toward the anode, loses its brightness. When Geissler tubes are filled with gases, as oxygen, hydrogen, carbonic acid, etc., the colors of the light differ from those obtained in a partial vacuum.

Discharges in high vacuum

255. When tubes are exhausted to a high vacuum, their glass walls become beautifully phosphorescent, but with this exception they remain almost dark. When articles, whether transparent or not, are interposed inside of the tube and in front of the cathode, then shadows are sharply projected on the opposite wall of the tube. Professor William Crookes made many important experiments (1874—1879) with partial and high vacuum tubes (Crookes tubes are shown in fig. 141.)

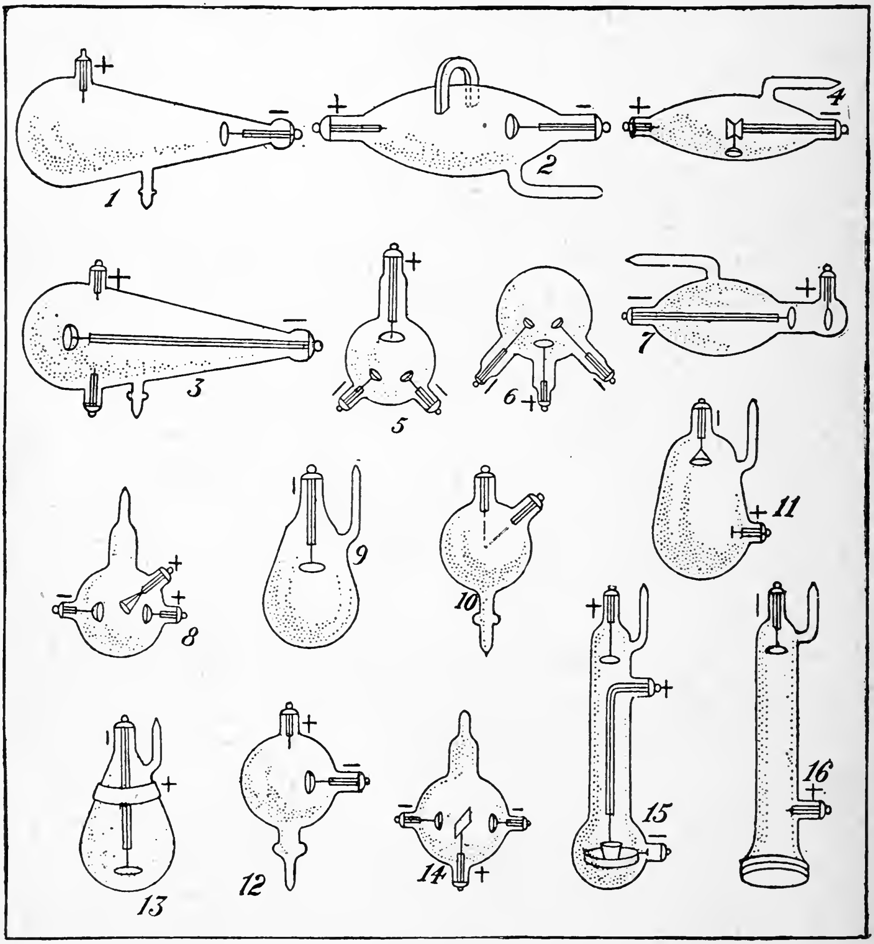


Fig. 141.

Roentgen's rays

256. Professor William Conrad Roentgen of Wuertzburg, Bavaria, discovered in 1895 that a current passing through highly exhausted Crookes tubes, generated invisible rays possessing peculiar qualities. Such rays pass freely through aluminum and zinc, through paper, wood and flesh, and excite a peculiar, brilliant fluorescence on plates covered with platinocyanide of barium. They also affect photographic plates in a manner similar to sun light. It was further observed, that rays possessing such qualities as described above, do not radiate from the cathode directly, but that they are given off from solid surfaces in the tube, against which the *cathode rays* (rays radiating from the negative electrode) are directed. Therefore small targets, usually made of platinum, uranium or osmium are placed in the tube so as to lie in the direction of cathode rays. These rays, as stated, pass through many substances, but lead, platinum, glass, stone and bones are impervious to them. In honor of their discoverer they were called *Roentgen-rays,* and because of their mysterious qualities, *X-rays* which name in America has become more popular than the former.

X-rays in medical use.

257. When a specially constructed Crookes tube, (a few different varieties of which are shown in fig. 141), is brought to light in a dark room in front of a fluorescent screen, and the human body is interposed between the tube and the screen, the rays generated will penetrate the flesh, and show only misty outlines of it; the rays, however, will be almost completely obstructed by the bones, which will throw dark shadows on the screen. In this way the presence of extraneous substances may be observed in living human bodies, without the necessity of using the surgeon's knife. X-rays are at present extensively used by physicians in locating foreign bodies and broken bones.

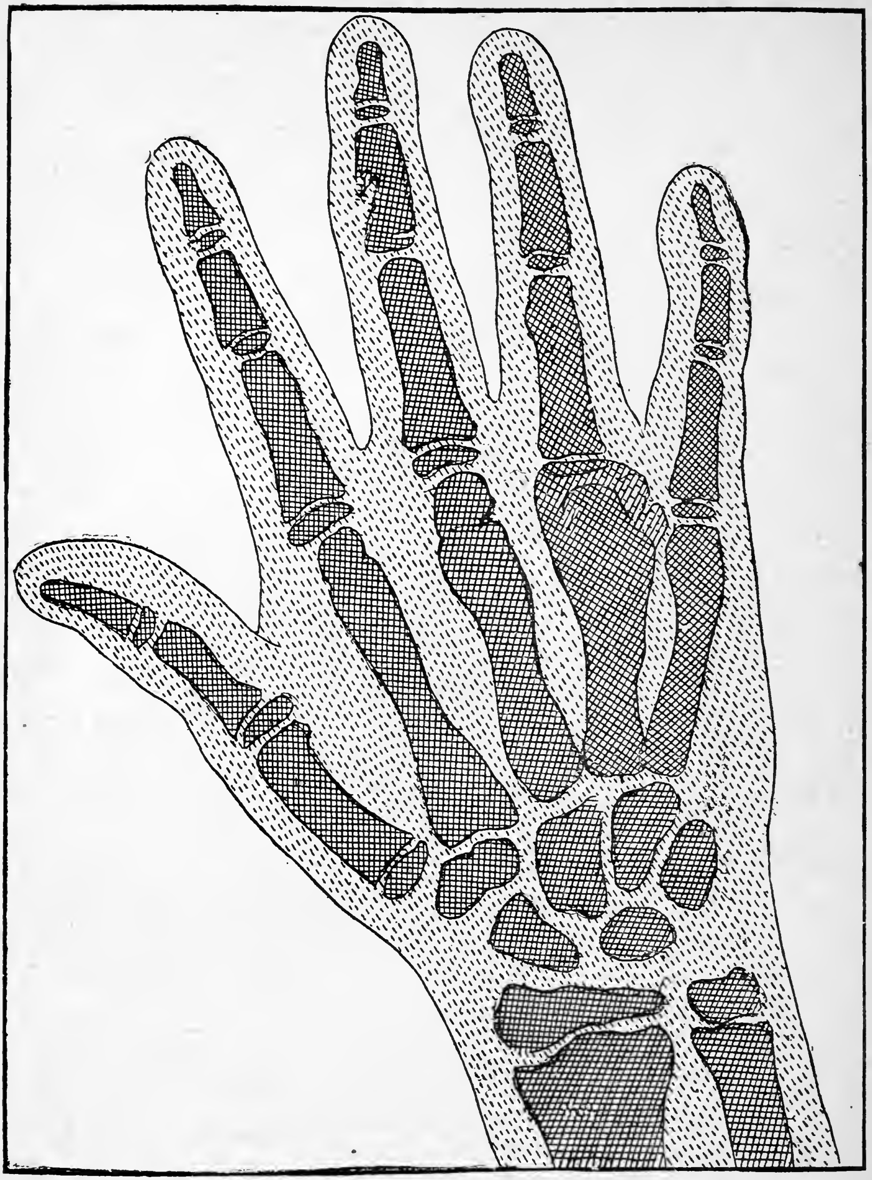


FIG. 142.

Shows abnormal growth of bone in the hand, as it appears on the screen.

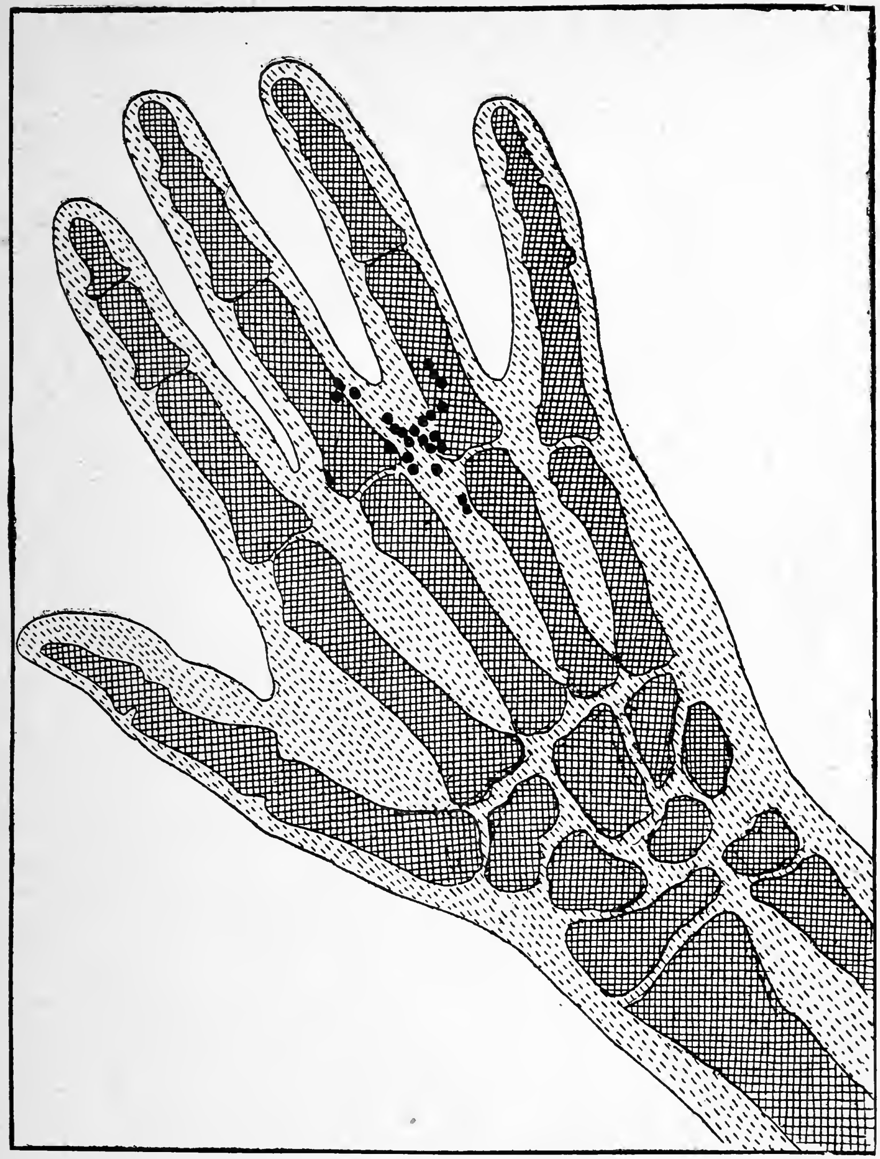


Fig. 143.

Shows a hand with shot located in the fingers.

The fluorescent screen by means of which such effects are observed, is usually enclosed in a black box, and is called a *fluoroscope.* Two commercial forms of such a fluoroscope are shown in figs. 144 and 145.


FIG. 144.

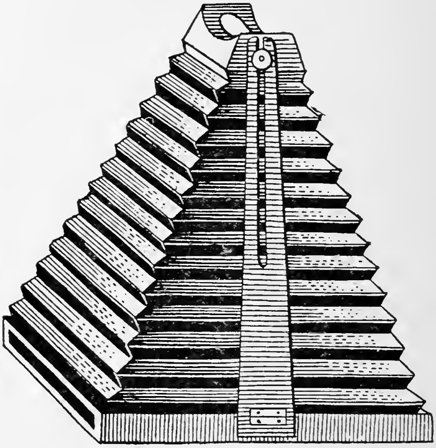


FIG. 145.

When, instead of the fluoroscope a photographic plate wrapped in black paper so as to protect it from sun-light is substituted (see fig. 146) the X-rays penetrate the paper cover and produce on the plate a picture, called a *radiograph,* which may be developed and fixed in the usual manner of developing and fixing photographs. The time of exposure varies greatly, depending upon the quality of the tube, the strength of the current and the transparency of the body to be radiographed. A brilliant

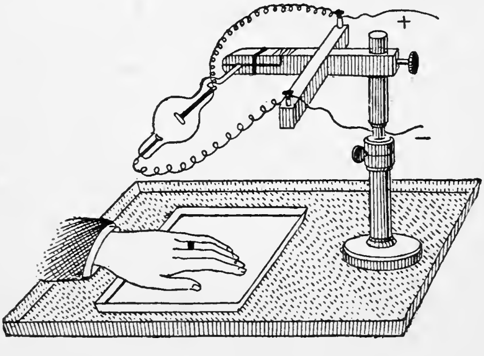


FIG. 146.

radiograph of a skull is shown opposite page 15. Time of exposure was only a minute. In this picture it may be seen (see dark spots) that some rays penetrated the bones of the skull and affected the plate, which in this case was an especially prepared radiographic film. Two nails which have been driven into the skull are shown by two white spots on the frontal bone. The long white line is an instrument which is inserted through the nose to operate in the frontal cavity of the skull. A radiograph of a rat is shown in fig. 147. It clearly shows the bones of the rat darker than the flesh. Fig. 148 shows the radiograph of a human chest. X-rays though a recent invention, were adopted so rapidly in surgical practice that there is now hardly a hospital not possessing an X-ray outfit.

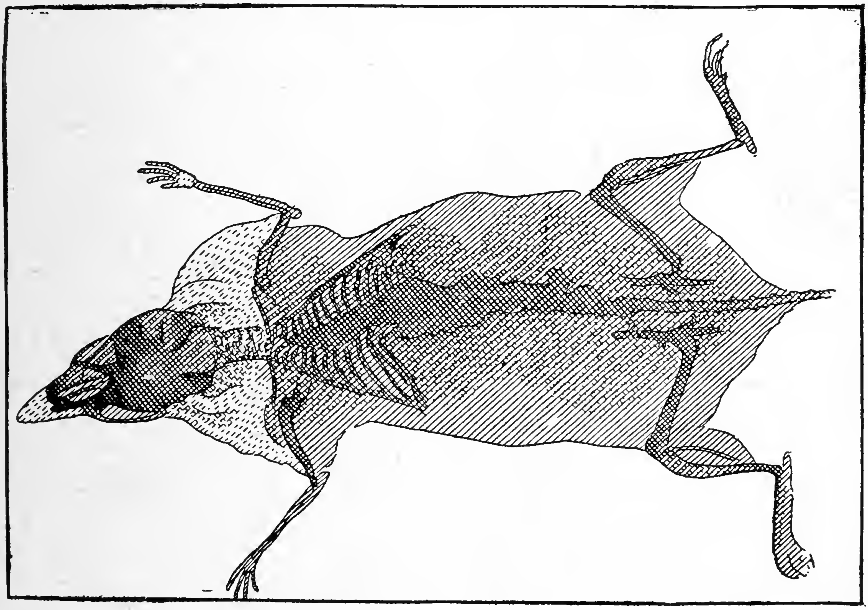


FIG. 147.

Radiographs

258. The cathode rays project from the cathode, which usually consists of a small parabolic mirror on the *anti-cathode,* where they theoretically meet in a single point, and from this point, the effective X-rays are reflected. The sharpness of the radiograph depends upon the condition that all rays are reflected from a single point of the anti-cathode. Rays reflected from any other point of the anti-cathode cause the picture to become misty. Misty pictures are also the result when the cathode rays, meeting on a part of the glass tube, and not on the anti-cathode, emit X-rays. One may ascertain whether the radiograph will become sharp, by holding a lead pencil against the

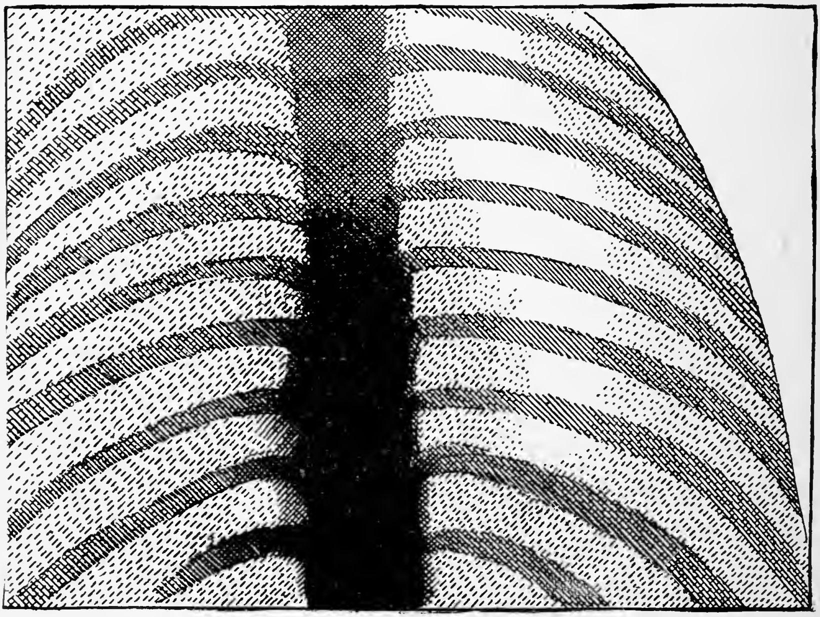


Fig. 148.

tube and observing how distinctly the lead of the pencil is projected on the fluoroscope.

The penetrating capacity of X-ray

259. The X-rays have greater penetrating qualities, when the vacuum in the tube is almost perfect; the more imperfect the vacuum, the less the efficiency of the X-rays, while the more perfect the vacuum, the greater the resistance of the tube, and therefore the greater the pressure of the current ($E=IR$), and the greater the penetrating power of the X-rays.

Tubes producing rays of high penetration are usually said to be *hard;* those producing X-rays of low penetration are said to be *soft*

The less its resistance, the softer the tube; and the lower the penetrating power of the X-rays, the greater becomes the current passing through and the greater the number of X-rays generated. Therefore they affect the photographic plate, which is placed behind the object to be radiographed, to a greater degree.

Life of tubes

260. The time during which tubes are able to produce effective X-rays is called the *life of tubes.* X-rays as supposed by modern scientists, are immeasurebly small gas-particles which leave the tube, passing through its glass walls when a current is sent through it. Then the vacuum of the tube becomes more perfect. Therefore every tube is able to give only a certain amount of X-rays, because after a certain time, the vacuum of the tube becomes perfect, and the tube containing no more gases to emit, X-rays cease to be generated. The life of the tube, therefore depends upon its size. In order to continue to use a tube the vacuum of which has become too perfect to generate X-rays, many different devices have been provided. These devices generally consist of small palladium tubes, or small mica plates, which are used inside of the tube (see fig. 149). When the vacuum becomes too great— the palladium being heated, usually by an alcohol flame from the outside of the tube,— draws the hydrogen from the flame, and transmitting a part of it to the tube, decreases its high vacuum, and thus renders the tube again serviceable. This process is known as Willard's method.

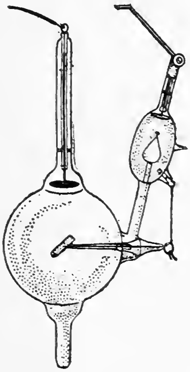


Fig. 149.

The other method is founded on the principle that the mica plates become heated by the cathode rays and give off a small quantity of gases. Neither of these devices, however, work satisfactorily; the amount of gases which they transmit to the tube being too small to replace the amount of gases consumed. The process of renewing the tubes, renders them softer. It is therefore advisable to select tubes which possess renewing devices in preference to those without them.

Constancy of tubes

261. The constancy of tubes is the quality they possess of maintaining their vacuum, and this depends greatly upon the manner in which the vacuum in the tubes has been produced. When selecting tubes, it is advisable to get those, which, when put into operation have a tendency to become softer, in place of those which have a tendency to become harder. The softer the tube, the darker will be he shadows on the screen.

The effect of X-rays on the human body

262. The therapeutic effect of X-rays, need hardly be mentioned in a work of this character. This is a distinct branch of medical science, of more interest to physicians then to electrical engineers, and the reader is advised to consult the numerous works upon the subject now on the market for a more exhaustive treatise upon the practical use of X-rays, for medical purposes.

Radium

263. Henry Becquerel in 1896 published the results of his experiments with invisible rays, which he had discovered in some preparations of the rare metal, uranium. Until 1898, nothing of importance was done in the way of adding to this discovery, when M. and Mme. Curie of Paris, published their very interesting papers on radium, a newly discovered metal, or chemical substance which, contrary to all the rules of physics, emitted a peculiar light which made the surrounding atmosphere a good conductor of electricity. M. and Mme. Curie found that some minerals, containing uranium and thorium emitted such rays. Uranium is a metal of steel white color, which occurs but sparingly in nature, and is found combined in two comparatively rare minerals. pitchblende and uranite, an emerald green ore. Thorium, which resembles nickel in its color, possesses about the same qualities as uranium. The energy of the rays given off by uranium is about three times the energy of the rays given off by thorium. The radio-activity of radium is a million times as great as that of uranium. At first, M. and Mme. Curie experimented with the pitchblende, chemically analyzed and separated it from the uranium and thorium, thus obtaining a substance, some of the rays of which were *visible* and about 400 times more active than those given off by uranium. This substance received the name of Polonium (from the birth-place of Mme. Curie). Later it was found that there was still another element in the pitchblende which emitted a vivid light, radioactive to a high degree, which received the name of radium.

Qualities of radium rays

264. The rays emitted by radium, usually called Becquerel rays, possess almost the same qualities as X-rays. They act on a plate of Calcium fluoride, rendering it phosphorescent, and radioactive, which means that the plate, after having been left under the influence of the radium rays for awhile, is itself enabled to give off radium rays. If a radium solution is put into a small glass bulb, and then sealed, and immersed for a short time in distilled water, the water will become radioactive to as high a degree as radium itself. As far as has been observed, after such experiments, there would be no loss in the weight of the radium solution. Radium like electric sparks changes oxygen into ozone.

When a diamond is left under the influence of radium rays for a certain length of time, it in itself, becomes radioactive, emitting light in the dark. Because glass and other crystals do not become radioactive, diamonds may be distinguished from imitations by testing them under the influence of radium rays. Recent experiments suggest the possibility of changing the color of diamonds, by subjecting them to the influences of radium rays.

The most important quality of radium rays is that which also gave to X-rays their importance:—that is, their action on photographic plates. The rays of radium appear to possess a greater intensity, demonstrated by the fact, that even when radium is enclosed in metal cases that X-rays could not penetrate, photographic plates become sensitive to their action. Radium rays produce peculiar burns on the skin, which in appearance are similar to those produced by X-rays.

Nature of radium rays

265. The nature of radium rays, like those of X-rays, electricity and ether, has not yet been discovered. Various hypotheses have been given which being in themselves based upon other hypotheses, are quite uncertain. The most credible explanation concerning the nature of radium rays is the following:—

Radium, and other similar substances in lesser degree, act in a somewhat similar manner to transformers. In other words they are able to transform one kind of energy into another; i. e. for instance, drawing electricity from the air and transforming it into light. Another hypothesis is that the ether particles become subjected to rapid vibration, thus generating light and heat.

The almost total lack of loss in weight, compared with the enormous energy manifested, introduced with the discovery of radium, a problem that puzzled the world's scientists.

It is very doubtful whether radium will ever become a *commercial* factor, but it has presented problems, the solving of which may revolutionize the accepted theories of physics.

CHAPTER XVII.— ELECTRICAL ENGINEERING.

The most important work required of an electrical engineer may be classified under the following three divisions:

1. Selection of system, calculation and design of plant;
2. Estimating the cost of erection of plant.
   - *a.* Cost of horse power, produced at the station.
   - *b.* Cost of transmission to place of consumption.
   - *c.* Cost of distribution.
3. Erection of plant.

Under the first division, the design of power machines, apparatus, etc., should also be mentioned, yet this would include too much detail; moreover, being a special phase of electrical engineering, upon which many books have been written, it has been omitted from this work. The first division, being first in importance will be treated at as great a length as necessary to give correct and reliable information covering cases that come up in ordinary practice. The second will be considered in its more important points. The third has been mentioned throughout the book; a few important details however will be given in this chapter.

Considering the branch of electrical engineering to which the above operations belong, we may classify them as follows:

1. Electric railway engineering.
2. Electric light engineering
3. Power transmission engineering.

Electric railway engineering

266. Suppose an electric railway is to be erected in a small town. The simple chart of this track is shown in fig. 150. The main line A–B–C, is to be double track; all other branches single track. A–B. = 25,000 ft. B–C. = 4,000 ft., B–D = 3,000, D–E. = 3,000, D–F. = 10,000 ft. and F–G. = 12,000 ft., with a grade of four per cent.; the length of this grade being 5,000 ft.

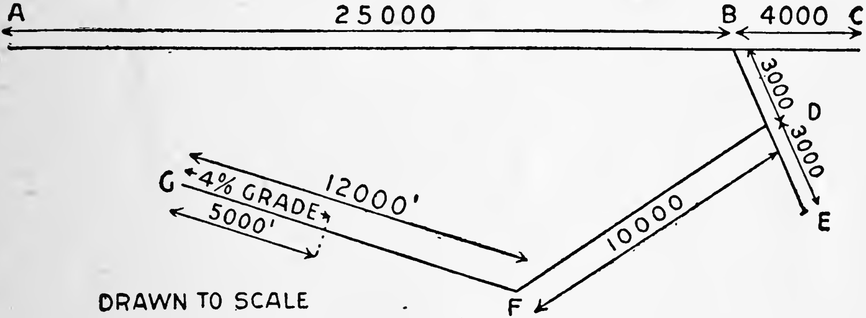


FIG. 150.

Rise in feet with each per cent of grade:

GRADE	FOR ONE MILE	FOR 1,000 FEET.
½ per cent.	26·4 feet.	5 feet.
1 " "	52·8 "	10 "
1½ " "	79·2 "	15 "
10 " "	528 "	100 "

Rise for other grades may be easily found by multiplication or division; thus for 15½ per cent per mile, the rise equals 52·8×15·5=818·40 feet.

When calculating the conducting system for a line, as in the example, it is best to follow the steps mentioned on the next page. (Bell's method.)

The extent of railway lines must be calculated. The track is to be mapped to scale, and all distances carefully noted. The railway lines which are to be built immediately may be drawn in heavy lines and the dotted lines may be used to indicate the proposed extension which may be built in the near future. Grades, their length and direction, and the proportion of length to elevation in per cent. is to be noted. (see fig. 150).

Divide the road into sections, in such a way that all of them, under ordinary circumstances will have fairly constant service; in this case, double track, A–B–C one section, the other separate sections being B–E D–F and F–G.

Calculate the average load on each section. Suppose that the town having a large population, will require 35, eighteen foot, single truck cars, each having a pair of 25 H. P. motors; line A–C, requires 20 cars, B–E, 6 cars, D–F, 4 and F–G 5. In this case the electric center of gravity of the system, will be independent of the absolute amount of horse power which is required for each of the cars.

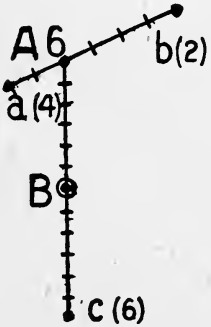


FIG. 151.

The center of gravity is a point which must be found in a geometrical way, and represents the point in which the electrical loads have the same effect on the whole system, as if they were uniformly distributed, for example: There are three points *a*, *b*, *c*, (see fig. 151) with loads, 4, 2, 6, respectively; connect two points, say *a* and *b*, by a line and divide thedistance between them, in $(4+2=)$ 6 equal parts. The center of gravity of the points, *a* and *b*, will be in *A*, which is two parts distant from *a* and four parts from *b*. (Which means that if *a–b* were considered the beam of a balance, supported at *A*, a weight of two pounds at *b*, would balance a weight of four pounds at *a*.) Then in the same way find the center of gravity of *A* (6) and *c* (6) by connecting them, and dividing *Ac* into (6+6=) 12 equal parts. Point *B*, which is the center of gravity of *A* and *c*, and at the same time the center of gravity of the whole system, lies 6 parts from *A* and 6 parts from *C*.

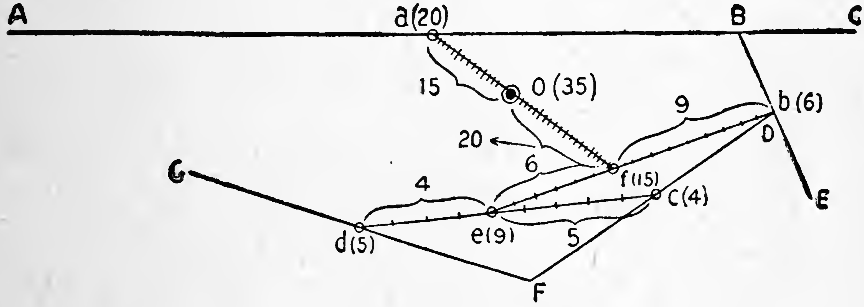


FIG. 152.

Find the center of gravity of this system (see fig. 152). Center of gravity of *AC* is in *a*. The center of *BE*. is in *b*, of *DF*, in *c*, of *FG*, in *d*. Because the load of every section is supposed to be uniform, the load of any section may be considered concentrated at its middle point. The center of gravity of points *a*, *b*, *c*, *d*. which in this case will be at the same time, the thereotical *center of distribution* of the whole system, is found to be *O*, as follows: —

The center of gravity of *c* and *d*, is found in *e*; the center of gravity of *e* and *b*, in *f*, and the center of gravity of *f* and *a* in *O*. (If the start were made, not from *c* and *d*, but from any other two points, for instance from *b* and *a*, the center of gravity of the whole system would also be found to fall in *O*.)

Mark the distance of points *a*, *b*, *c*, *d*, from the center of distribution *O*. (see fig. 153). After the theoretical center of distribution *O*, is found, the distances *Oa*, *Ob*, *Oc*, and *Od*, are measured according to scale.

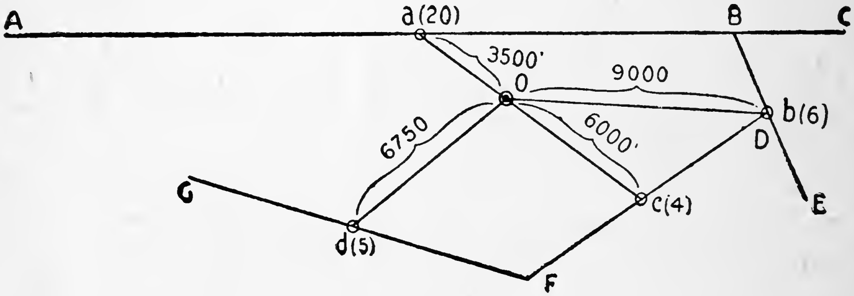


FIG. 153.

Distance *Oa* is 3500 feet, *Ob*, 9000, *Oc*, 6000 ft. *Od*, 6750 ft. approximately. The weight of copper in the feeding lines for the different points on the main line is figured as follows:—

For *a*.—Number of cars× amps. consumed by a single car

$$\times \left[\frac{\text{distance of } a \text{ from the center of distribution } O.}{1,000} \right]^2 \times \frac{33}{\text{Drop in voltage}}$$

The weight of copper in feeding lines for the whole system, equals the sum of the weights of feeding lines to all the points considered. If the center of distribution were shifted from the point *O*, found in this example, the cost of copper in feeding lines would increase. The total weight of copper required for the feeding lines of this system is, when figuring with an allowable drop in line of 30 volts and when 25 amperes are needed by every car.

$$\text{for } a \ldots 20 \times 25 \times \left[\frac{3500}{1000}\right]^2 \times \frac{33}{30} = 25 \times \frac{33}{30} \times 245$$

$$\text{for } b \ldots 6 \times 25 \times \left[\frac{9000}{1000}\right]^2 \times \frac{33}{30} = 25 \times \frac{33}{30} \times 486$$

$$\text{for } c \ldots 4 \times 25 \times \left[\frac{6000}{1000}\right]^2 \times \frac{33}{30} = 25 \times \frac{33}{30} \times 144$$

$$\text{for } d \ldots 5 \times 25 \times \left[\frac{6750}{1000}\right]^2 \times \frac{33}{30} = 25 \times \frac{33}{30} \times 229$$

$$\text{For the whole system} = 25 \times \frac{33}{30} \times (245 + 486 + 144 + 229)$$

$$= 30{,}360 \text{ pounds of copper}$$

At 16c per pound for copper, the whole cost of copper in feeders for this system would be $4,857.60.

The above figures are approximate ; because in practice, it is in many cases impossible to secure a suitable lot situated in the theoretical point of distribution, at a reasonable price and because the wires may not be spanned in straight lines. Sometimes it is more convenient to disregard the theoretical center of distribution, especially when material and power may be had cheaper at some other point, or when using the power of a distant water-fall.

Now find the maximum load of each line. The power required at car wheels for a speed of about 8 miles per hour, (the most suitable speed for city railways) amounts approximately to 0·4 H. P. with additional 0·4 H. P. per ton for each per cent of grade, or to state a formula for estimating: *the total power required at car wheels of every maximum loaded car, equals the sum of the weight of the car body and the maximum weight of passengers multiplied by the* *sum* $(0{\cdot}4 + 0{\cdot}4 \times \textit{per cent. grade.})$ In case there are no grades, the per cent is taken as naught.

Assuming the car has a pressure of 500 volts, its efficiency from trolley to wheels about two thirds, it will be found correct to figure with $1\frac{1}{4}$ amperes per ton of the car loaded to its maximum capacity, and to allow $1\frac{1}{4}$ amperes per ton for each per cent of grade. The maximum current may be considered as three times the average current, or in our example :—

	AVERAGE LOAD.	MAXIMUM LOAD.
In section AC	300 amperes	900 amperes
" " BE	90 "	270 "
" " DF	60 "	180 "
" " FG	65 "	195 "
Total	515 "	1545 "

Then the maximum load of the whole track would probably never reach 1545 amperes, as the factors producing maximum loads very seldom act on all sections at once.

The trolley wire and the *track return* must now be considered. A drop of 6 per cent may be allowed in the trolley wire (30 volts) and therefore No. 00 B & S being heavy enough will answer all requirements. The *track return* is quite an important factor for a good line, but supposing the rails are *bonded* well, it does not need to be considered. The sections of rail bonds in circular mils will equal (when dealing with 60 pound rails) thirteen times load times length of line divided by voltage.

Now consider the feeding system; for the central station at *O* (see fig. 154) and from A to C, there are two No. 00 trolley wires, from B to E, and D over F to G only one trolley wire. The length of the trolley wires fed by one feeder will equal circular mils of the trolley times the allowed drop in volts, divided by thirteen times the load (13 being the constant for track return). In this example the length named above, for one car will equal

$$\frac{133{,}000 \times 30}{13 \times 15} = \frac{3{,}990{,}000}{195} = 20{,}462 \text{ feet approx.}$$

For two cars 10,231 ft., for four cars, 5,115 ft. etc.

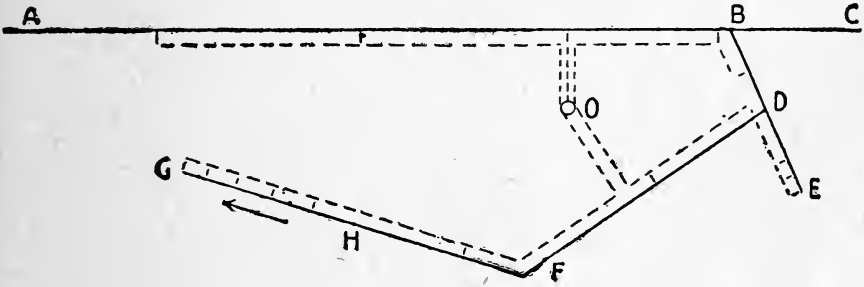


FIG. 154.

Hence the feeder system may be arranged as shown in fig. 154. Here special care must be taken in regard to the grade on the end of the line F–G and B–E at E. More feeders must be provided there. The feeders measured from sketch amount to about 65,000 ft. of No. 000 weather proof feeder wire, weighing about 39,000 pounds and costing about $6,240.00.

The trolley wire proper is about

AB . .	2 × 25,000 =	50,000
BC . .	2 × 4,000 ×	8,000
BE		6,000
DF		10,000
FG		12,000
		86,000

86,000 feet long, containing about 34,400 pounds of copper and costing about $5,504.00 The total cost of copper would be approximately, $11,744.00

including the feeders. The amount of power needed is 500 (volts) × 515 (amperes average load) × 18 (hours per day) = 4,635 kw. hours per day of 18 hours. At 2c per kw. hour, the daily cost of this would be $92.70 or approximately about $33,835.50 for the year.

MATERIAL REQUIRED PER MILE OF TRACK

NAMES OF ARTICLES.	For Single Track. B-D-E, D-F-G.	For Double Track A-B-C.
No. 00. B. & S. trolley	2117 pounds	4234 pounds
No. 000. B. & S. feeders	466 "	732 "
7 strand No. 12 galv. iron span wire . .	760 "	760 "
7 strand No. 15 galv. iron guy. wire . .	300 "	450 "
60 pounds rails	94.3 tons	188.6 tons
Joints	360 pieces	720 pieces
Angle bars	720 "	1440 "
Bolts	2160 "	4620 "
Spikes 5 × ½ inch	7800 "	15,600 "
Ties	2150 "	4300 "
Bonds	400 "	800 "
Channel pins	800 "	1600 "
Poles, 125 feet apart	90 "	90 "
Cross arms ¼ × 18 inches	45 "	45 "
Cross arm braces, ½ × 8 inches	90 "	90 "
Lag screws for cross arms ⅜ × 3 inches	45 "	45 "
Lag screws for braces	144 "	144 "
Eye bolts	90 "	90 "
Hardwood pins	45 "	45 "
Section insulators	2 "	4 "
Turn buckles	90 "	90 "
Chain insulators	90 "	90 "
Plain ears	45 "	90 "
Splicing ears	1 "	2 "
Feeder ears	10 "	20 "
Insulating caps	45 "	90 "
Insulating cones	45 "	90 "
Insulator holders	45 "	90 "
Lightning arresters	3 "	3 "
Section switch boxes	2 "	2 "

The force required to lay this track consists of one engineer, one roadman, two gangs of men, each numbering 25 laborers, with one foreman for the diggers, and one foreman for the track layers; also four spikers and three general helpers. This force would finish the road considered in the example, in about three months, each gang laying about 500 feet of single track per day.

The tools for each of these gangs should consist of one small flat car, one portable forge, four cold chisels, one cross cut saw, one double handed saw, two monkey wrenches, two track wrenches, one complete set of track drills, one rail bending machine, thirty picks with ten extra pick handles, thirty shovels (six short handled and twenty-four long handled), ten tampers, five wheel barrows, two track gauges, one level, one straight edge, five spiking hammers, four pair rail tongs, three crow bars, two spike claw bars, one reel line cord, braided, two six-pound hammers, one twelve-pound sledge, two axes, two adzes, 15 red lanterns (when working out of town, only six lanterns), one broad blade hatchet, six gallons of kerosene, one quart black oil, one squirt oil can, one box of lump chalk, and for the engineer and roadman, one engineer's transit, one leveling rod, ten surveyor's marking pins, and one steel tape.

The cost of the material named above may be found easily, by consulting a catalogue and marking the prices there specified. The sum will give the cost of material per mile of single track and double track, and must be multiplied by the number of miles of the system which is to be constructed to give the total cost of material for the whole system. Then the cost of tools, labor, surveying, drawings and estimates, traveling expenses of engineers and laborers. cost of property and franchise, etc., must be added. The cost of labor and material being subject to constant change is not figured in the above estimate.

Cost of single railway tracks

267. With 55 pound rails, the cost approximates $23,000 per mile; with 75 pound rails, the cost approximates $33,000 per mile. It is evident that these figures can not be exact for every system, as they depend upon several different factors; but they may be used safely in a preliminary calculation of cost.

Notes for estimating on electric railways

268. Approximate weight of trolley wires may be determined as follows:

Weight per mile of copper wire in pounds $=$ (diameter in mils)$^2 \div 62{\cdot}5$.

Resistance per mile in ohms is $54{,}892 \div$ (diameter in mils)^2.

Normal load is that at which the car motor will develop its rated H. P. when running at its normal speed on level ground.

H. P. of motor $=$ pounds of pull $\times$ miles per hour $\times\ 0{\cdot}0027$. Pounds of pull is the pull at the periphery of driving wheel.

To start a standard car on a straight, level track requires a tractive force of about 118 pounds, and on curves about 225 pounds, for every ton of total weight of car and load.

To keep the car running at an average speed of six miles per hour requires a tractive force of about 16·2 pounds per ton of total weight.

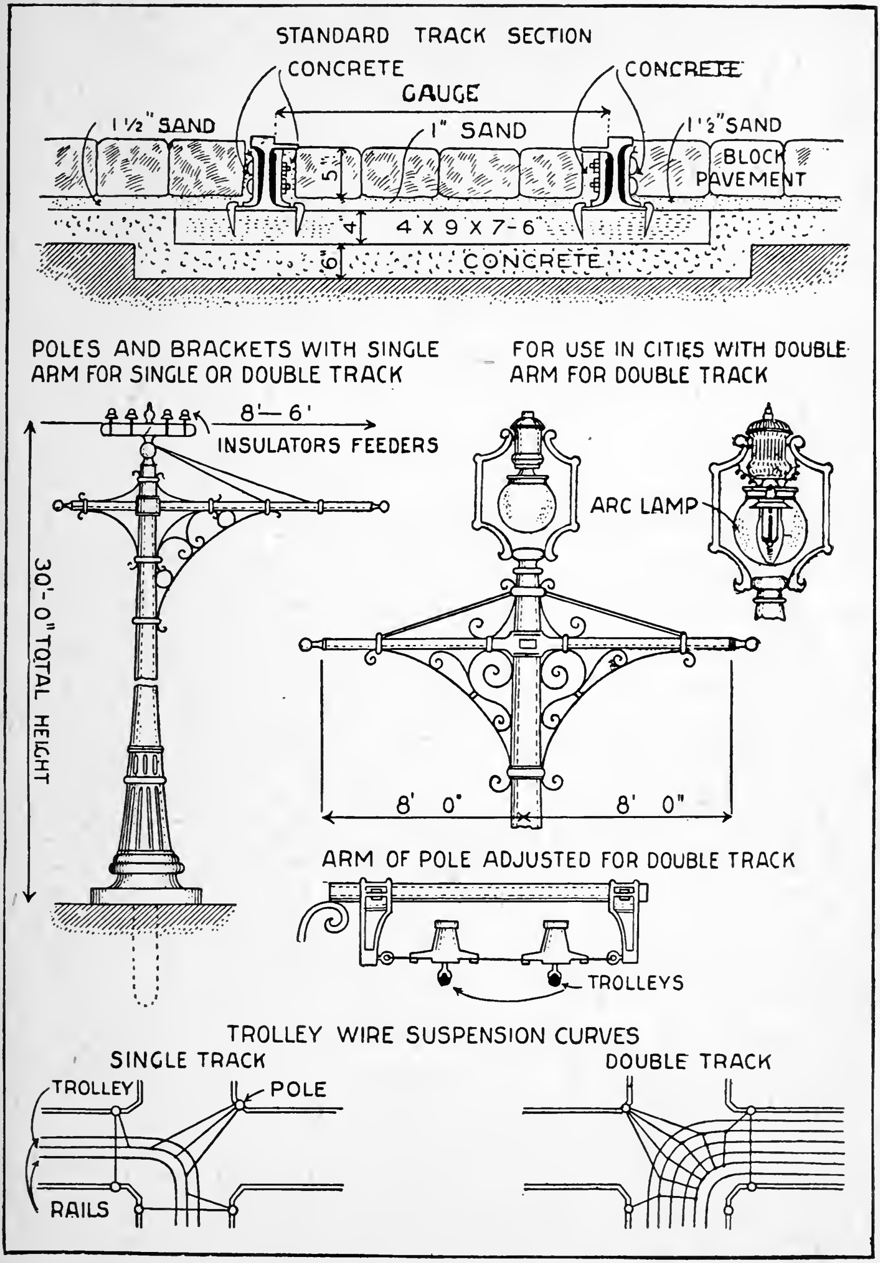

STANDARD TRACK SECTION
CONCRETE
CONCRETE
GAUGE
1 1/2" SAND
1" SAND
1 1/2" SAND
BLOCK PAVEMENT
5"
4"
4 X 9 X 7-6
6"
CONCRETE
POLES AND BRACKETS WITH SINGLE ARM FOR SINGLE OR DOUBLE TRACK
FOR USE IN CITIES WITH DOUBLE ARM FOR DOUBLE TRACK
8'—6'
INSULATORS FEEDERS
30'-0" TOTAL HEIGHT
ARC LAMP
8' 0"
8' 0"
ARM OF POLE ADJUSTED FOR DOUBLE TRACK
TROLLEYS
TROLLEY WIRE SUSPENSION CURVES
SINGLE TRACK
TROLLEY
POLE
RAILS
DOUBLE TRACK

FIG. 155.

WEIGHT AND CAPACITY OF CARS.

DESCRIPTION	Weight of car in pounds.	Length over platforms in feet.	Maximum load and seating capacity.
4-wheel baggage car.......	5,000	12	16,000 pounds.
8-wheel " "	5,500	14	20,000 "
Regular passenger "	3,500	24	50–60 passengers
Passenger car for suburban service..................	10,000	25	40–50 "
Open car.................	9,600	31	70–90 "

These cars require from 5,000 to 12,000 watts for a speed of eight miles per hour.

All the cars specified are for United States standard gauge tracks, which are 4 feet $8\frac{1}{2}$ inches wide (measured inside the rails, as shown in the standard track section in fig. 155).

Railway curves

269. The curves of railways are usually stated in the degrees of their angle of declination from a straight line.

A curve of 1° (degree) has a radius* of 5730 feet.

A curve of 2° has a radius of $\left[\frac{5730}{2}=\right]$ 2,865 feet.

A curve of 10° has a radius of $\left[\frac{5730}{10}=\right]$ 573 feet.

A curve of 50° has a radius of $\left[\frac{5730}{50}=\right]$ 114 feet.

Curves should be made with the greatest possible radius, as they add greatly to the resistance of a car, due to friction of the wheels on the rails. A 200° curve adds about as much resistance as a five per cent. grade.

---

*Radius equals one-half of diameter.

Elevation of outside rails on curves

270. For a United States standard gauge track (4 feet $8\frac{1}{2}$ inches), the elevation of the outside rail in inches above the horizontal plane $= 1 \cdot 78 \times$ (the square of velocity of car in feet, per second) $\div$ (the radius of curve in feet).

Power station

271. The proper location of a power station is affected by various factors, the most important of which are:— the cost of copper for feeders, the cost of coal, and the cost of water. Taking these factors into consideration, the value of the property may be determined. If it chances that a suitable piece of property lying in the center of distribution of a system can be bought, it is wise to pay even a high price for it, if necessary, as it makes possible the cheapest kind of distribution, and saves not only in the cost of copper but in the cost of power. Every mile separating the central station from the center of distribution, increases the cost of copper and power.

Special attention must be paid to the cost of handling coal. A piece of property lying near railway tracks, from which it is allowable to run a side track into the station, so that the coal may be delivered directly from the cars into the bins,would offer a great advantage. It is very unsatisfactory to pay extra for the work of re-handling the fuel, and often very detrimental to the interests of a company, as the loading and forwarding a ton of coal over a distance of one mile or less, costs from 18 to 30 cents. The station of a system similar to that considered in the foregoing example, would need at least nine tons of coal per day, and the cost of re-handling the coal, not figuring the shrinkage in weight, would add more than $720.00 to the yearly expenses.

Another important requirement, is the nearness of the source of cheap water supply. The station mentioned in the foregoing example, would annually consume in its boilers, approximately, 535,000 cubic feet of water. In cities where water must be bought at $1.00 per 1,000 cu. feet per annum, this extra expense of the central station would amount to about $535.00. When possible, the central station should be near the car-barn, but at such a distance, that a fire in the central station could not ignite the barn or cars within it. If the car-barn is situated too near the central station, the cost of insurance is increased.

Before figuring on the foundation for the station house and the cost for machinery, careful tests must be made to determine the quality of the ground upon which they are to rest. It is advisable to make borings at a few different points.

These borings are made with piles which are driven into the soil by a ram of known weight. The extreme load per sq. foot (the load per sq. foot which would cause sinking of the ground) may be determined by using Trautwine's formula:

Extreme load (in tons) =

$$\frac{\begin{matrix}\text{Cube root of fall} \\ \text{in ft. (of hammer)}\end{matrix} \times \begin{matrix}\text{wt. of ram} \\ \text{in pounds}\end{matrix} \times 0.023}{\text{last sinking of pile in inches} + 1}$$

This would show for a fall of 8 feet, weight of ram 1,000 pounds and sinking 0·25 inches an

$$\text{extreme load} = \frac{\sqrt[3]{8} \times 1000 \times 0{\cdot}023}{0{\cdot}25 + 1} = \frac{2 \times 1000 \times 0.023}{0{\cdot}25 + 1}$$

$$= \frac{46}{1{\cdot}25} = 36{\cdot}8 \text{ tons.}$$

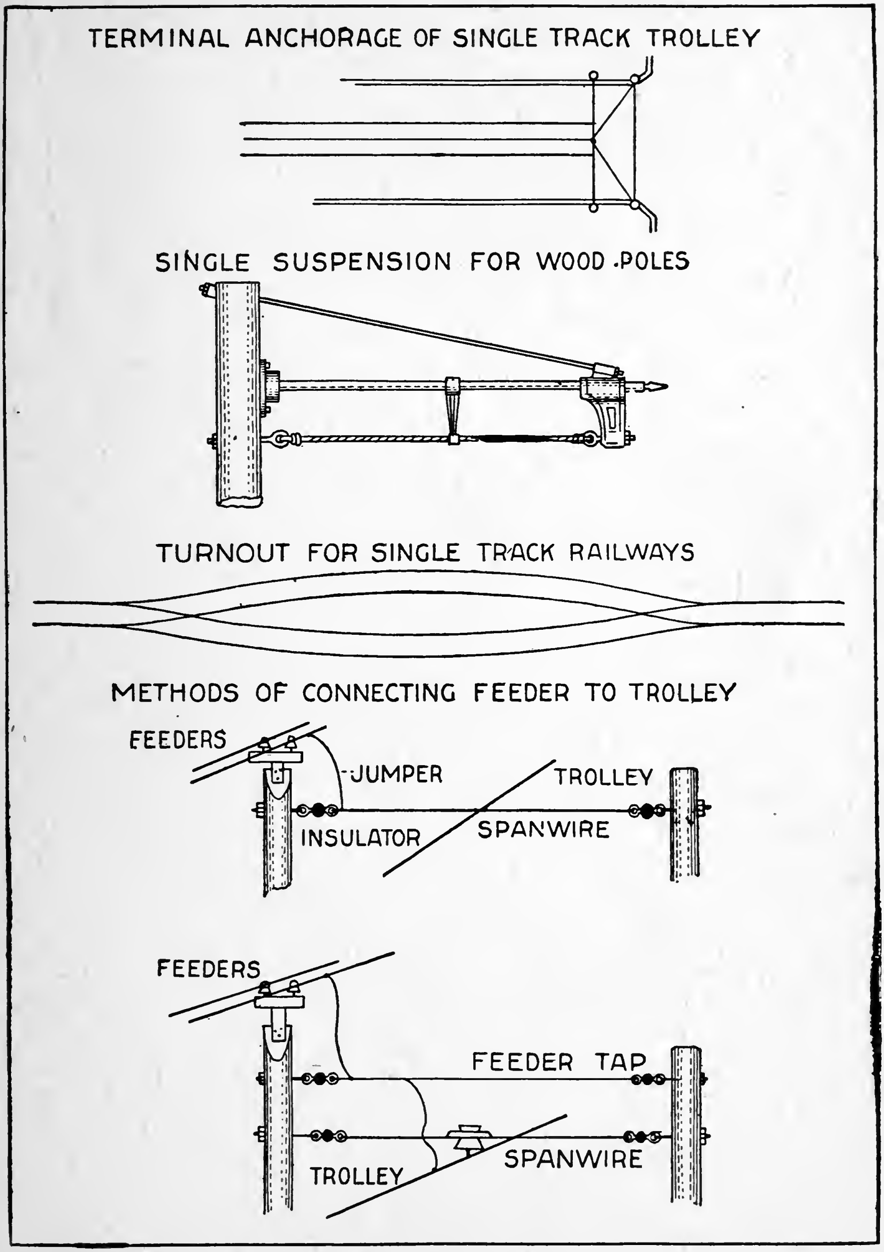

TERMINAL ANCHORAGE OF SINGLE TRACK TROLLEY
SINGLE SUSPENSION FOR WOOD POLES
TURNOUT FOR SINGLE TRACK RAILWAYS
METHODS OF CONNECTING FEEDER TO TROLLEY
FEEDERS
JUMPER
TROLLEY
INSULATOR
SPANWIRE
FEEDERS
FEEDER TAP
SPANWIRE
TROLLEY

Fig. 156.

Allowing a safety of 2, 18·4 tons would be the safe load per square feet.

The *bearing* power of different soils, ranges from 30 tons, (for *hard* rock,) to one ton, (for quick sand,) per square foot. The foundations for machinery should be built of good concrete; the foundations and walls of the station of good brick, stone or concrete; the *roof trusses* of steel and the covering of corrugated iron. Of course the cost of the central station depends upon the material used, depth of foundations, etc.

Electric light and power transmission

272. It is almost impossible to give examples under this heading which will enable the reader to use the figures given below in practical estimating. The wires may never be drawn in straight lines; the number of poles, insulators, switches, etc., vary considerably with the locality or the shape of the rooms in which electric light is to be installed. The amount and cost of labor also varies to such a degree that it is impossible to state a definite amount of work which may be performed by a "wire-man" in a day, or the cost of labor for installation.

It is wise to thoroughly examine the locality where the electric light is to be installed, and to consider all circumstances carefully. The examples given below, will give the reader an idea of how to calculate the details for electric wiring for light and transmission purposes, and the authors hope this will prove of considerable value to all those who are engaged in electrical engineering.

When considering incandescent lamps, it must be remembered that all the requirements of lamps must be fulfilled to assure proper working of the plant, with a maximum light, at a minimum expense.

Proper use of an incandescent lamp requires: That the lamp be supplied with not more than its rated voltage; that the voltage be kept constant; that dimly burning lamps be immediately replaced, because lamps burning after they cease to give good light, waste considerable power.

If a 16-candle power lamp burned properly for 1200 hours, and then was used for an additional 600 hours, it would consume the same amount of current, yet the light it would give would equal only about 8-candle power. If the current be supplied at a cost of 0.55c per lamp hour, the total cost of current for the entire 1800 hours during which the lamp burned, would equal 1800×0.55c or $9.90. If instead of this lamp, three other 800 hour rated lamps were used, each of them costing about 20 cents, the average light would have been doubled at an increased expense of not more than 40 cents or about 4 per cent. of cost of current, and the customer would receive a light 100 per cent. better, as one new lamp gives twice the light of an old one, at one half the cost of current.

In figuring on the life of lamps, 600 hours should be taken as the maximum. A station supplying 100,000 lamps of average life, not exceeding 600 hours, would have to exchange $\frac{100{,}000}{600}$ or 166 lamps in a month.

Energy required for an incandescent lamp equals the product of square of the current and hot resistance.

Thus for a lamp of $\frac{1}{2}$ ampere and 220 ohms hot resistance, the energy required equals $0{\cdot}5^2 \times 220 = 0{\cdot}25 \times 220 = 55$ watts.

Heat units required for an incandescent lamp of 110 volts and 0·5 amperes in 10 minutes equals

$$110 \times 0{\cdot}5 \times {\cdot}24 \times 600 = 792 \text{ calories.}$$

Average cost of light for a 16 c. p. incandescent lamp per hour varies from $0.003 to $0.02. (When burning 10 hours or $\frac{1}{2}$ hour per day)

Average cost of 2000 C. P. arc lamps per hour varies from $0.02 to $0.18. (When burning 10 hours or only $\frac{1}{2}$ hour each day.)

EXAMPLE 71.

In a large building, 300 lamps are to be fed by a circuit 100 feet long at a loss of 6 per cent. Each lamp requires 110 volts and 0·5 amperes. The size of the main wire is to be calculated.

Resistance of a wire equals the constant of the material of the wire used, times the quotient of its length and area of cross section. The constant of commercial copper is taken as 10·8. The circular mils of the wire equal the quotient of 10·8 times the length of the wire and resistance. The resistance of any number of lamps in parallel, equals the quotient of the hot resistance of one lamp, divided by the number of lamps.

The section of the mains in circular mils equals the product of 10·8, twice the length of the mains, number of lamps and 100 minus per cent. drop in mains, divided by the product of the hot resistance of each lamp and the per cent. of drop in mains.

The hot resistance for 110 volt lamps is 220
" " " " 50 " " " 50

Substituting figures in the example, the section in circular mils of the main may be found

$$\text{Circular mils} = \frac{10{\cdot}8 \times 2 \times 100 \times 300 \times (100-6)}{220 \times 5} = 55{,}374$$

circular mils, which corresponds to No. 2 B. & S. gauge. The whole length being 2 × 100 = 200 ft., the weight of this wire in weatherproof insulation will be 50 pounds. (250 per 1000 ft.) and the price about $20.00. The number and cost of other articles necessary for the construction of the circuit in this example, depends largely upon local circumstances; therefore no attention need be paid to them.

EXAMPLE 72.

50 electric arc lamps are supplied by direct current of 9 8 amperes and E. M. F. of 42·5 volts at the terminals of each lamp. The resistance of leads is 3·2 ohms. The dynamo delivers 38·45 H. P, at the armature which has a resistance of 23·5 ohms.

1. What is the amount of power consumed by each lamp?
2. What is the amount of power lost in the circuit?
3. What is the total power expended?
4. What is the total E. M. F.?
5. What is the mechanical efficiency?

Answer.

1. The power consumed by each lamp = volts × amperes

$$42{\cdot}5 \times 9{\cdot}8 = 416{\cdot}5 \text{ watts}; \quad \frac{416{\cdot}5 \text{ watts}}{746} = 0{\cdot}55 \text{ H. P.}$$

2. The power lost in the circuit, equals square of current multiplied by the sum of resistances (here: the resistance of the armature and resistance of the leads) =

$$9{\cdot}8^2 \times (23{\cdot}5 + 3{\cdot}2) = 96{\cdot}04 \times 26{\cdot}7 = 2564{\cdot}268 \text{ watts}$$

$$\text{or, } \frac{2564{\cdot}268}{746} = 3{\cdot}43 \text{ H. P.}$$

3. The total power equals the power consumed by one lamp multiplied by the number of lamps, plus power lost in circuit =

$$50 \times 0{\cdot}55 + 3{\cdot}43 = 30{\cdot}93 \text{ H. P.}$$

4. The total E. M. F. equals the product of current and the sum of resistance (here: resistance of the armature and resistance of the leads) plus product of terminal voltage of each lamp and number of lamps =

$$9{\cdot}8 \times (23{\cdot}5 + 3{\cdot}2) + (50 \times 42{\cdot}5) = 2386{\cdot}66 \text{ volts}$$

5. Mechanical efficiency equals the quotient of the energy consumed by one lamp times number of lamps, plus energy lost in the circuit, and the energy delivered at the armature of dynamo =

$$\frac{50 \times 0{\cdot}55 + 3{\cdot}43}{38{\cdot}45} = \frac{30{\cdot}93}{38\ 45} = 0{\cdot}80 = \frac{80}{100} = 80 \text{ per cent.}$$

EXAMPLE 73.

A direct current of 50 amperes is to be transmitted. The cost of one H. P. is $0.005; the price of a cubic centimeter of copper is $0.006, and its specific resistance is 0.00000157. What section (in square centimeters) must the copper conductor have in order to transmit the energy most economically?

Answer.—The work done per second by the current in a conductor, one centimeter long, in

$$\text{joules} = \frac{50^2 \times 0{\cdot}00000157}{\text{section of conductor}}, \qquad \text{which corresponds to}$$

$$\text{Horse Power } \frac{50^2 \times 0\ 00000157,}{746 \times \text{ section of conductor}}, \text{ per second.}$$

This work is lost because it is converted into heat, thus causing a loss, amounting to

$$\$\frac{50^2 \times 0\,00000157 \times 0{\cdot}005}{746 \times \text{section of conductor}} \text{ per second.}$$

And if the work lasts ten hours a day, or 36,000 seconds, the daily loss will amount to

$$\$\frac{50^2 \times 0{\cdot}00000157 \times 0{\cdot}005 \times 36{,}000}{746 \times \text{section of conductor}}$$

or in a year of 365 days at 10 hours each.

$$\$\frac{50^2 \times 0{\cdot}00000157 \times 0{\cdot}005 \times 13{,}140{,}000}{746 \times \text{section of conductor}}$$

Price of one cubic centimeter of copper is \$0.006; price of one centimeter length of conductor will be \$0.006 × section of conductor, and a loss must also be figured of at least

$$\$\frac{0{\cdot}006 \times \text{section of conductor}}{20},$$

accounted for interest on capital.

Therefore, the total loss per centimeter length of conductor per year will amount to

$$\$\frac{50^2 \times 0{\cdot}00000157 \times 0{\cdot}005 \times 13{,}140.000}{746 \times \text{section of conductor}} + \frac{0{\cdot}006 \times \text{section of conductor}}{20}$$

The loss is at minimum when the sections of conductor equal (Thompson's formula):

$$50 \times \sqrt{\frac{20 \times 0{\cdot}00000157 \times 0.005 \times 13.140{,}000}{746 \times 0{\cdot}006}} =$$

$$50 \times \sqrt{\frac{20{\cdot}6298 \times 0{\cdot}1}{4{\cdot}47}} = 50 \times \sqrt{\frac{2{\cdot}06298}{4{\cdot}47}} = 50 \times \sqrt{0.4625}$$

$$= 50 \times 0{\cdot}68 = 34 \text{ sq. millimeters.}$$

When dividing by $\pi = 3{\cdot}1416$, the square of radius of the section of wire is found to be $\frac{34}{3{\cdot}1416} = 10.82$, from which the radius equals $\sqrt{10{\cdot}82} =$ 2·21 millimeters, or 87 mils (about No. 11 of B. & S. gauge).

EXAMPLE 74.

A system of lighting is to be installed in a theater, and 250 lamps, each 110 volts and 0·5 amperes (hot resistance of each 220), are to be fed by a circuit 200 feet long; five per cent. drop is allowed. Calculate the size and cost of wires when a three-wire system is used instead of a two-wire system.

With two-wire system:

$$\begin{array}{c}\text{section of}\\ \text{wire in}\\ \text{circular mils}\end{array} = \frac{\begin{array}{c}\text{specific}\\ \text{resistance}\\ \text{of copper}\end{array} \times \begin{array}{c}\text{twice the}\\ \text{length of}\\ \text{circuit}\end{array} \times \begin{array}{c}\text{number}\\ \text{of}\\ \text{lamps}\end{array} \times \begin{array}{c}\text{100—}\\ \text{per cent.}\\ \text{drop}\end{array}}{\text{Hot resistance of a single lamp} \times \text{per cent. drop}}$$

$$= \frac{10{\cdot}8 \times 2 \times 200 \times 250 \times (100-5)}{220 \times 5} = 93{,}272 \text{ cir. mils, which}$$

corresponds to No. 0, B. & S. gauge.

When two dynamos are used, one terminal of each being connected to one of the circuit wires, the common junction being connected to the third wire, three wires are required. (see § 156). In such a circuit, two lamps are in series between the positive and negative wires, and therefore require only one half of the current which an equal number of lamps would require on the two-wire system. The voltage between the outside wires is twice that of the two-wire system, the current being only one half of the current of the two wire system. Therefore for a given drop, the drop of voltage in this system will be twice that of the two-wire system; the resistance is four times that of the two-wire system, and therefore the cross section of any of the three wires equals only one fourth of the cross section, determined for the two-wire system.

The middle, neutral wire might, if necessary, be made of a smaller cross section, yet it must be remembered that it has to carry the excess back to the machine if the numbers of lamps on both sides of it are unequal.

Considering all three wires of equal cross section

$\frac{93,272}{4} = 23,318$ circular mils, or No. 7 B & S. gauge,

the total amount of copper needed for the three-wire system is only three eighths of the amount of copper for the same number of lamps on a two-wire system. The circuit for the two-wire system is

$2 \times 200 = 400$ feet of No. 0 B & S. and costs about $84.00, and for the three-wire system, $3 \times 200 = 600$ ft. of No. 7 B & S. and costs about $42.60, when using rubber insulated wire.

This shows a saving of $41.40 in the three-wire system. Yet this saving is considerably diminished by the extra cost of installing and the extra cost of using two machines instead of one.*

EXAMPLE 75.

800 lamps, rated 110 volts, 0·5 amperes, are supplied with direct current through circuit 500 ft., long at a loss amount-

---

* See diagrams No. I and II, and explanation given in the appendix.

ing to 6 per cent. Calculate the size, the weight and price of the wire.

Answer. Section of wire in circular mils =

$$\frac{\text{Constant (2160)} \times \text{watts delivered to lamps} \times \text{length of circuit}}{\text{square of E. M. F. lost in line} \times \text{per ct. watts at the lamps}}$$

For this example (the factor being 2160)

$$\text{Section of wire in CM.} = \frac{2160 \times 800 \times 0{\cdot}5 \times 110 \times 500}{110^2 \times 6}$$

$$= \frac{47{,}520{,}000{,}000}{726{,}000} = 65{,}454 \text{ CM,}$$

corresponding to No. 2 B & S.

Volts lost in circuit =

$$\frac{\text{E. M. F. at lamp end} \times \text{per cent watts lost in circuit}}{100}$$

$$= \frac{110 \times 6}{100} = \frac{660}{100} = 6{\cdot}6 \text{ volts.}$$

Weight of copper =

$$\frac{\begin{matrix}\text{Constant} \\ 6{\cdot}04\end{matrix} \times \begin{matrix}\text{watts delivered} \\ \text{to lamps}\end{matrix} \times \begin{matrix}\text{Constant} \\ 2160\end{matrix} \times \begin{matrix}\text{square of length} \\ \text{of circuit}\end{matrix}}{\text{sq. of E. M. F. at lamps} \times \text{per cent. watts lost in line} \times 10^6}$$

$$= \frac{6{\cdot}04 \times 800 \times 110 \times 0{\cdot}5 \times 2160 \times 500^2}{110^2 \times 6 \times 10^6}$$

$$\frac{143{,}510{,}400{,}000{,}000}{726{,}000{,}000{,}000} = \frac{1{,}435{,}104}{7260} = 197{\cdot}6 \text{ pounds copper.}$$

at \$0.35 per lb., the cost of copper is $197{\cdot}6 \times 0{\cdot}35 = \$69.16$.

EXAMPLE 76.

In a water power station, a four wire line is installed to transmit 2500 horse power over three miles to a sub-station;

containing *step-down* transformers The current is two phase alternate current with 40 periods frequency.

The E. M. F. of the generators in the power station is such as to result in 5,000 volts at the primaries of the step-down transformers. Line loss is 8 per cent., of delivered power; transformer efficiency 97 per cent., and load of such character as to make the power factor about 80 per cent; calculate size of the circuit, and cost of copper.

Answer. Power at secondary coil of transformers =

$$2500 \text{ H. P or } 2500 \times 746 = 1865 \text{ kw}$$

Power at primary coil of transformers

$$\frac{1865 \times 100}{97} = 1922{\cdot}6 \text{ kw.} = 1{,}922{,}600 \text{ watts.}$$

Loss due to transmission 8 per cent.,

therefore the section of circuit in circular mils equals

$$\frac{\text{Constant } 1690 \times \text{watts delivered} \times \text{length of line in feet}}{\text{sq, of E. M. F.} \times \text{per cent., of power lost}} =$$

$$\frac{1690 \times 1{,}922{,}600 \times 3 \times 5280}{5000^2 \times 8} = \frac{51{,}467{,}232{,}960{,}000}{200{,}000{,}000}$$

$$= \frac{514{,}672{\cdot}3296}{2} = 257{,}336 \text{ circular mils.}$$

Taking four No. 2 wires (66,370 cir. mils.) in parallel the area of section $= 4 \times 66{,}370 = 265{,}480$ cir. mils.

With this arrangement $4 \times 4 = 16$ No 2 wires are used and the per cent loss is,

$$\frac{\begin{matrix}\text{Constant}\\ 1690\end{matrix} \times \begin{matrix}\text{watts}\\ \text{delivered}\end{matrix} \times \begin{matrix}\text{length}\\ \text{of line}\end{matrix}}{\begin{matrix}\text{sq. of}\\ \text{E. M. F}\end{matrix} \times \begin{matrix}\text{area of section of}\\ \text{conductor}\end{matrix}} = \frac{1690 \times 1{,}922{,}600 \times 3 \times 5280}{5000^2 \times 265{,}480}$$

$$=\frac{51,467,232,960,000}{6,637,000,000,000}=\frac{5,146,723.296}{663,700,000}=7{\cdot}76 \text{ per ct.}$$

Therefore the power lost in transmission equals

$$\frac{2\,500\times 7{\cdot}76}{100}=194 \text{ H. P.}$$

$$\text{Loss of E. M F} = \frac{\dfrac{\text{Constant*}}{1{\cdot}10}\times\begin{array}{c}\text{E. M F. at}\\ \text{transformers}\end{array}\times\begin{array}{c}\text{per cent. of}\\ \text{power lost}\end{array}}{100}=$$

$$\frac{1{\cdot}10\times 5000\times 8}{100}=440 \text{ volts.}$$

E. M. F. of generator = 5000 + 440 = 5440 volts.

$$\text{Current in line}=\frac{\text{Constant } 0{\cdot}625\times \text{power in watts delivered}}{\text{E. M. F}}=$$

$$\frac{0{\cdot}625\times 1,922,600}{5.000}=240{\cdot}325 \text{ amps.}$$

Core loss in transformer, . . 1·5 per cent. 3·604 "

Total current, 243.929 "

Weight of copper in pounds =

$$\frac{\text{Const. } 12{\cdot}08\times\begin{array}{c}\text{watts}\\ \text{delivered}\end{array}\times \text{Const. } 1690\times\begin{array}{c}\text{square of length}\\ \text{of circuit}\end{array}}{\text{sq. of E. M. F.}\times \text{per cent of power loss in transmission}\times 10^6}$$

$$\frac{12{\cdot}08\times 1.922\,600\times 1690\times(3\times 5280)^2}{5000^2\times 7{\cdot}76\times 10^6}=$$

$$\frac{11,421,477,751,799,808,000}{194,000,000,000,000}=58,870 \text{ pounds of copper.}$$

and taking \$0.35 as price of one pound of copper, the cost of copper is 58,870 × \$0 35 = \$20,604 50.

---

* This constant is suitable only for alternating current of 40 cycles; power factor being 80, and wires No. 2–18 inches apart.

EXAMPLE 77.

A large factory has a single phase, alternate current, three-wire system installed, with a frequency of 60 cycles. The power station contains a generator *A*. (See fig. 157.)

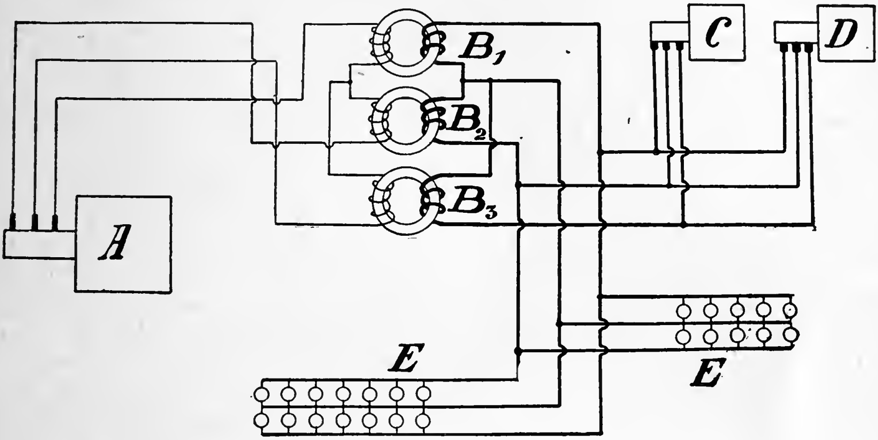


FIG. 157.

The power is transmitted by three wires to secondary coils of transformers, B_1, B_2, B_3. The distance from generator to transformers is 1,000 feet. The secondary current feeds two twenty H. P. induction motors; the distance from these motors to transformers is 300 feet; 1500 lamps, E, rated at 110 volts and 0.5 ampere; the center of lights is 250 feet from transformers. Drop in primary mains, 3 per cent; drop in secondary mains about 10 volts; drop in transformers 3·5 per cent.; the energy lost in transformers amounts to 3 per cent.; the efficiency of the indnction motors amounts to 85 per cent. Calculate the details of this system

Answer.

1. For light:

The power needed for lamps $= 1500 \times 0.5 \times 110 = 82{,}500$ watts.

For 10 volts loss in secondary mains, loss of power =

$$\frac{\text{volts loss} \times 100}{\text{constant } 1{\cdot}34 \times \text{E. M. F.} \times 2} = \frac{10 \times 100}{1{\cdot}34 \times 111 \times 2} = 3{\cdot}3 \text{ p. ct.}$$

Section of conductor in circular mils =

$$\frac{\text{constant } 2400 \times \text{power delivered in watts} \times \text{length of circuit}}{\text{square of E. M. F.} \times \text{per cent. loss of power.}}$$

Section of conductor =

$$2400 \times \frac{82{,}500 \times 250}{220^2 \times 3{\cdot}3} = \frac{49{,}500{,}000{,}002}{159{,}720} = 309{,}917 \text{ cir. mils.}$$

Take 3 No. 0 wires, B. & S. gauge (area = 115,534 cir. mils).

Total area of section = 3 × 105,534 = 316,602 cir. mils.

Loss of power in per cent. =

$$\frac{\text{constant } 2400 \times \text{power delivered in watts} \times \text{length of circuit}}{\text{section of conductor} \times \text{square of E. M. F.}} =$$

$$\frac{2400 \times 82{,}500 \times 250}{316{,}602 \times 220^2} = \frac{49{,}500{,}000{,}000}{15{,}323{,}536{,}800} = 3{\cdot}2 \text{ per cent.}$$

$$\text{Drop in voltage} = \text{const. } 1.34 \times \frac{\text{E. M. F.} \times \text{p. ct. loss of power}}{100}$$

$$= 1{\cdot}34 \times \frac{220 \times 3{\cdot}2}{100} = 9{\cdot}43 \text{ volts or approximately, 9 volts.}$$

E. M. F. at the secondary coils of transformers = 220 + 9 = 229 volts. Current in secondary lighting circuit =

$$\frac{\text{constant } 1{\cdot}052 \times \text{watts delivered}}{\text{E. M. F.}} = 1{\cdot}052 \times \frac{82{,}500}{220} = \frac{86{,}790}{220}$$

= 395 amperes.

The two outside lines may each consist of three No. 0 B. & S., and the neutral (center) line of (one-third of the outside lines) one No. 0 (B. & S.) wire.

Length of wire in outside line $= 3 \times 250 = 750$ ft. of No. 0 B. & S.

Length of wire in second outside line $= 3 \times 250 = 750$ ft. of No. 0 B. & S.

Length of wire in neutral (center) line $= 1 \times 250 = 250$ ft. of No. 0 B. & S.

Total length of No. 0 B. & S. wire equals 1,750 feet.

Weight of copper in 1,750 feet of No. 0 B. & S. wire (0·3195 lbs. per foot) $= 0{\cdot}3195 \times 1750 = 559{\cdot}125$ lbs.

2.) *for motors.*

$$\text{Power needed} = \frac{\text{H. P. of motor} \times 746 \times \text{number of motors}}{\text{efficiency}}$$

$$= \frac{20 \times 746 \times 2}{0{\cdot}85} = 35{,}106 \text{ watts.}$$

$$\text{or on each circuit} = \frac{35{,}106}{2} = 17{,}553 \text{ watts.}$$

Power factor 80 per cent. Drop on motor circuits 3·5 per ct.

Area of section of conductor

$$= \text{const. } 3380 \times \frac{\text{power in watts} \times \text{length of circuit}}{\text{sq. of E. M. F.} \times \text{per ct drop}}$$

$$= 3380 \times \frac{17{,}553 \times 300}{220^2 \times 3{\cdot}5}$$

$$= \frac{17{,}798{,}742{,}000}{169{,}400} = 105{,}068 \text{ circular mils.}$$

Take one No. 0 wire (B. & S.) area $= 105{,}534$ cir. mils.

Per cent. loss of power =

$$\text{const. } 3380 \times \frac{\text{power delivered in watts} \times \text{length of circuit}}{\text{sq. of E. M. F.} \times \text{area of sec. of conductor}}$$

$$= 3380 \times \frac{17{,}553 \times 300}{220^2 \times 105{,}534}$$

$$= \frac{17{,}798{,}742{,}000}{5{,}107{,}845{,}600} = 3{\cdot}5 \text{ per cent.}$$

Drop of E. M. F. =

$$\text{constant } 1.49 \times \frac{\text{E. M. F.} \times \text{per cent. loss of power}}{100}$$

$$= 1{\cdot}49 \times \frac{220 \times 3{\cdot}5}{100} = \frac{1147{\cdot}3}{100} = 11{\cdot}473 \text{ volts,}$$

or 11 volts approx.

$$\text{Current} = \text{const. } 1{\cdot}25 \times \frac{\text{power in watts}}{\text{E. M. F.}} = 1{\cdot}25 \times \frac{35{,}106}{220} =$$

199·9 amperes, or nearly 200 amperes.

3) *Total.*

Total load = 82,500 + 35,106 = 117,606 watts.

Power lost in transformation =

$$\frac{\text{total power}}{\dfrac{100 - \text{loss in transformers}}{100}} =$$

$$\frac{1117{,}606}{\dfrac{100-3}{100}} = \frac{11{,}760{,}600}{97} = 121{,}243 \text{ watts.}$$

E. M. F. in primary circuit = 229 × 1·035 × 9 = 2133 volts.

Section of primary feeder in cir. mils (see the preceding part of this example)

$$=\frac{82{,}500\times 2400+35{,}106\times 3380}{121{,}243}\times\frac{121.243\times 1000}{2133^2\times 3{\cdot}5}$$

$$=\frac{37{,}180{,}169.842{,}040{,}000}{1{,}930{,}662{,}801{,}994{\cdot}5}=19{,}259 \text{ circular mils.}$$

Take No. 7 (B. & S.) wire $=20{,}817$ cir. mils.

Per cent. power lost $=\dfrac{2634\times 121{,}243\times 1000}{2133^2\times 20{,}817}=3{\cdot}37$ per ct.

Power factor =

$$\frac{82{,}500\times 95+35\ 106\times 80}{121{,}243}=\frac{10{,}645{,}980}{121{,}243}=87 \text{ per cent.}$$

Drop of voltage in primary circuit =

$$\frac{1{\cdot}175\times 2133\times 3{\cdot}37}{100}=84 \text{ volts.}$$

E. M. F of generator $=2133+84=2217$ volts.

Current in primary circuit $=1{\cdot}14\times\dfrac{121{,}143}{2133}=65$ amperes.

Total copper:	For lamps = - - - - -	559·125 lbs.
	For motors, 900 ft. No. 0 = 900 × 0·3195 = - - - -	287·55 "
	In primary circuit: 3,000 ft. No. 7 = 3000 × 0·6302 = -	1890·60 "
	Total,	2737·275 lbs.

Cost of 2,737·275 lbs. of copper at \$0.35 = \$958·05.

AN ESTIMATE

taken from actual practice shows for a 1000 H. P. plant the following figures:

Cost of plant:

Hydraulic works with wheels, complete	$49,732
Power station with dynamos, complete	24,635
Transmission circuit	6,200
Pole line 3½ mile, complete	1,972
Transformers	11,024
Distributing lines, complete	21,000
Miscellaneous	6,212
Total,	$120,775

Operating expense per year:

Interest and depreciation, 10 per cent.	$12,077
Engineers and electrician in plant	5,100
Linemen, teams, etc.	3,212
Office expense	4,210
Supplies and repairs	3,200
Taxes, rent and miscellaneous	1,225
Total,	$29,024

One kilowatt hour is produced in a plant of this size at $0·0141.

APPENDIX

Corrosion of pipes by electrolysis

The quality of electric current used in commercial electrolysis, to dissolve metals in liquids, is quite frequently the cause of corrosion of water and gas pipes. The current employed in a grounded trolley system, is supposed to return through the bonded rails back to the dynamo in the central station; but the resistance offered to the flow of current by the rails, and sometimes by broken rail-bonds is often so high, that the current leaves the rails to return to the dynamo through other and better conductors. Water and gas pipes possessing a large sectional area, offer the current a good return; but wherever the current leaves a conductor in the presence of a liquid the surface of the conductor becomes *corroded* owing to the electrolytic quality of the current. Hence pipes under these circumstances soon show a rusty place where the current leaves them, the place enlarging with time and hollowing out until the pipe leaks. Rails also are corroded in the place where the current leaves them.

The argument may be raised that small currents cannot cause very much damage; but experiments have demonstrated that a steadily flowing current of one ampere, will dissolve nineteen pounds of iron (if in contact with liquid), during one year. 75 pounds of lead would be dissolved in a like manner under similiar conditions. At this rate, a current of 300 amperes would corrode 5,700 pounds of iron or 22,500 pounds of lead in the course of one year.

Fig. 158 shows a diagram of a railway, the rails of which have been used as the return path for the current. The current flows from the generator through the trolley, leaving it at *a,* passing through the motors of the car and entering the rails, but the pipe lying underground, in proximity to the track, offers the current less resistance than the rails and is entered by the current at *b;* it then leaves the pipe at *c,* to flow through a part of the rails back to the dynamo. The car moving, the current changes the place of entering the pipe, yet the point *c,* near the power station remains the place where the current leaves, and is thus subject to a constant corrosion, and will leak in the course of one year, or even sooner.

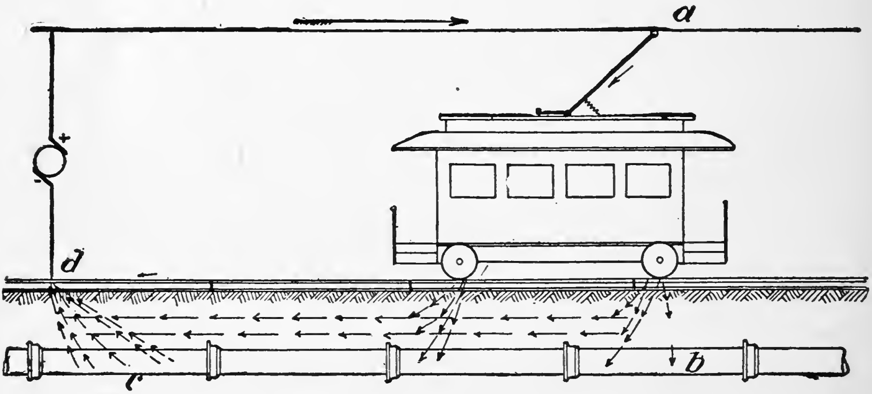


FIG. 158.

Experiments have been made to protect the pipes by painting them with asphalt and other substances, but it has been found that the corrosion even occurs under the coating of paint.

Especially frequent is the corrosion of pipes in joints. Fig. 159, represents the joint of two gas pipes *A* and *B,* through which a current flows in the direction of the arrow. Frequently owing to oxidation, it happens that the lead joint in *c,* offers the current a high resistance. Then the current leaves the pipe *A*, passing through the ground and entering the pipe *B*, behind the joint, thus causing a ring of corrosion where it leaves the pipe to enter the ground (*ab*). It is therefore quite important not to use water or gas pipes as a part of any circuit, unless they are electrically continuous.

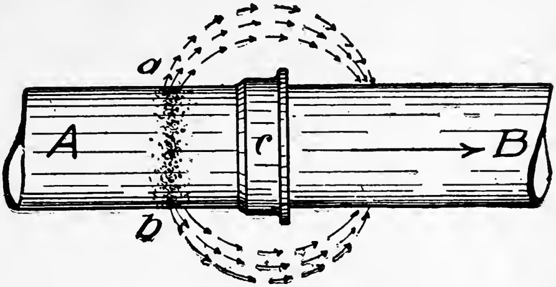


FIG. 159.

To avoid such corrosion, many remedies have been tried; but the best results are shown by proper bonding and especially by electrically welding the rails thus decreasing their resistance.

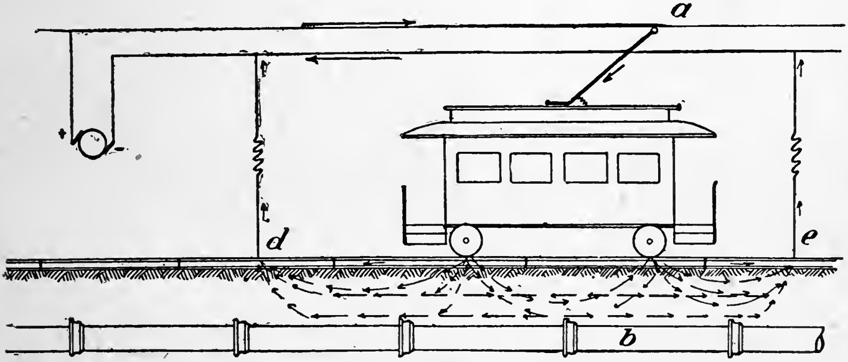


FIG. 160.

Fig. 160 shows a diagram of a railway system where precautions have been made against electrolytic corrosion of pipes. As may be observed, the current enters the trolley at the power station, leaves it at *a*, passes through the car motors into the rails, and enters the return feeds *d* and *e*, to return back to the generator. It may also be observed that there exists no electrical connection between the dynamo and ground; on the contrary in practice the dynamo is carefully insulated from the ground, the current being carried back to the dynamo by special wires which at frequent intervals connect with the rails.

The most important points to be considered when dealing with electrolytic corrosion of pipes, given by I. H. Farnum, and based upon his researches on this subject, are stated below.

1. All single trolley railways employing rails as the return circuit cause corrosion of pipes in their vicinity, unless special provisions are made to avoid it.
2. A potential difference of a fraction of a volt between pipes and damp ground is sufficient to cause such corrosion.
3. Bonding of rails with bonds of small area of section is insufficient to prevent the damage.
4. Insulating of pipes from ground is insufficient to prevent damage and is impractical.
5. Breaking the metallic continuity of pipes at frequent intervals is impractical.
6. It is advisable to connect the positive pole of the dynamo to trolley.
7. Large conductors leading from the dynamo and connecting to pipes in danger at every few hundred feet will sufficiently protect the pipes (see *d* and *e* in fig. 160.)
8. It is advisable to use separate conductors for each set of pipes to be protected.
9. Connections only at power station to water and gas pipes are not sufficient to insure their safety.

10. Connection between pipes and rails, or rail return wires outside of the danger district should be carefully avoided.

11. Frequent voltage measurements between pipes and ground should be obtained and such changes in the return conductors made as the measurements indicate.

Efficiency of dynamos and motors

Let $E =$ E. M. F. at motor brushes
$e =$ counter E. M. F. developed by the motor
$I =$ current flowing through the motor's armature
$r =$ internal resistance of the armature
$W =$ electrical energy delivered at brushes
$w =$ electrical energy lost in armature ($I^2 r$)
$v =$ electrical energy lost in field coils ($I^2 r$)

Then $$I = \frac{E - e}{r}$$

and $$e = E - (I \times r)$$

The mechanical power developed by a motor (including power needed to overcome friction and power expended in eddy currents and hysteresis) $P = e \times I$.

Electrical efficiency of a dynamo is the ratio of the electrical energy delivered at brushes, to the total energy generated, and equals

$$\frac{W}{W + w + v + \text{iron and friction losses}}$$

$$\textit{Commercial efficiency} = \frac{\textit{Output}}{\textit{Intake}} = \frac{W}{W + w}$$

Losses in a dynamo may be classified as follows:

1. Mechanical losses (friction)

2. Electrical losses ($I^2 R$ losses in the armature and field coils, also losses due to hysteresis and eddy currents.)

Copper Equivalent of Steel Rails

C. M. = 16000 × W (Weight of rail per yard).

Example : — What is the copper equivalent of a rail weighing 65 pounds per yard ?

C. M. = 16000 × 65 = 1,040,000 C. M.

That is, the rail has a conductivity equal to a copper wire of 1,040,000 C. M., and two rails would be equivalent to 2,000,000 C. M. of copper.

Metric System of Weights and Measures

MEASURES OF LENGTHS

1	Millimeter	=	0 001	Meter	=	0.0394	Inch.
1	Centimeter	=	0.01	Meter	=	0.3937	Inch.
1	Decimeter	=	0.1	Meter	=	3.937	Inches.
1	Meter	=	1.	Meter	=	39.37	Inches.
1	Dekameter	=	10.	Meters	=	393.7	Inches.
1	Hectometer	=	100.	Meters	=	328 Feet, 1	Inch.
1	Kilometer	=	1000.	Meters	=	3280 Feet, 10	Inches.
1	Myriameter	=	10000.	Meters	=	6,2137	Miles.

It will be noticed that 10 Millimeters equal 1 Centimeter, 10 Centimeters equal 1 Decimeter, and so on.

MEASURES OF VOLUMES

1	Milliliter	=	0 001	Liter	=	0.061	Cubic Inch.
1	Centiliter	=	0.01	Liter	=	0 6102	Cubic Inch.
1	Deciliter	=	0.1	Liter	=	6.1022	Cubic Inches.
1	Liter	=	1.	Liter	=	0.9081	Quart.
1	Dekaliter	=	10.	Liters	=	9.081	Quarts.
1	Hectoliter	=	100.	Liters	=	2 Bushels, 3.35	Pecks.
1	Kiloliter	=	1000.	Liters	=	1.308	Cubic Yards.

WEIGHTS

1	Milligramme	=	0.001	Gramme	=	0.0154	Grain.
1	Centigramme	=	0.01	Gramme	=	0.1543	Grain.
1	Decigramme	=	0.1	Gramme	=	1.5432	Grains.
1	Gramme	=	1.	Gramme	=	15.432	Grains.
1	Dekagramme	=	10.	Grammes	=	0.3527	Ounce.
1	Hectogramme	=	100.	Grammes	=	3.5274	Ounces.
1	Kilogramme	=	1000.	Grammes	=	2.2046	Pounds.
1	Myriagramme	=	10000.	Grammes	=	22.046	Pounds.

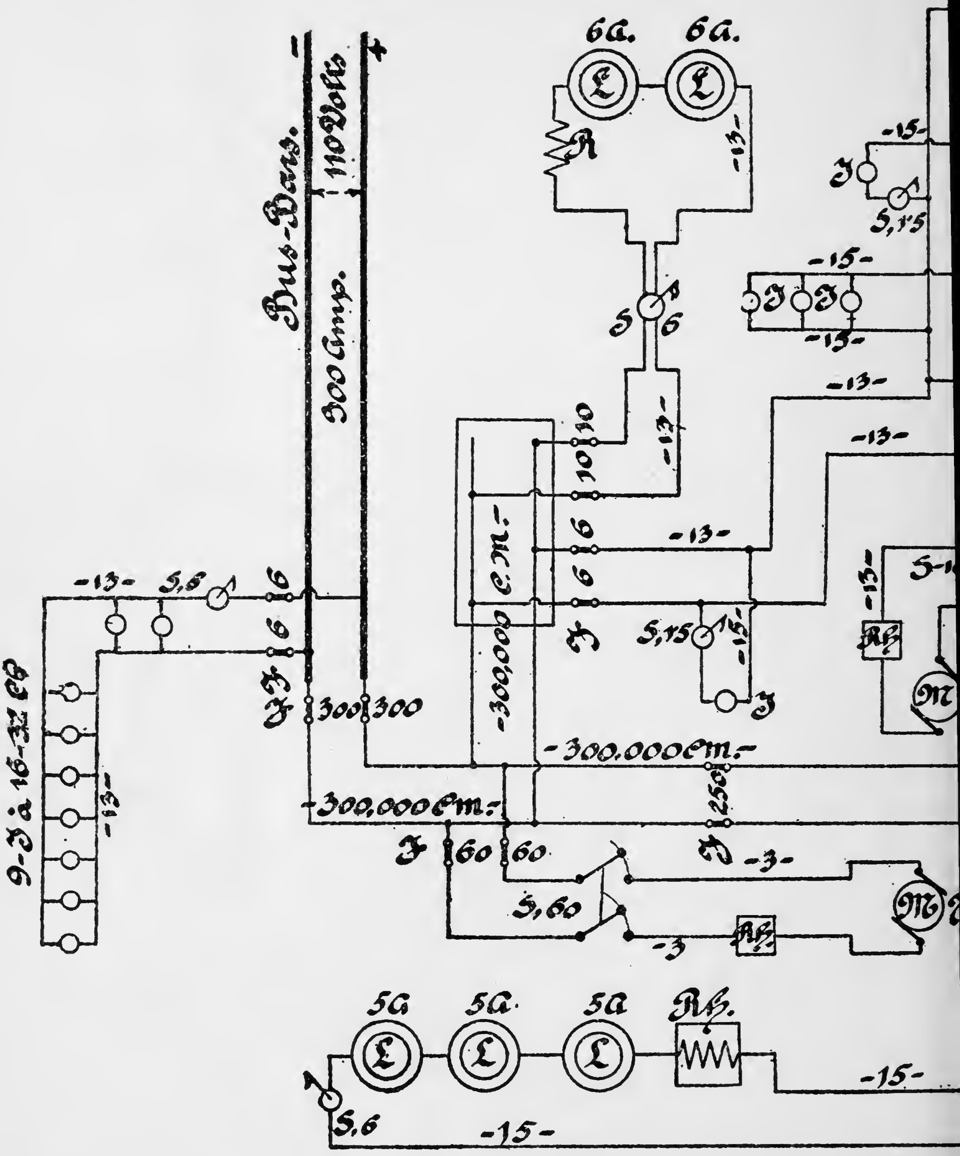
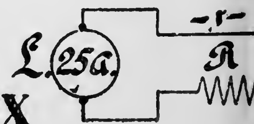
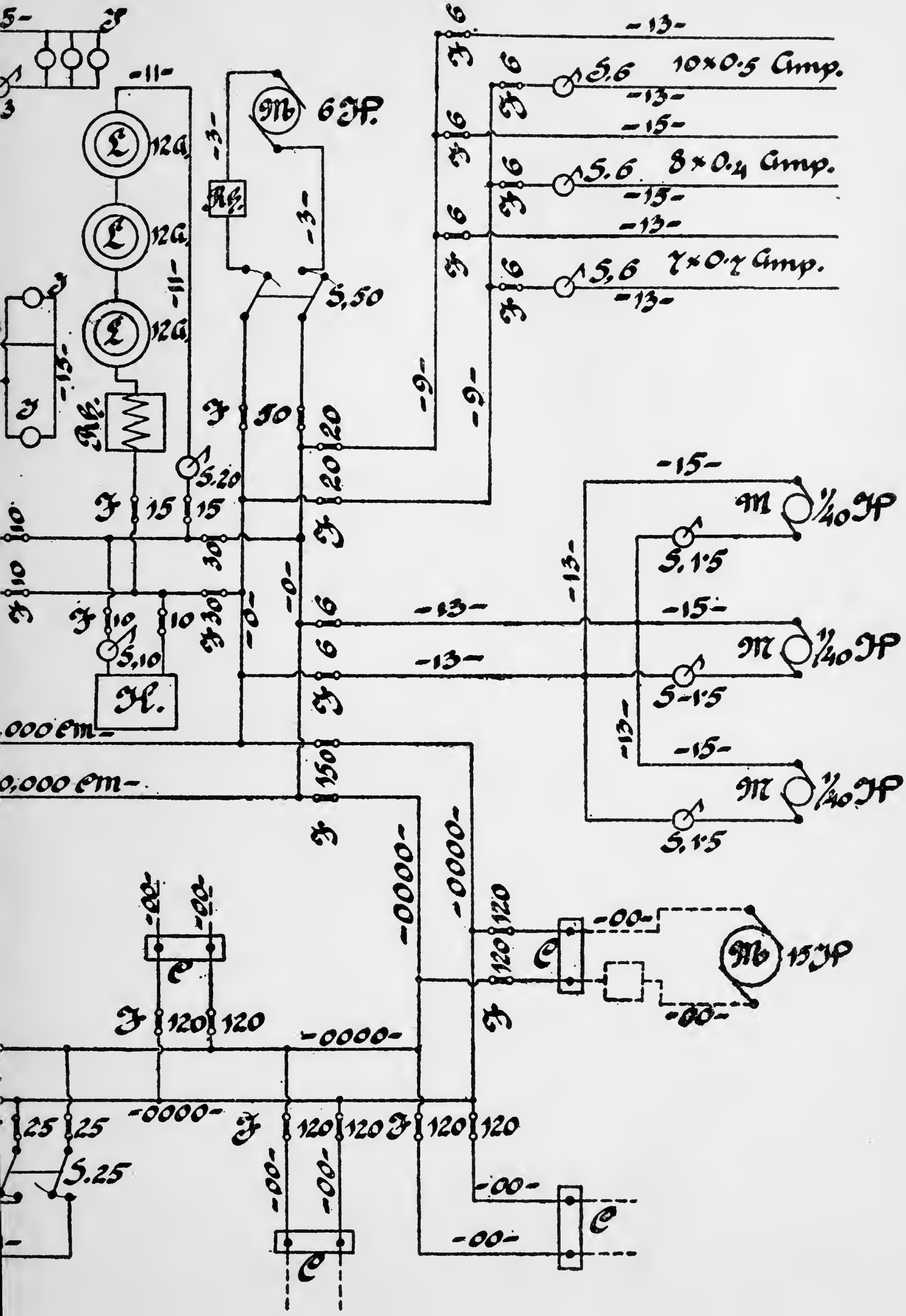


DIAGRAM No. I
TWO WIRE SYSTEM
FOR EXPLANATION SEE APPENDIX

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English and Metric Equivalents

1 Mil = 1-1000 part of an Inch = .001 Inch.
Circular Mils = Diameter in Mils, squared.
1 Inch = 25.4 Millimeters.
1 Kilogramme = 2.2046 Pounds.
1 Square Mil = 1.2732 Circular Mils.
1 Circular Mil = .7854 Square Mil.
1 Millimeter = 39.37 Mils.
1 Kilogramme per Kilometer = .67196 Pound per 1000 Feet.
1 Pound per 1000 Feet = 1.4882 Kilogrammes per Kilometer
Diameter in Millimeters = Diameter in Mils ÷ 39.37
Diameter in Mils = Diameter in Millimeters × 39.37
Area in Square Millimeters = $(\text{Diameter in Millimeters})^2 \div 1.273$
Diameter in Millimeters = $\sqrt{\text{Area in Sq. Millimeters} \times 1.273}$
Area in Square Millimeters = Area in Circular Mils ÷ 1973.5
Area in Circular Mils = Area in Sq. Millimeters × 1973.5
Pounds per 1000 Feet = Weight in Kilogrammes per Kilometer ÷ 1.4882.
Kilogrammes per Kilometer = Weight in pounds per 1,000ft. ÷ .67196
Pounds per 1000 Feet = Area in Circular Mils × .003027
Feet per Pound = 330360 ÷ Circular Mils.

Metric and English Equivalents

Inches = Millimeters ÷ 25.4
Feet = Meters × 3.28083
Yards = Meters × 1.09361
Miles = Kilometers ÷ 1.60935
Sq. In. = Sq. Millimeters × .00155
Sq. Ft. = Sq. Meters × 10.7641
Acres = Sq. Kilometers × 247.114
Cu. In. = Cu. Centimeters ÷ 16.3870
Cu. Ft. = Cubic Meters × 35.3140

Lbs. Avoirdupois = Kilogrammes × 2.20462
Tons (2000 lbs.) = Kilogrammes ÷ 907.18
Lbs. per Foot = Kilo. per Meter × .67196
Lbs. per Cu. Ft. = Kilo. per Cu. Meter × .06243
Sq. Millimeters = Square Inches × 645.137
Sq. Meter = Square Feet × .0929
Grammes = Ounces × 28.3495
Grammes = Pounds × 453.5926
Kilogrammes = Pounds × .45359

Symbols of the More Important Metals and Chemicals Used in Electric Cells.

SYMBOL.	NAME.	FORM.
Fe	Iron	Metals.
Cu	Copper	
Zn	Zinc	
C	Carbon	
Ag	Silver	
Pb	Lead	
Hg	Quicksilver, Mercury	metal liquid.
Cl	Chlorine	green-yellow gas.
H_2O	Water	liquid.
H_2SO_4	Sulphuric acid	liquid.
$K_2Cr_2O_4$	Potassium dichromate	large red crystals.
HNO_3	Nitric acid	liquid.
MnO_2	Black oxide or manganese dioxide	ore.
CuO	Copper monoxide, cupric oxide, or Black Oxide	red powder.
$ZnCl_2$	Zinc chloride	white powder.
NH_4Cl	Sal-ammoniac, ammonia hydrochlorate	white crystals.
KOH	Potassium hydroxide	white sticks.
Fe_2Cl_6	Ferric chloride	red crystals.
$CaSO_4$	Calcium sulphate (gypsum)	white powder.
$ZnSO_4$	White vitriol, zinc sulphate	long white crystals.
$CdSO_4$	Cadmium sulphate	yellow crystals.
PbO_2	Lead dioxide	brown powder.
PbO	Lead monoxide, litharge	Straw-colored powder
Hg_2Cl_2	Mercurious chloride, calomel	white powder.
$HgSO_4$	Mercuric sulphate	
$AgCl$	Silver chloride	white mass.
$CuSO_4$	Copper sulphate, blue vitriol	long blue crystals.
HCl	Hydrochloric acid, hydrogen chloride	liquid.

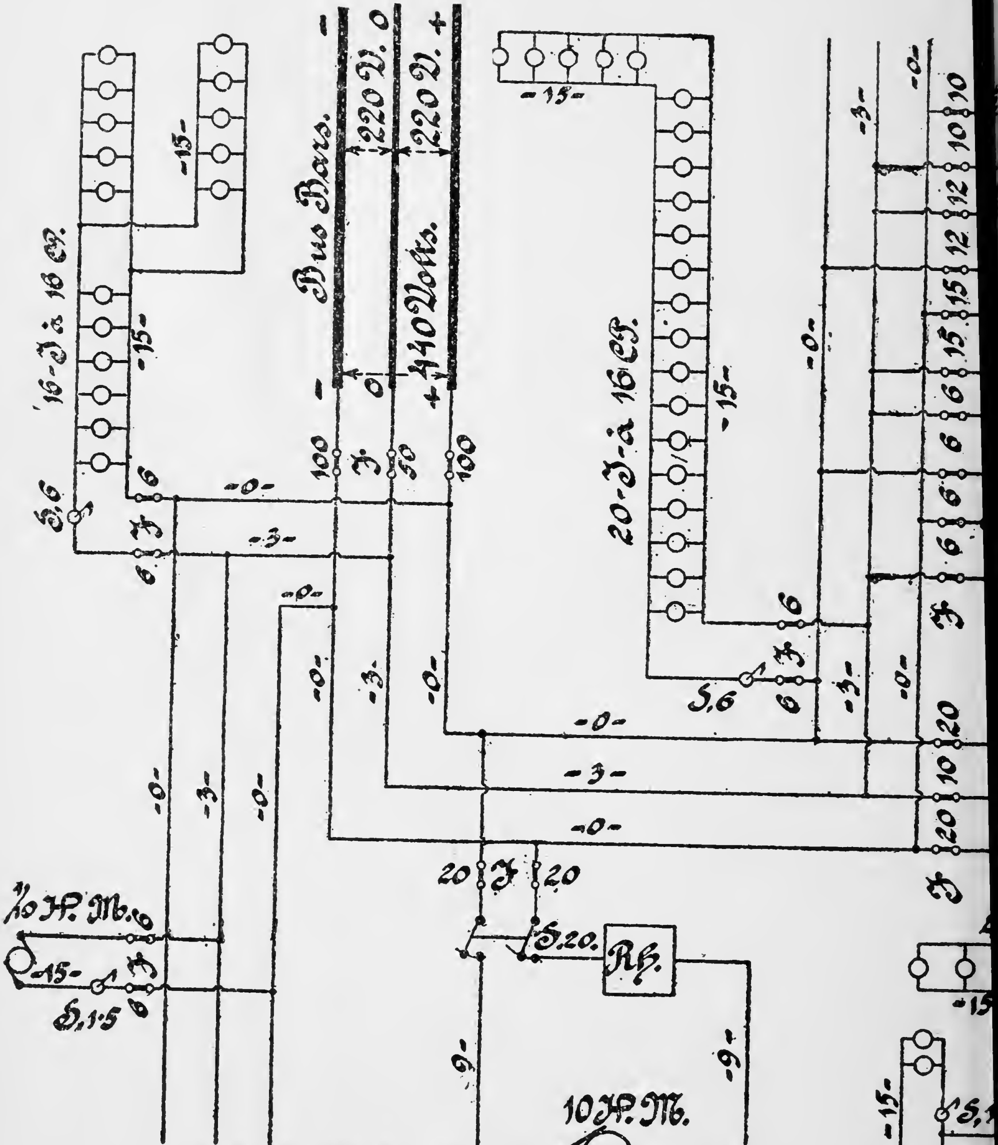
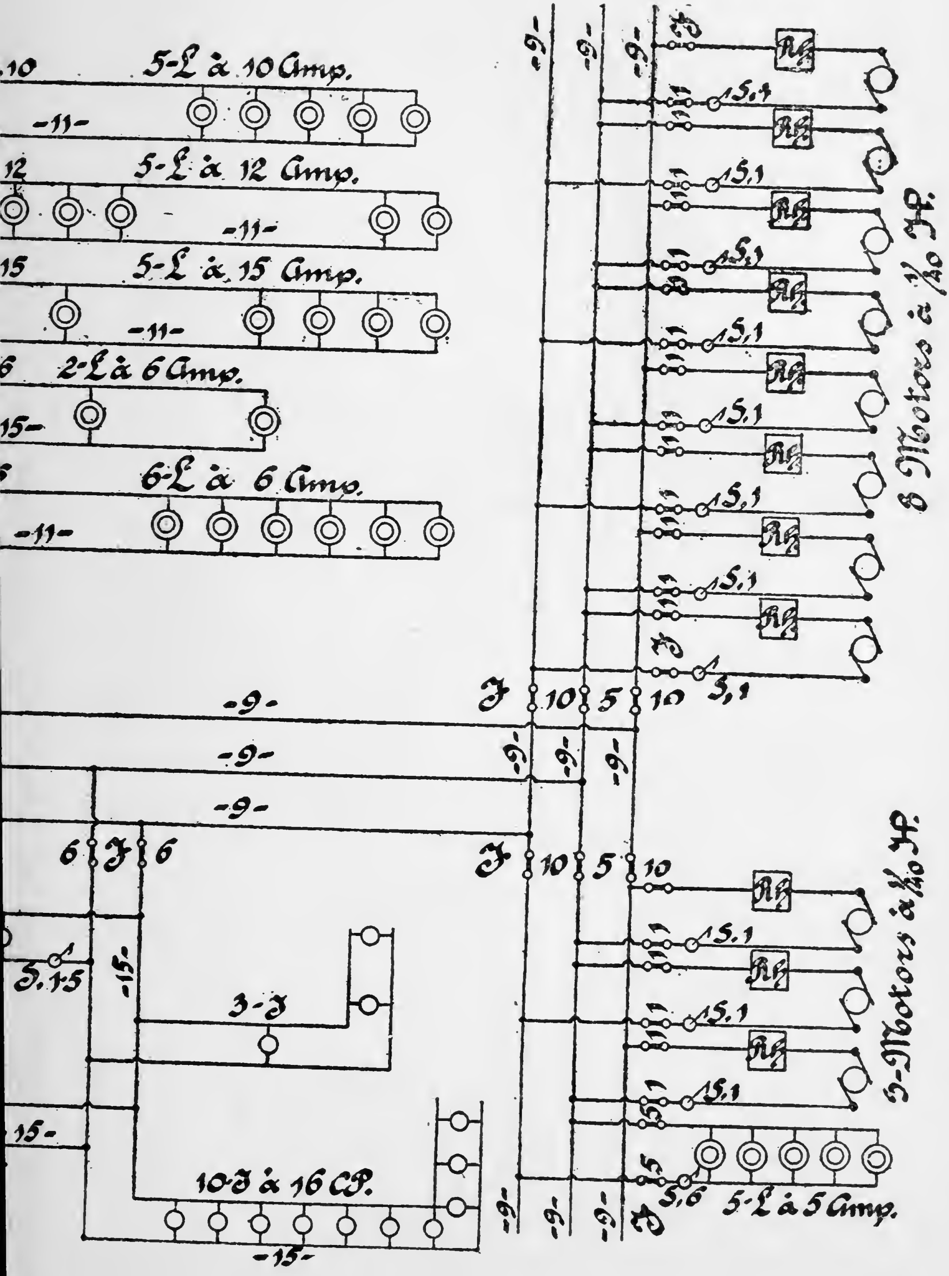


DIAGRAM No. II
THREE WIRE SYSTEM
FOR EXPLANATION SEE APPENDIX


.10
5-L à 10 Amp.
-11-
12
5-L à 12 Amp.
-11-
15
5-L à 15 Amp.
-11-
6
2-L à 6 Amp.
15-
6-L à 6 Amp.
-11-
-9-
J
10
5
S,1
S,4
Rh
8 Motors à 1/10 HP.
-9-
-9-
-9-
6
J
6
S.15
-15-
3-J
15-
10-J à 16 CP.
-15-
J
10
5
10
S,1
Rh
9-Motors à 1/10 H.
S,6
5-L à 5 Amp.

Explanation of Diagram No. I,

This diagram shows the two-wire system of distribution of current from bus bars of the power station generating a maximum current of 300 amperes at a difference of potential 110 volts,

F-6, F-250, etc., indicatefuses for a maximum current of 6,250, etc., amperes respectively.

L-5, L-12, etc., are arc lamps requiring a current of 5, 12 etc., amperes respectively.

I, are incandescent lamps.

M, are motors with their rated horse power.

S-6, S-60, etc., are knife switches with the indicated maximum current for which they may be used. Single or double pole switches may be distinguished in the drawing.

R, are resistances for arc lamps, etc,

Rh, are motor starting boxes.

C, are connecting blocks.

H, are heaters.

The size of wires is given in B & S. gauge —15— indicating No. 15 B & S., —0000— No. 0000 B. & S. etc.

Cables are given in circular mils —300,000 CM.— indicating a cable of 300,000 CM.

Explanation of Diagram No. II

Diagram No. II, shows the three-wire system of distribution of a current from bus bars. The same letters for indicating switches, motors, lamps etc., have been used as in Diagram No. I.

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