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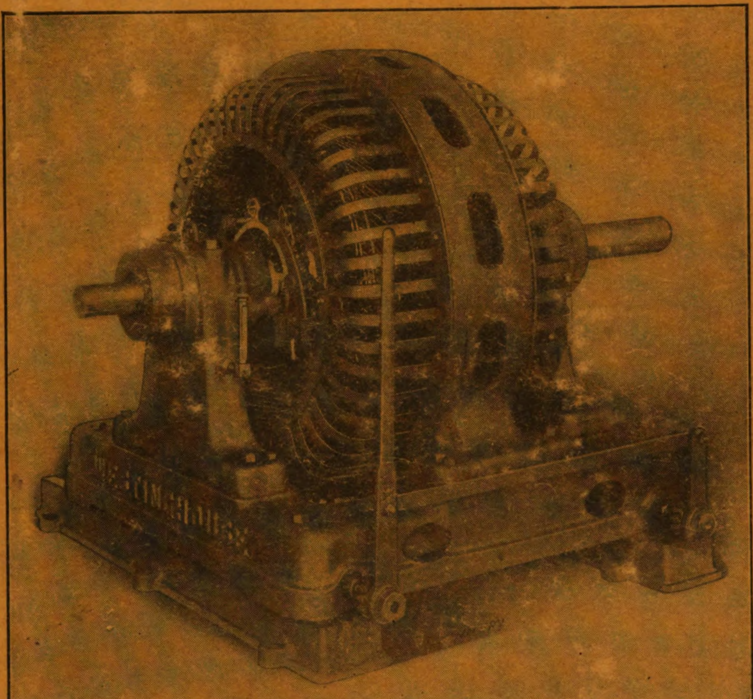
PRINCIPLES AND APPLICATIONS OF

ELECTRICITY

PART II—ELECTRO-MAGNETISM—
ELECTRO-PLATING

SECOND EDITION



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PRINCIPLES AND APPLICATIONS OF ELECTRICITY

By NEWTON HARRISON

PART II

MAGNETISM—ELECTRO-MAGNETISM—ELECTROPLATING

SECOND EDITION

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CHAPTER I

MAGNETISM

The ancients had many legends founded upon the wonderful properties of the lodestone. In the Arabian Nights, Sinbad the Sailor describes the destruction of the vessel in which he and his companions sailed, by approaching too close to a mountain of lodestone. The nails were drawn from the vessel and it fell to pieces. The lodestone was originally found in Magnesia, from which was derived the name magnet. From a chemical standpoint it may be represented by the formula Fe_3O_4, which means a combination of iron and oxygen, forming an oxide, sometimes called magnetite. This mineral possesses permanent magnetic properties, by which is meant that it has the power of attracting light fragments of iron, and holding them with considerable tenacity.

Sir Isaac Newton, the distinguished discoverer of the laws of gravitation, was very proud of a piece of lodestone he possessed set in a ring. It was powerful enough to lift several hundred times its own weight, and in addition betrayed the presence of poles. By this is meant, that at certain points in this mineral, the power seems to be concentrated, and this may be considered as the chief peculiarity of the lodestone.

If we dip a lodestone into a cup of iron filings, and then withdraw it, it will be noted that the filings cluster at each end very thickly. This is merely a manifestation of the peculiar property of all magnets whether natural or artificial—they have two poles. At these points (see Fig. 1), an emission apparently takes place, to which the old experimenters gave the name of magnetic fluid, but which in the language of modern science, is called a magnetic field.

Magnetic Field and Magnetic Poles

Perhaps no more familiar instance of the presence of a magnetic field can be given, than that of the earth itself. Like the lodestone it possesses poles and similarly sends out that remarkable emanation called a magnetic field. For this reason the earth exerts an influence upon a piece of lodestone suspended by a light thread. The lodestone will slowly swing until it has assumed a certain position, to which it will inevitably return, no matter how often displaced. This shows clearly, that the earth exercises a directive effect upon a lodestone, and in consequence the end of the lodestone pointing north has been called the north pole.

It has been stated on good authority that lodestones have been used by the Chinese for many centuries as compasses or guides to the geographical north. Whether this be correct or not, it is well known that by rubbing a piece of tungsten steel with a lodestone, the magnetic properties of the lodestone are imparted to the steel, and that the steel will act in all respects as the lodestone itself. It will possess poles, and naturally a magnetic field. If properly mounted, it will swing around and point north, and, in fact, it becomes an indispensable agent of civilization, namely, a compass needle. If the end of a magnet pointing north is called a north pole, it is but a step to conclude that

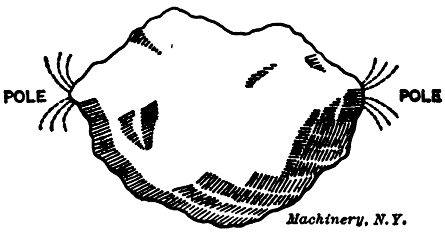

Fig. 1. Poles of the Lodestone

the other end must point south, and will be called a south pole. From this conclusion arises a line of demarkation between the two poles.

If two pieces of steel are magnetized, and mounted as in Fig. 2, so as to swing freely, they will turn so as to present opposite poles to each other. It is useless to attempt to turn them from their positions with regard to each other in this respect. They will inevitably return to the position which brings the north and south pole nearest to each other,

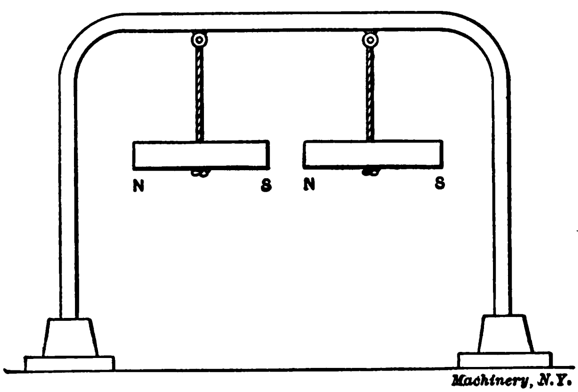

Fig. 2. Swinging Magnets, Demonstrating that Opposite Poles Attract Each Other

and, in fact, they betray a repulsive force when an attempt is made to place them with like poles in proximity to each other.

This has led to the discovery of the operation of certain laws, which may be stated in the following manner:

Unlike poles attract each other.

Similar poles repel each other.

It has, owing to the principles expressed by these laws, become a matter of argument as to which is really the north pole of a magnet with respect to the earth. According to the above laws the end of a magnet pointing north would be a south pole, as this is the only pole the north pole of the earth could attract. By some it is called the "marked pole" or the "blue pole," and finally it is termed by others, rather sensibly, the "north seeking pole." The navigator and scientists in general call it the north pole, in spite of this fact, and it will be so called in the present treatise.

The Geographical and Magnetic North

Lest there should be any misapprehension regarding the relative positions of the geographical and magnetic poles, which are entirely

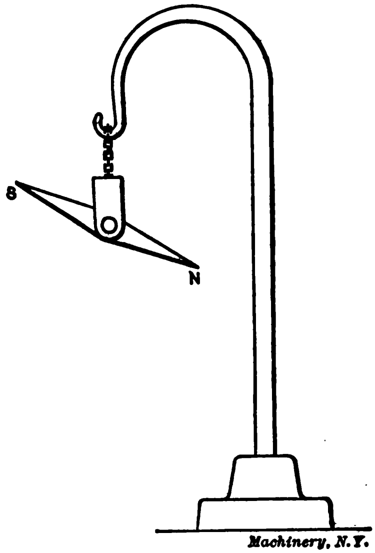

Fig. 3. The Dipping Needle

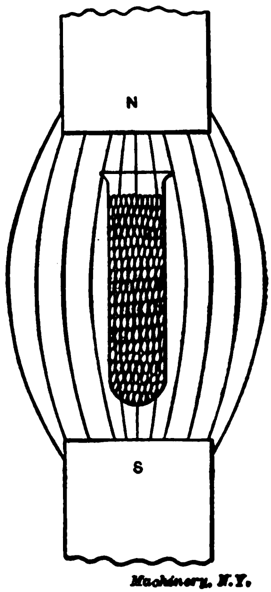

Fig. 4. Tube with Magnetized Iron Filings

different, it may be stated at once that the geographical north pole of the earth is a geometrical point on the earth's surface. On the other hand, the magnetic north pole is located somewhere in the neighborhood of Hudson Bay, Canada.

A magnetic needle supported on a horizontal axis becomes what is commonly known as a dipping needle. At the equator the needle would practically have no dip. But as it is moved north or south a few hundred miles either the north end or the south end begins to dip, as shown in Fig. 3. If moved north until it approaches the magnetic north pole, the dip becomes very pronounced, and if placed over the magnetic north pole, the north pole of the needle would point directly down. From the standpoint of practical utility, however, the movement of the needle in a horizontal plane, as a compass, is of the most direct importance. In navigation, allowance is made for the difference between the magnetic and geographical north in steering a vessel.

Magnetic Induction

If a magnet is held near a piece of iron, even though no contact takes place, the piece of iron develops poles, as shown at *A* in Fig. 5. The influence of a magnet upon a neutral piece of iron or steel is called

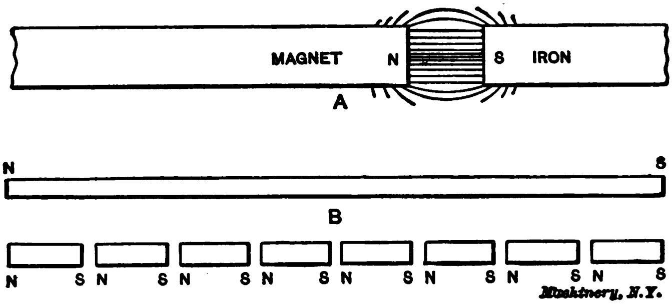

Fig. 5. Graphical Illustrations of Magnetic Induction and of the Magnetic Properties of Molecules

magnetic induction. This explains the attraction which results before contact takes place, and also shows how such attraction can be explained in the light of the law which states that unlike poles attract each other. If a piece of hardened steel is thus exposed to the influence of a magnet it becomes permanently magnetized, that is to say, it will retain its magnetic properties after the source of magnetism has been removed. A piece of soft wrought-iron will not hold its magnetism like steel. Therefore, as both can exhibit magnetism, in the one

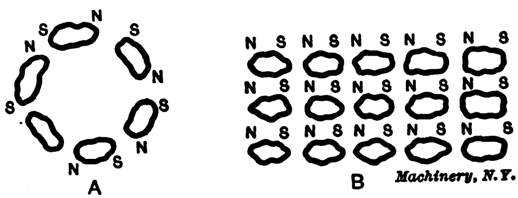

Fig. 6. Arrangement of Molecules in an Unmagnetized and in a Magnetized Piece of Iron

case permanently, and in the other case temporarily, they are called permanent magnets and temporary magnets.

Theory of Magnetism

The theory of magnetism is based upon the idea that it is a molecular phenomenon. The molecules of iron and steel differ in this respect, that when the molecules of steel are disturbed by magnetism they are not free to move back to their original position, whereas in the case of wrought-iron, they possess this power. According to this theory, and an experiment about to be described, every molecule of iron and steel is by nature a magnet. The means by which this idea is proved is as follows: A long steel needle or wire is carefully magnetized and its poles tested by a compass needle. It will be found to have a north and south pole. The wire is cut in half and then tested. Each half will be found to possess a north and a south pole. A repetition of this process will reveal the fact that every piece of steel has become a magnet with two poles, as shown at *B* in Fig. 5. If one of these pieces of steel is supposed to be divided and subdivided beyond the practical limits possible, a point is reached where a molecule of steel is obtained. This molecule, according to preceding experiments, must possess a north and south pole. With regard to this polarized molecule, it may be said that the assumption of its existence is indispensable at present in relation to the explanation it gives of most of the magnetic phenomena observed in connection with iron or steel.

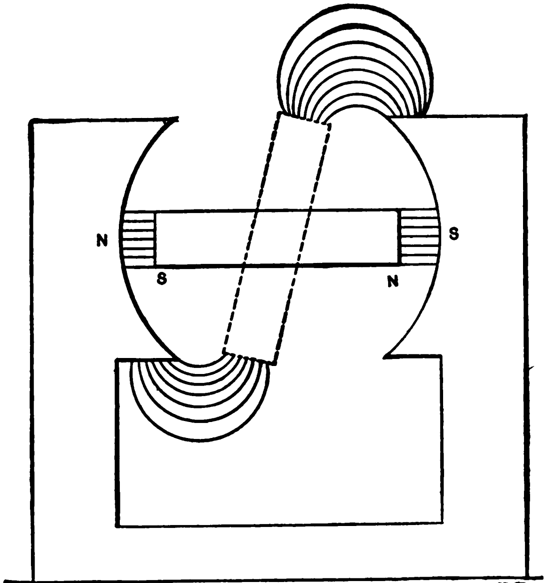

Fig. 7. Graphical Illustration of the Action of Magnetic Forces on a Piece of Iron Pivoted at the Center of a Magnetic Field

If a test tube is filled with iron filings and exposed to a magnetic field, as shown in Fig. 4, the filings will arrange themselves in an end to end manner, each particular grain of metal placing itself so as to bring its opposite poles in contact with the opposite poles of its neighbor. When removed from the magnetic field, the filings, of course, become disarranged. The experiment seems to indicate that magnetism in iron or steel is equivalent to a certain position of the molecules. If a piece of iron or steel is not magnetized the molecules are irregularly arranged, that is to say, they do not point end to end throughout the length of the iron rod. In fact, the molecules are arranged in small closed magnetic circuits which effectively shut off all external signs of magnetism from the body as a whole. These rings of magnetic elements are composed of what are called polarized molecules, that is to say, infinitesimal permanent magnets, whose natural position is that illustrated at *A* in Fig. 6. When the magnetic field affects them, however, they are torn or forced from this position and arrange themselves as shown at *B*. By this means one end of the bar becomes north pole and the other south pole, and it is easy to see that the fracture of the bar at any point whatsoever would result in opposite poles appearing, each at the respective ends of the fractured section. Therefore, when a permanent magnet is broken in half, two magnets appear; if broken again, four magnets are produced, etc.

One of the most useful of magnetic principles is that which states that "lines of force tend to arrange themselves parallel to each other."

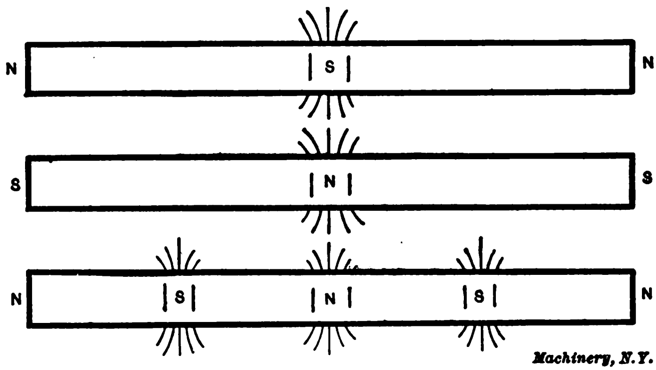

Fig. 8. Magnetized Bars with Consequent Poles

This principle is clearly shown in the repeated efforts of a compass needle, when diverted from its normal position by the finger or another magnet, to return to one in which its lines of force lie parallel to those of the earth. If a bar of iron is held almost at right angles to the magnetic field of a powerful magnet, as shown by the dotted lines in Fig. 7, the tendency of the field to twist the bar around to the horizontal position is due to this principle, and also to the fact that the poles in the bar induced by magnetic induction are thus brought closer to the poles of the magnet.

It is generally supposed that a magnet can only have two poles, but this is not so, as indicated in Fig. 8. Here the magnet has two north poles or it may have two south poles. This would give either a south or a north pole in the middle of the bar. Such a pole is called a *consequent* pole and is, as shown, a pole belonging to each of the magnets of which it constitutes a part. This shows that a magnet as thus understood is not necessarily a bar of steel or iron with a pole at each end, as such a bar may really consist of several magnets, depending upon the magnetization of the bar. For this reason the distribution of the magnetic field must be ascertained and investigated by means of a compass needle, otherwise it would be very confusing to find similar poles at the two ends of a magnetized bar.

Horseshoe Magnets

In order to obtain in full the effect of the two opposite poles a bar magnet is bent around, forming the familiar type of the horseshoe magnet, as shown in Fig. 9. This magnet is supplied with an armature of soft iron which is generally left in contact with the poles when not in use. Under this condition, very little, if any, magnetism can be detected outside of the magnet, and it constitutes in this form a closed magnetic circuit.

The lines of force emanating from a horseshoe magnet's poles and sides follow a curved path, as shown in Fig. 9. This can be readily observed by placing a sheet of paper over the magnet and sifting iron filings on it. When they fall, they will arrange themselves in curved

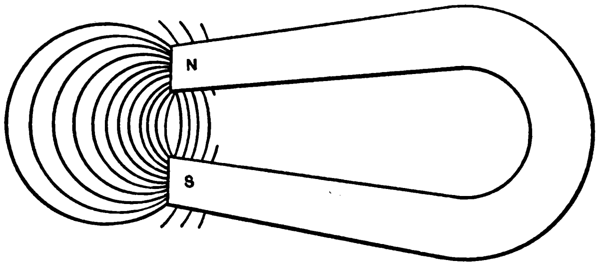

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Fig. 9. The Magnetic Field of a Horseshoe Magnet

lines showing the direction of the magnetic field. At each individual pole they repel each other, because, according to the fundamental laws, north lines repel north lines and south lines repel south lines. But they curve around in spite of this repulsion and meet each other according to the law that the lines of force of opposite poles must attract each other.

A Unit Pole

The exact measurement of magnetism is carried out by basing all calculations upon certain units, which are derived by reference to the centimeter, gram and second system. The unit pole may be regarded as the foundation of such a system and is defined as follows: A unit pole repels a similar and equal pole at a distance of one centimeter with the force of one dyne. Thus, the measurement of magnetism is based upon an idea easily comprehensible. A magnet repelling another magnet with a given degree of force, is thus named in accordance with the requirements of the definition.

Were the magnetic poles so powerful that the repulsion could be measured in pounds, then the principle would be capable of demonstration with exactitude on a large scale. But this is not the case, and the force developed is very small.

Law of Magnetic Attraction

The law governing the attractive or repulsive force of magnetism is the same as that which holds in the case of gravitation; and the same law is true also for light, which varies inversely as the square of the distance. By this is meant that magnetism in common with gravitation, light, and heat, varies according to the law of inverse squares, as it is called. When the distance between two magnetic poles is *doubled*, the intensity of the magnetic field is diminished to *one-quarter;* if tripled the field is reduced to one-ninth, etc. (See Fig. 10.) And this is also true of the attraction between magnetic poles of opposite polarity. It seems, in total, as though all actions taking place through the ether, such as magnetism, light, heat, gravitation, etc., act in accordance with the general law that the effect is inversely proportional to the square of the distance. This fact is noteworthy,

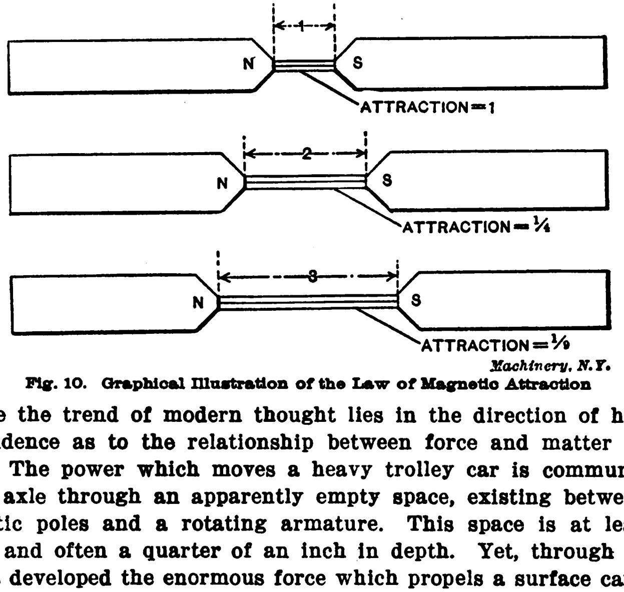

Fig. 10. Graphical Illustration of the Law of Magnetic Attraction

because the trend of modern thought lies in the direction of hunting for evidence as to the relationship between force and matter in the ether. The power which moves a heavy trolley car is communicated to the axle through an apparently empty space, existing between the magnetic poles and a rotating armature. This space is at least an eighth and often a quarter of an inch in depth. Yet, through it and in it is developed the enormous force which propels a surface car, or a train of electric cars or huge electric locomotives, such as those recently completed for several of the steam roads in the United States and abroad.

If the question should be asked, "where does the power go to in a dynamo?"—it might be said that as the dynamo is called upon to produce more and more electricity for outside consumption, in like proportion it becomes more and more difficult to overcome the force developed in this visually empty space between the magnetic poles and the armature. The engine, therefore, gives up its mechanical force in overcoming this drag, and it thus becomes evident that the ether in the space mentioned plays a very practical part in the consideration of either the dynamo or the motor.

Lines of Force

By placing a piece of glass or paper upon a magnet and gently sprinkling iron filings upon it, as mentioned, images of the magnetic lines of force are formed which may be retained if the paper has been paraffined and is then heated after sifting the filings. These lines were called by Michael Faraday physical lines of force and actually represent the distribution of the magnetic field. The physical lines of force of a bar magnet are shown in Fig. 11.

The physical lines of force as they appear cannot be readily "measured"' in number or magnetic force; it is impossible to count them, and for that reason a theoretical line of force must be arrived at whose value is unchangeable and, therefore, reliable. But this line of force must at the same time represent the magnetic force referred to as physical, only differing from it in this respect, that the physical line

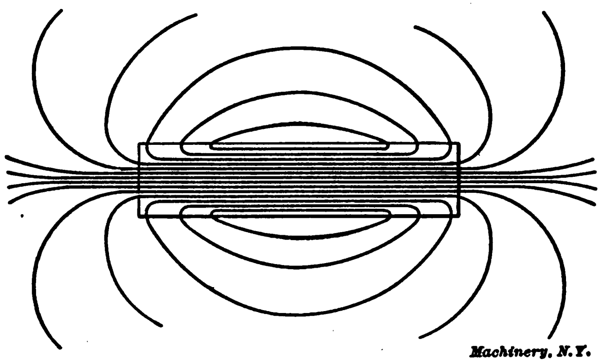

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Fig. 11. The Lines of Force of a Bar Magnet

of force is of arbitrary value, while the scientific or theoretical lines of force are absolute.

Having defined a unit magnetic pole, it is now essential to come to some conclusion regarding the number of lines of force it produces. To accomplish this a sphere is assumed with a unit pole at its center. The size of the sphere is clearly defined as of one centimeter radius, and if the unit pole is at its center this pole is radiating its magnetism in all directions. If the amount of magnetism passing through one square centimeter on the surface of this sphere is considered, it will be found to be exactly equal to that passing through any other square centimeter. This amount of magnetism is called *a line of force* and represents the exact value of the line of force used in the design and calculation of magnets, dynamos, and motors.

The surface of any sphere is equal to four times the area of its greatest circle; therefore, to obtain the area of the surface of this sphere of one centimeter radius, obtain the area of its great circle, which is $\pi \times r^2$, and multiply this area by 4. But as $r = 1$, the square centimeters of surface of the sphere are equal to 4π, or about 12.57, which equals the number of lines of force a unit pole produces.

The Permeability of Iron or Steel

Lines of force enter iron or steel and produce within iron and steel a polarized condition of the molecules. If the magnetic field between the poles of a powerful magnet is taken as a basis for experiments, then the following facts will be noted if equal sized bars of cast iron, steel and wrought-iron are tested:

Experiment with cast iron:—Pull very strong.

Experiment with mild steel:—Pull stronger.

Experiment with wrought-iron:—Pull greatest of all.

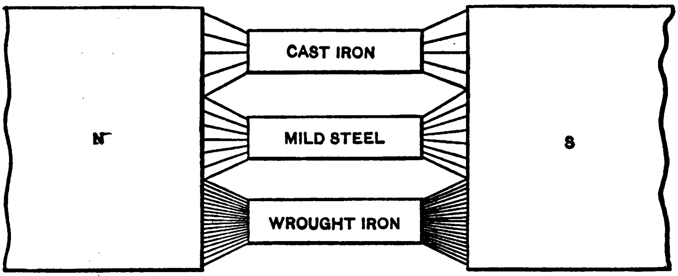

Fig. 12. Graphical Illustration of the Permeability of Different Metals

The meaning of this experiment is as follows: The number of lines of force the cast iron develops are less than those of either the steel or wrought-iron. (See Fig. 12.) If the number of lines of force are any measure of the pull of a magnet, then the cast iron, mild steel and wrought-iron differ from each other as far as magnetism is concerned. If a bar of each of these metals of one square inch cross-section is exposed to the influence of a powerful magnetizing force, then if some means were provided by which the magnetism or number of

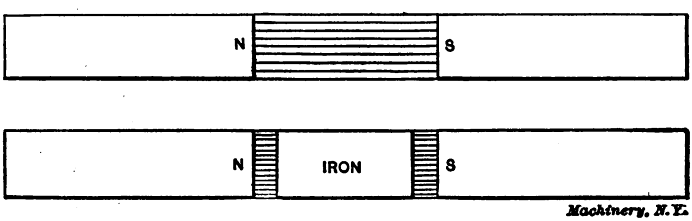

Fig. 13. The Number of Lines of Force through Air and through Iron

lines of force excited in each of these bars, respectively, could be measured, some comparison could be made between them for the purpose of discovering in what respect and to what extent they differ.

By employing an electric current in connection with a large electro-magnet, sufficient magnetism can be obtained to make a test of each of these bars. A button of wrought-iron attached to a spring balance, as shown in Fig. 14, with a little reel to gradually develop the pull is all that is required. The wrought-iron, according to such an experiment, will then show the greatest pull in pounds, then comes the mild steel and finally the cast iron. It is possible to test any sample of iron or steel by this means, and if the device is well constructed, considerable accuracy is attainable. The three metals referred to are greatly used in the construction of electrical machinery.

It is evident that if magnetizable metals behave in this manner, it is necessary to use some distinguishing phrase to mark this difference. The term "permeability" is employed for this purpose, and the metals are referred to by saying "the permeability of wrought-iron is greater than that of steel," or "the permeability of steel is greater than that of cast iron," etc.

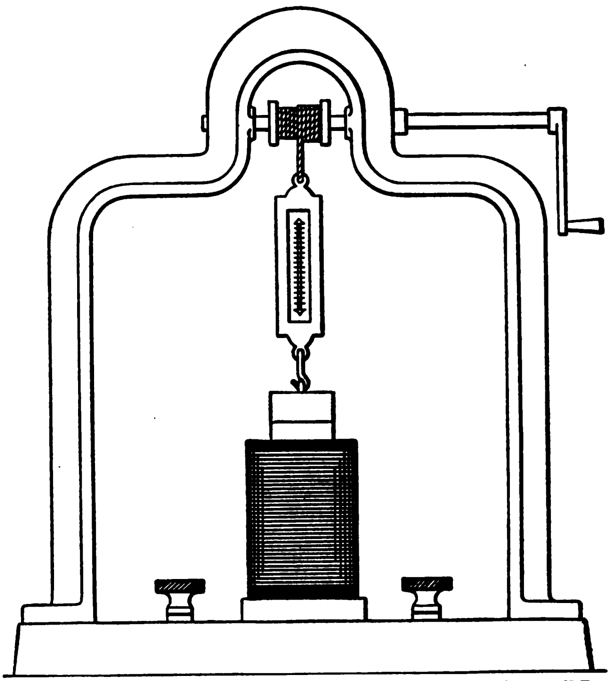

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Fig. 14. Measuring the Pull of a Magnetised Iron Core

The permeability is expressed as the ratio between the strength of a magnetic field with iron in the field, and with iron out of the field, the lines of force in the latter case passing simply through the air, as shown in the upper view in Fig. 13. Suppose the number of lines of force between the poles of a magnet is measured, and then when a piece of iron whose permeability is to be discovered is placed in this magnetic field, as in the lower view in Fig. 13, its field is also tested. If the lines of force of the iron are divided by the lines of force of the original field the permeability is obtained. The permeability is generally represented by the Greek letter μ (mu), and the formula is as follows:

$$\text{Permeability} = \frac{\text{Lines of force in iron}}{\text{Lines of force in air}} = \mu.$$

It can, therefore, be said that permeability is a natural qualification of magnetizable metals. Why one has more permeability than another is, in all probability, dependent upon the ease with which the molecules move when magnetized; but there is no distinct criterion for this, and the two extremes of permeability as found in daily practice are that of air and Swedish wrought-iron. Air is taken as the standard and is said to have a permeability of 1. Wrought-iron has a permeability of at least a thousand, depending, of course, upon its quality. The lines of force are measured with reference to the square centimeter or square inch. In bars of equal size, the greater the number of lines per unit area, the greater the magnetic pull.

CHAPTER II

ELECTRO-MAGNETISM

It is customary to term magnetism produced by electricity *electro-magnetism*, to distinguish it from that which has been produced by lodestones and permanent magnets. Permanent magnets can be made by electro-magnets as well as by the lodestone or other permanent magnets. In fact, the permanent magnet is simply a special case of retained magnetism, while in the production of electro-magnetism, either no iron is used at all, or, if employed, it is what is generally known as soft or wrought-iron or mild steel—a magnetizable material which does not retain its magnetism permanently. Many expressions are in use in relation to magnetism, such as natural magnets, artificial

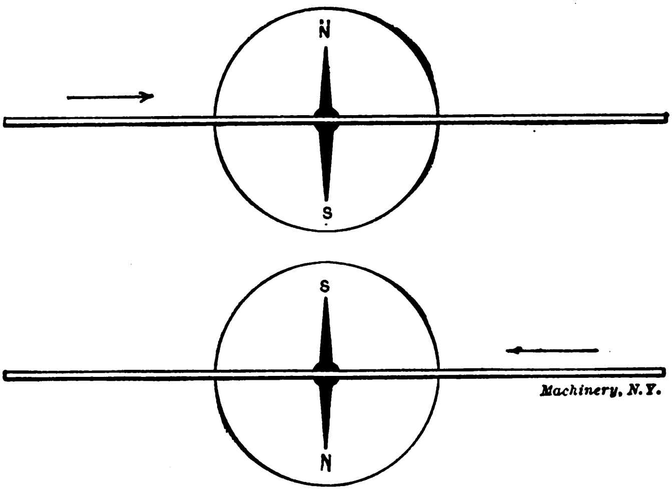


Fig. 15. The Effect of an Electric Current on a Magnetic Needle

magnets, permanent magnets, and temporary magnets. There are other phrases and words, some obsolete and some modern, which do or did apply to the subject of magnetism. Many of these are unscientific and misleading and it is best to cling to the later and more correct titles of to-day. If magnets are classified, irrespective of other considerations, as permanent magnets and electro-magnets, a beginning can be made for a correct practical and theoretical consideration of electro-magnetism. The last is what constituted the discovery of Oersted, namely that an electric current produced all the characteristics of a magnet.

If a copper wire is used to carry a current of electricity from one pole of a battery to another, the entire wire will be found to be surrounded by magnetism. This magnetism, or lines of force, as it is more properly called, can be detected by bringing a compass needle near the wire, as shown in Fig. 15. The needle will be affected to such a marked degree and in such a manner that it will place itself at right angles to the wire. Another curious phenomenon will be noticed. While the current is flowing in one direction through the wire, the needle will hold its position at right angles, as described, but if the current in the wire is reversed, the needle will swing around, and although it will settle itself at right angles to the wire in this case as well as the other, it will be discovered that the positions of the poles have changed—they have reversed.

If the wire carries a very powerful current and it be thrust through a sheet of cardboard and iron filings scattered around, the presence of concentric circles of filings will be apparent upon lightly tapping the cardboard. The presence of magnetism as thus shown, simply proves

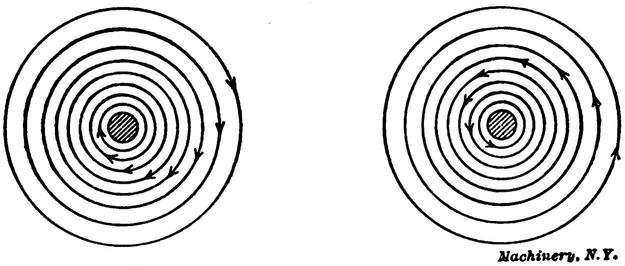


Fig. 16. Magnetic Whirl around a Wire Carrying an Electric Current

the existence of a magnetic field whose center is the wire and whose influence extends beyond it. The experiment of reversing the current, however, shows by the reversal of the poles of the adjacent magnetic needle, that the magnetic field around the wire has reversed as well. The wire which carries a current is apparently the seat or source of a magnetic whirlpool. The direction of this whirlpool looking at the wire endwise, as in Fig. 16, is entirely a question of the direction of the current. Knowing this as an established fact of the greatest consequence in everyday practice, it is not difficult to explain why the needle reverses its poles with the reversal of the current.

The lines of force of a magnetic needle pass out of the north pole and return to the south pole after describing a path through the surrounding space, which can be indicated by means of iron filings, as mentioned in the previous chapter. It is only for purposes of convenience that this assumption is made, as either pole may be regarded as the one from which the magnetism issues, provided this pole is distinguished from the other. A wire carrying current also represents a case where the lines of force surrounding it have a definite direction. Bringing a current-carrying wire and a compass in close juxtaposition, has the effect of forcing the needle to a right-angled position, simply because the lines of force of the needle and wire, instead of opposing each other, place themselves in such a position as to become parallel to each other. The needle, being free to move, responds to this tendency, and thus illustrates the principle that *lines of force tend to arrange themselves parallel to each other.*

In this particular case the lines of force of the wire direct the position of the freely moving needle, and its north pole points along the

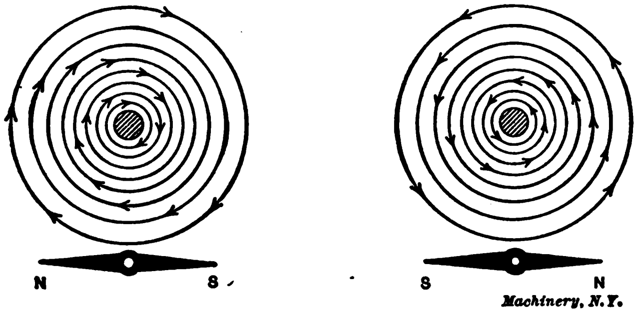


Fig. 17. Relation between Direction of Magnetic Whirl and Position of a Magnet Needle

direction of rotation of the magnetic field or whirl around the wire, as shown in Fig. 17. If the current is reversed in the wire, the magnetic whirl reverses and the needle likewise, in accordance with the principle enunciated.

Attractive and Directive Action

The law, that unlike poles must attract each other, explains the phenomenon of magnetism so far as the actual movement of opposite poles

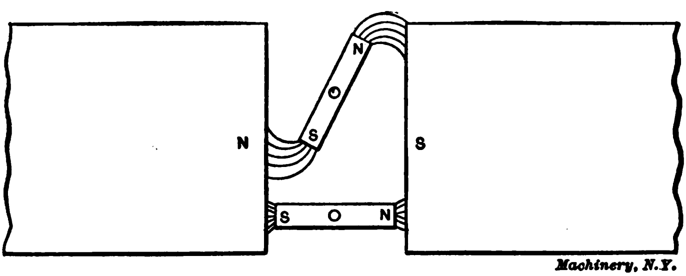


Fig. 18. Graphical Illustration of the Tendency of the Lines of Force to Set Themselves Parallel to Each Other

is concerned, but when the action of the earth's magnetic field upon a compass needle is considered, it becomes evident that here the action is directive, due to the fact that the lines of force of the earth and the needle set themselves parallel to each other.

When a soft iron bar is placed in a magnetic field, as in Fig. 18, it becomes magnetized through induction, and hence, being for the time a magnet, its lines of force, so to speak, endeavor to pull toward the lines of force of the original field and in this way a twisting or turning tendency is developed, forcing or tending to force the bar into a position in which it lies parallel to the magnetic field surrounding it. This directive influence, as well as the actual attraction, are the sources of mechanical energy found in electric motors.

The discovery of Oersted led him to regard a turn of wire carrying a current as the equivalent of a flat magnet. On bringing a compass near a loop of wire carrying a current, the needle will act as if the current-carrying turn of wire were a magnet itself. In fact, this is so; the lines of force surrounding the wire will produce on one side a north magnetic pole, and on the other side a south magnetic pole. The lines of force issue from one side of the loop and pass around

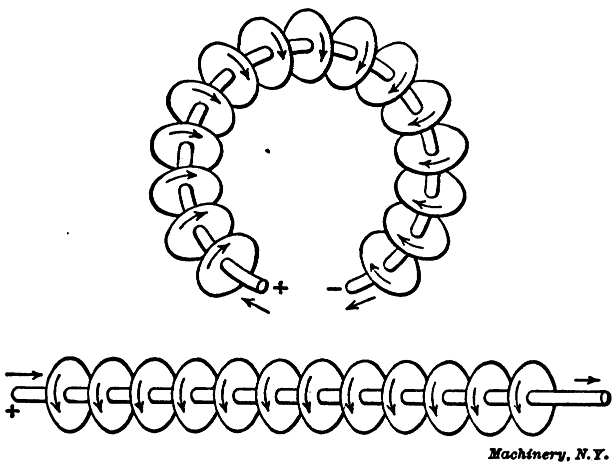


Fig. 19. Graphical Illustration of the Direction of Current in a Wire and the Magnetic Whirl Around It

through space to the other. The idea can be best represented, as in Fig. 19, by a number of wheels on a metal rod, all rotating in the same direction, whether the rod remains straight, is bent, or brought around into a loop. Looking at one side of this loop, the rims of the wheels are rotating outwardly, and on the other side they are entering. In a similar manner the lines of force ceaselessly rotate around a current-carrying wire as an axis, only reversing their direction of rotation when the current in the wire is reversed. If the wire remains in the form of a loop, and the current in it is reversed, the side of the loop from which the rotation or direction of the magnetic lines emanates in the first place will now be the side in which they will enter instead of leaving, and *vice versa.*

Poles and Direction of Current

A new and very important fact now presents itself with respect to the loop of wire carrying a current. When the needle is brought near one side, tne north pole of the needle is attracted, and when it is presented to the other side the south pole of the needle is attracted. If the direction of the current is noted with respect to the direction of motion of the hands of a clock, it will be seen that the current appears to pass in the wire coil from one side in a direction *opposite* to the hands of a clock, and from the other side *with* the hands of a clock. In other words, the direction of flow of the current will be dependent

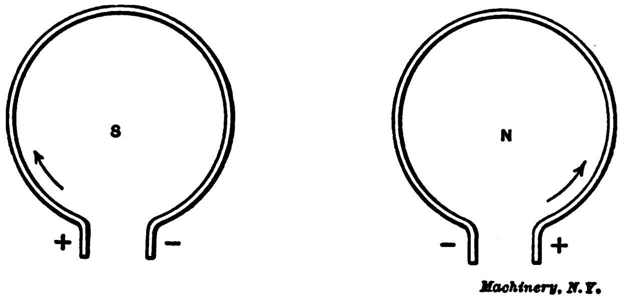


Fig. 20. Relation between Direction of Current and Polarity

upon the end of the coil nearest to the point of observation. It will be found that on that side of the coil where the direction of the current is opposite to the motion of the hands of a clock, a north pole appears, and conversely, on the other side of the current-carrying loop, where the current circulates from its positive to its negative pole in a direction *similar* to the movement of the hands of a clock, a south pole ap-

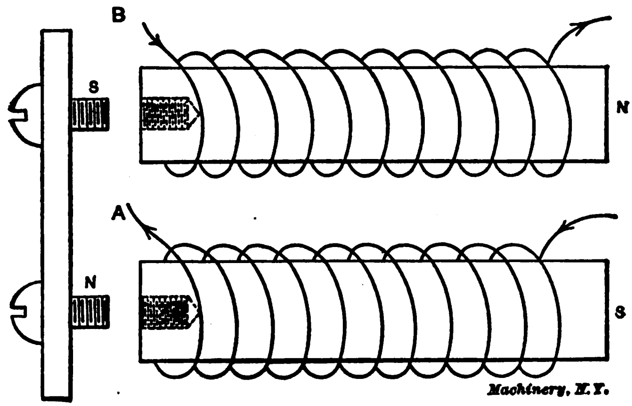


Fig. 21. Method of Winding Electro-magnets

pears. Here then is a means of pre-determining the north or south pole of a coil with reference to its winding and the flow of the current; *with* the hands of a clock a *south* pole, *opposite* to the hands of a clock, a *north* pole. (See Fig. 20.)

Winding Magnets

It will now be understood that the method of obtaining two different poles in an electro-magnet becomes merely a question of connecting the ends of the coils correctly. Fig. 21 shows two cores wound with a single layer of wire to exemplify the principle. Here all the elements of the ordinary magnet are found: two soft iron cores and the connecting bar of soft iron, or keeper, with screws to hold the parts tightly together. The illustration shows that on both cores the winding is wound in the same way. This requires that the two end wires *A* and *B* be twisted together to give opposite poles at the ends of the cores. The coils of wire may be wound on sleeves, and then after soaking in melted paraffin or shellac slipped off, and put aside for future use. In this manner a great many coils can be prepared for magnets before they are assembled. It is only necessary to see that when they are slipped on the cores the windings all begin at the same end. If the direction of the current is traced in the illustration given, it will

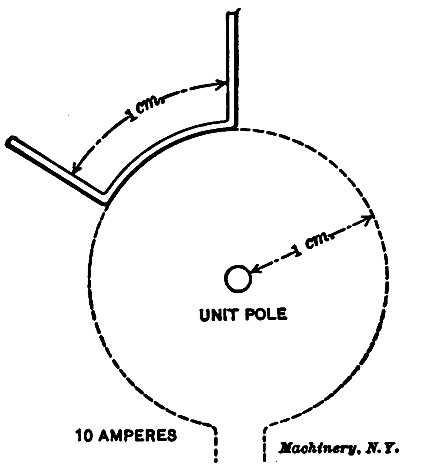


Fig. 22. Graphical Illustration of the Method used for Defining the Unit of Current

be seen that the polarity is indicated on the basis previously stated. If the coils of a magnet are not placed or wound so as to require the ends most conveniently connected to be brought together, then the only recourse is to carefully trace the direction of the current, and connect the ends that will give opposite poles, even though wires are connected from the opposite ends of each coil.

Unit of Current

The magnetic effect of a turn of wire through which a current is flowing has been utilized in arriving at the value of a unit of current. A whole turn of wire is not used, but only one centimeter. This centimeter length of wire forms an arc which constitutes part of a circle of one centimeter radius, as shown in Fig. 22. In other words, if a circle of wire is constructed of unit radius, and if only a unit length of this circle of wire is employed to carry a current, then when the current in this one centimeter of wire of one centimeter radius is sufficiently strong, it will exercise a magnetic force on a unit magnetic pole equal to one dyne. The current which is able to exercise a force of one dyne in a centimeter of wire of one centimeter radius upon a unit north pole placed at the center, is a current of 10 amperes. The absolute unit of current is thus not the unit commonly employed, but is equal only to one-tenth of the absolute unit and called one ampere.

The development of a mathematically exact quantity of force by every equal length or portion of a wire carrying a current of uniform strength, is one of the fundamental propositions of magnetism.

Laws of Electro-magnetism

In practical work it is possible to calculate with the greatest accuracy results in electro-magnetism by using a simple law embracing all of its applications. In order to fully grasp the idea it represents it is necessary to know the meaning of the constituents by which it is presented for practical use and through which the relationship between the parts of an electro-magnetic circuit are best understood.

The electro-magnet consists of a coil of wire carrying a current and either possessing a core of iron or not, as the circumstances require. It will be understood that the production of magnetism depends upon the number of loops of wire carrying a current. It is also evident that not only are the number of loops to be considered, but the strength of current they carry as well. Hence, the greater the number of turns or loops of wire and the greater the current in these turns, the greater the magnetic effect produced in total. It is customary to speak of the loops of wire as turns and the combination of current and turns as *ampere-turns.* From a purely physical standpoint the "magnetism producing" elements of an electro-magnet are the ampere-turns. These are obtained by multiplying the turns of wire composing the magnet by the amperes passing through, the total representing ampere-turns. For instance, if an electro-magnet consists of 1000 turns carrying a current of 10 amperes, the ampere-turns $= 10 \times 1000 = 10{,}000$. If the turns are 1000 and the current is decreased to 1/10 ampere, then the product equals $1/10 \times 1000 = 100$ ampere-turns. If, for example, there are 10,000 turns and 1 ampere, or 1 turn and 10,000 amperes, then in either case the total ampere-turns equal 10,000, which means that the *magneto-motive force* is the same. A graphical illustration of the relation between number of turns, amperes, and lines of force is shown in Fig. 23.

In calculating the magneto-motive force, the ampere-turns are multiplied by 4π giving as the total value $4\pi nc$ where $\pi = 3.1416$, $n =$ turns, $c =$ amperes. For instance, the magneto-motive force of a coil of 1000 turns carrying 10 amperes is equal to $4 \times 3.1416 \times 10 \times 1000$, $= 125{,}664$.

If the current is reduced the magneto-motive force is reduced correspondingly, and the power of the coil to force magnetism through an iron bar is also reduced.

The magneto-motive force, therefore, bears a distinct relation to the ampere-turns required to force magnetism through a bar of iron. If the bar is long it would require more magneto-motive force to produce a certain number of lines of force throughout than if the bar is short. In other words, the dimensions of the iron bar, its length, breadth and thickness, will have to be considered in conjunction with the magneto-motive force in order to arrive at a clear and adequate idea of the conditions governing the development of a magnetic field produced by electro-magnetism.

The law of electro-magnetism states that *the magnetic flux is directly proportional to the magneto-motive force and inversely propor-*

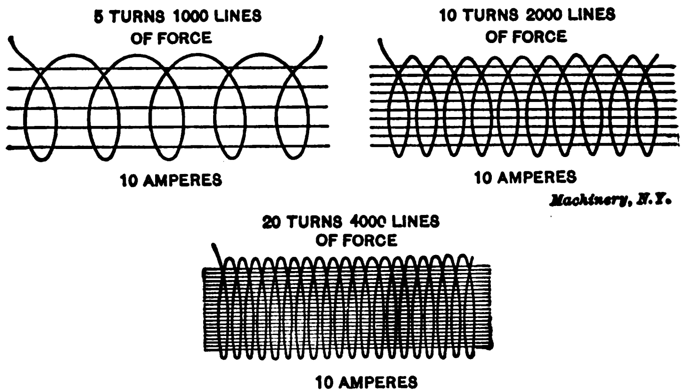


Fig. 23. Graphical Representation of the Effect of an Increasing Number of Ampere-turns

tional to the magnetic reluctance. This can be represented in the following form:

$$\text{Magnetic flux} = \frac{\text{Magneto-motive force}}{\text{Magnetic reluctance}}$$

The magnetic flux and reluctance will each be treated separately and will be found to represent, respectively, first, the number of lines of force produced, and, secondly, the conditions through which the magneto-motive force must operate to produce the magnetic flux. These conditions consist of the dimensions of the space or material through which the magnetism is being produced and the permeability of the material magnetized.

Magnetic Reluctance and Permeability

The reluctance of a material to be magnetized calls for a greater or less magneto-motive force to produce a given magnetic flux, the same as the greater the resistance of an electric circuit, the greater the electro-motive force required to send through it a current of given strength. The reluctance of any magnetic circuit consists of four items, three of which are dimensions and the fourth is the peculiarity of the material called permeability, which has already been referred to in the previous chapter. The dimensions are naturally the length, breadth and thickness, or the length and cross-section of the material undergoing magnetization.

Permeability, as previously mentioned, is the ratio between the lines of force in iron and the lines of force in air.

$$\text{Permeability of iron} = \frac{\text{Lines of force in a magnetized bar}}{\text{Lines of force without iron}}.$$

For instance, if the magneto-motive force of a coil carrying a certain current produces 10,000 lines of force in air, which when a bar of iron is inserted increase to 10,000,000, then the permeability or multiplying power of the iron can be represented by the ratio of 10,000,000 to 10,000, or

$$\text{Permeability} = \frac{10,000,000}{10,000} = 1000.$$

Many cases could be cited to illustrate the meaning of permeability in iron, steel or air which would disclose the fact that in the softer grades of iron like wrought-iron and mild steel the permeability is higher than in cast iron or any of its modifications.

As stated in the previous chapter, air is taken as a standard of permeability and is called 1. In comparison the magnetizable metals rate very high and range according to the following schedule as regards their permeability:

Air	1
Cast Iron	800
Mild Steel	2,000
Wrought-iron	3,000

The result of a lower permeability is less lines of force when the same magnetizing force is employed by means of a coil. This idea can be well represented by making three bars of cast iron, wrought-iron and steel, of exactly the same dimensions, and placing them in three coils of the same number of turns and supplied with exactly the same current apiece, as shown in Fig. 24. This would give the same magneto-motive force to each coil and the same dimensions to each magnetizable bar; the only difference would be found in the different permeabilities of the metals respectively.

Formulas and Examples

The law that the magnetic flux is proportional to the magneto-motive force and inversely proportional to the reluctance can now be represented symbolically as follows:

$$F = \frac{M}{R}$$

in which F = flux, M = magneto-motive force, and R = reluctance.

If the magneto-motive force is expressed by $4\pi nc$ and the permeability is represented by the Greek character μ, then the flux can be calculated by the following formula which presents exactly the same proposition

but has a symbol for all the elements which compose a problem of this kind:

$$\text{Lines of force} = \frac{4 \times \pi \times n \times c \times \mu \times q}{10 \times l}$$

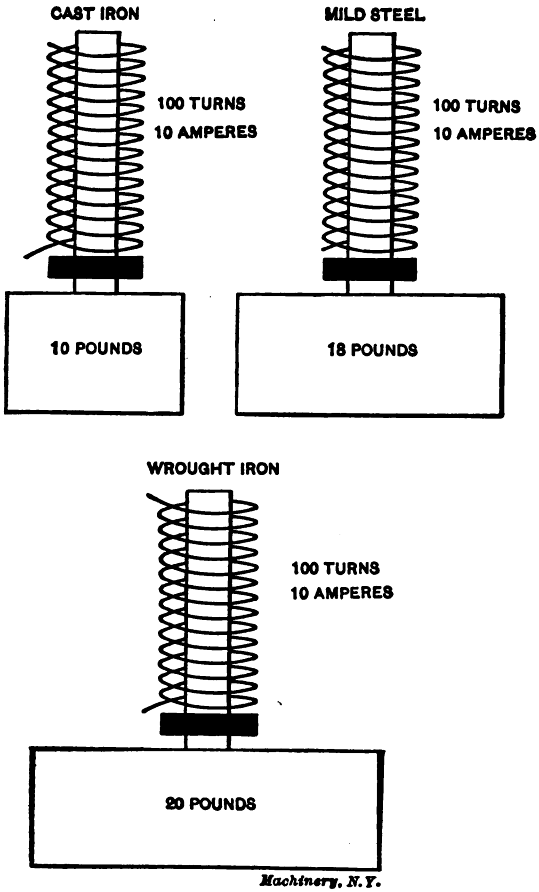


Fig. 24. The Difference in Effect of the Same Number of Ampere-turns on Cast Iron, Mild Steel and Wrought-iron

in which $4\pi n\,c$ = magneto-motive force,

μ = permeability,

q = cross-section of iron in square centimeters,

l = length of iron in centimeters.

To show the application of the formula, suppose a coil has 500 turns and carries 2 amperes. The iron has 10 square centimeters cross-section and is 20 centimeters long, with a permeability at that point of magnetization of 1000; how many lines of force will be produced?

$$\text{Lines of force} = \frac{4 \times 3.1416 \times 500 \times 2 \times 1000 \times 10}{10 \times 20} = 628{,}320.$$

The formula can be transformed to suit the requirements of the English system by making every centimeter equal to 0.4 of an inch, or 1 inch equal to 2.5 centimeters, and every square inch equal to 6.25 square centimeters.

The formula just given may be written as below:

$$\text{Lines of force} = \frac{4\,\pi n\,c}{10\left(\dfrac{l}{\mu\,q}\right)}.$$

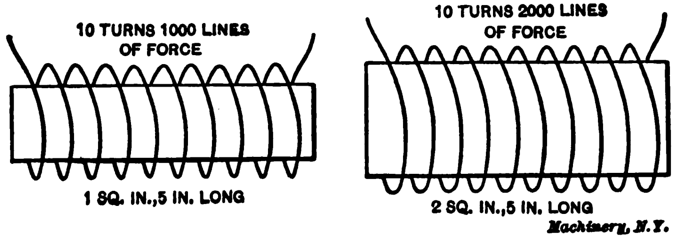


Fig. 25. The Effect of Reduced Reluctance

Here the μ and q have been placed in the denominator to constitute what is called the reluctance, thus giving as the elements of the formula:

$$\text{Magneto-motive force} = 4\,\pi n\,c$$

$$\text{Reluctance} = \frac{l}{\mu\,q}$$

The factor 10 in the denominator reduces amperes into absolute units of current which are equal to 10 amperes. If 10 amperes were employed in the coil only 1 absolute unit of current would appear in the formula. It is clear from the formula that if the reluctance becomes less, the lines of force will increase with the magneto-motive force remaining the same. If the reluctance increases, the lines of force diminish if the magneto-motive force remains the same. Fig. 25 graphically illustrates the effect of reduced reluctance. If the formula for the reluctance is examined it will be found that the reluctance can only be increased by increasing l or the length of the magnetic circuit, or decreasing μ or q, the permeability and cross-section of the circuit. On the other hand, the formula, as given, shows that a great magnetic reluctance can be compensated for by increasing the magneto-motive force.

Winding Magnets

The winding of magnets is accomplished by considering first the number of lines of force per unit of area of cross-section and, secondly, the number of ampere-turns required to produce a uniform magnetic condition throughout the iron, steel or air under process of magnetization. The number of lines of force per square inch of cross-section is the basis of most estimates made in this direction. The estimates of the amount of magnetism produced from a magnetic circuit first became accurate through the application of the method of John Hopkinson, an English scientist and engineer.

This method consists of the division of the magnetic circuit into its separate parts, such as the cast iron, the wrought-iron and the air-gap.

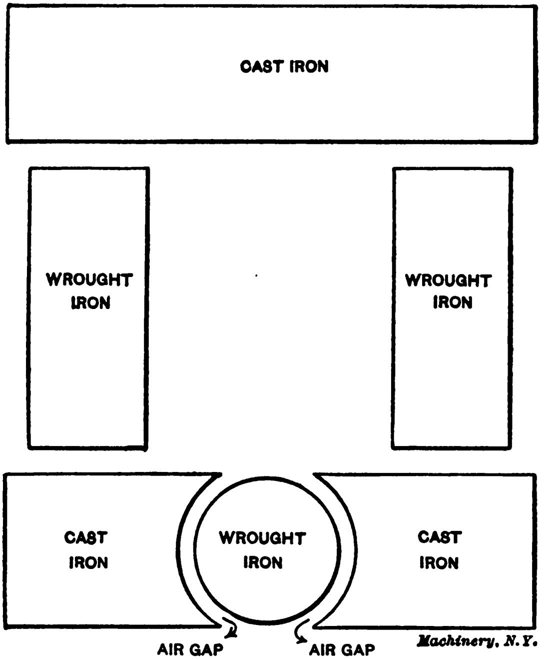


Fig. 26. Diagrammatical View of the Essential Parts of a Dynamo

Each part carries a certain number of lines of force per square inch and has a certain length. In other words, it is necessary to provide a certain magneto-motive force for each distinct part of the magnetic circuit. All of these magneto-motive forces are added together in the shape of a sum total of ampere-turns constituting the field winding. Thus two processes are necessary: First, that of obtaining the total magneto-motive force, and, second, that of obtaining the correct winding, size of wire, etc.

To illustrate the idea involved in the application of the Hopkinson method, take the case of a dynamo, which, as seen in Fig. 26, represents a magnetic circuit composed of many parts—the keeper, of cast iron, the magnet cores of wrought-iron, the pole pieces of cast iron, the armature core of wrought-iron, and finally the air-gap lying between the armature core and the pole pieces. The problem from an everyday practical standpoint is that of finding the total number of ampere-turns required to force a given number of lines of force through the armature core from pole piece to pole piece. In order to do this, as stated before, each individual part of the magnetic circuit must be provided with sufficient magneto-motive force to develop in it the amount

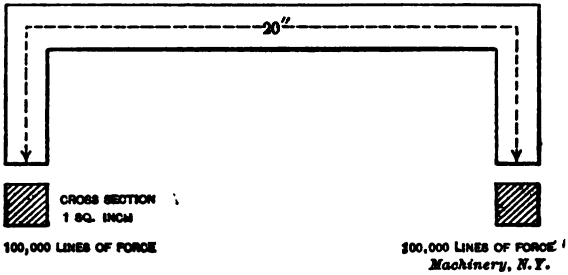


Fig. 27

of magnetism or number of lines of force required to establish this result.

Suppose, for purposes of illustration, that in order to send 100,000 lines of force per square inch through wrought-iron, it takes 92 ampere-turns per inch of length. Then, if the bar is 20 inches long and of 1 square inch cross-section, as shown in Fig. 27, and carries 100,000

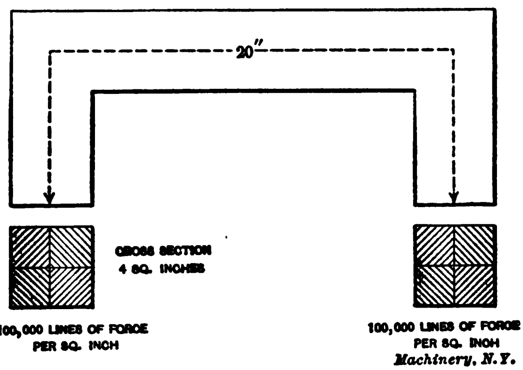


Fig. 28

lines of force, the number of ampere-turns required would be equal to $20 \times 92 = 1840$, to produce the induction, as it is called, per square inch. If a magnetic circuit of the same material, the same length, but four times the cross-section, as shown in Fig. 28, is considered, then the fact to be remembered is this—that here the length of the magnetic circuit has not changed and therefore the magneto-motive force will not be any greater than in the first case; but the cross-section of the iron being four times as great means a magnetic reluctance of one-quarter and, therefore, four times as many lines of force in consequence.

The same number of ampere-turns would be required for either bar of wrought-iron because the length and quality of the iron of each is the same. Now it does not make much difference whether these ampere turns are placed along the whole length of the bar or at one portion of it. The total number required in this particular case is 1840 to produce 100,000 lines of force per square inch throughout the bar. The bar might have a cross-section of 100 square inches; if it has the same length the same number of ampere-turns will be required to give every square inch of its cross-section an induction of 100,000 lines. The important part is to provide the required number of ampere-turns

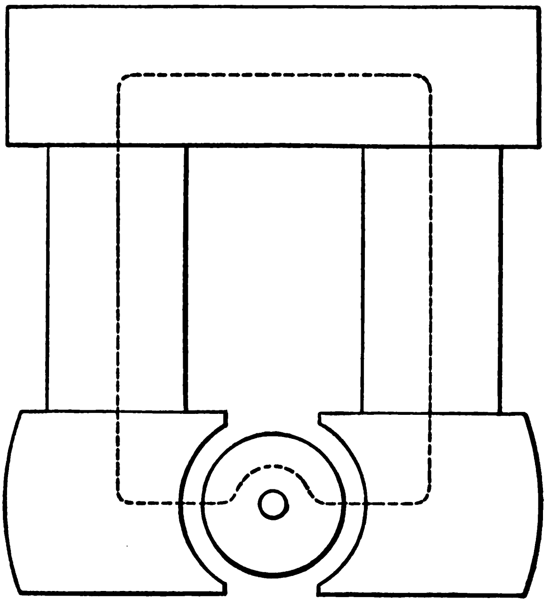


Fig. 29. The Mean Path of the Lines of Force through a Dynamo

per inch length. This number, for different grades of iron or steel, can be obtained from curves or tables. A very important table of this character, prepared by A. E. Wiener, is given on page 30 for the uses indicated, namely, the calculation of the ampere-turns of any magnetic circuit of any material in ordinary use.

The Hopkinson method requires a determination of the following factors:

1.—Lines of force per square inch in cast-iron keeper and the corresponding ampere-turns per inch length.

2.—Lines of force per square inch in wrought-iron cores and the corresponding ampere-turns per inch length.

3.—Lines of force per square inch in cast-iron pole pieces and the corresponding ampere-turns per inch of mean length.

4.—Lines of force per square inch in wrought-iron armature and the corresponding ampere-turns per inch of length.

5.—Lines of force per square inch of air gap and the corresponding ampere-turns per inch or part of an inch of length.

The selection of the mean path through the parts of a dynamo is shown by the dotted lines in Fig. 29. After getting the total ampere-turns for each part of the dynamo the following schedule is arranged:

Ampere-turns for magnet cores	1000
Ampere-turns for keeper	200
Ampere-turns for pole pieces	300
Ampere-turns for armature core	100
Ampere-turns for air gaps	2400
Total ampere turns	4000

With the total ampere-turns found, the next step is to find the proper size of wire as called for by the electromotive force of the armature which supplies the field winding.

Formula for Size of Wire

The simple formula employed for finding the size of wire to use calls for a knowledge of the total ampere turns, the volts to be applied to the terminals of the coils, and the average or mean length of one turn. This last is obtained by taking the diameter of the magnet core and adding to it the anticipated depth of winding in inches. Between these two an average is obtained and multiplying by π gives mean length of one turn. The size of wire is given by its area in circular mils.

$$\text{Circular mils} = \frac{\text{Total ampere-turns} \times \text{mean length of turn}}{1.106 \times \text{volts of coil}}.$$

In the case of a dynamo whose total ampere-turns equal 4000, the mean length of a turn equals 12 inches, the size of wire required equals the following at 110 volts:

$$\frac{4000 \times 12}{1.106 \times 110} = 395 \text{ circular mils} = \text{No. 24 B. \& S. gage, approx.}$$

Allowing 1000 circular mils per ampere gives a current of approximately 0.4 of an ampere. Dividing the total ampere-turns already decided upon (4000) by 0.4, gives the number of turns as 10,000; as each turn is one foot, there are approximately 10,000 feet of wire.

The temperature of the coil must also be considered, because the greater the amount of power dissipated in the coil in the form of heat, the higher its temperature becomes. This will destroy the coil unless regulated by the outer surface of the coil itself and the depth of winding. A simple formula gives the temperature in degrees Fahrenheit to which a coil will rise when two things are known, the power (watts) wasted in the coil, and the number of square inches of radiating surface of the coil.

To obtain the power wasted in heat in the coil, the resistance of the wire in ohms must be multiplied by the square of the current. For in-

UNIT MAGNETO-MOTIVE FORCES
Ampere-turns per Inch Length

Magnetic Density, Lines of Force per Square Inch	Annealed Norway Iron	Soft Cast Steel	Mitis Iron	Cast Iron Containing 6.5 of Aluminum	Cast Iron (ordinary)	Air
2,500	1.2	2.0	2.5	7.0	9.0	783
5,000	1.7	2.8	3.4	9.6	13.0	1,566
7,500	2.1	3.4	4.0	11.6	16.0	2,350
10,000	2.2	3.7	4.4	13.5	18.5	3,132
12,500	2.4	4.0	4.8	15.7	21.3	3,916
15,000	2.7	4.3	5.2	18.2	24.1	4,700
17,500	3.1	4.6	5.6	21.0	27.1	5,483
20,000	3.5	5.0	6.0	24.0	30.5	6,266
22,500	4.0	5.4	6.5	27.2	34.5	7,050
25,000	4.5	5.8	7.0	31.0	39.0	7,833
27,500	5.0	6.2	7.5	35.5	44.0	8,616
30,000	5.5	6.6	8.1	41.5	50.0	9,400
32,500	6.0	7.1	8.7	47.5	57.0	10,162
35,000	6.5	7.6	9.4	54.0	65.0	10,966
37,500	7.0	8.2	10.1	62.0	76.0	11,750
40,000	7.5	8.8	10.9	72.0	88.0	12,532
42,500	8.0	9.4	11.7	83.0	101.0	13,315
45,000	8.5	10.1	12.6	95.0	116.0	14,100
47,500	9.0	10.9	13.6	110.0	136.0	14,882
50,000	9.6	11.8	14.7	128.0	160.0	15,665
52,500	10.3	12.8	15.9	149.0	189.0	16,450
55,000	11.1	13.9	17.3	173.0	222.0	17,233
57,500	12.0	15.1	19.0	200.0	260.0	18,016
60,000	13.0	16.2	21.0	230.0	295.0	18,800
62,500	14.2	17.8	23.2	263.0	340.0	......
65,000	15.7	19.3	25.6	300.0	400.0	......
67,500	17.5	20.9	28.5	345.0	470.0	......
70,000	19.6	22.7	32.0	400.0	570.0	......
72,500	22.0	24.7	36.0	460.0	700.0	......
75,000	24.7	27.0	41.0	525.0	.....	......
77,500	27.7	30.0	47.0	600.0	.....	......
80,000	31.2	34.0	54.0	700.0	.....	......
82,500	35.2	39.0	62.0	.....	.....	......
85,000	39.7	44.0	70.0	.....	.....	......
87,500	44.7	50.0	80.0	.....	.....	......
90,000	50.7	57.0	92.0	.....	.....	......
92,500	58.0	68.0	109.0	.....	.....	......
95,000	67.0	75.0	131.0	.....	.....	......
97,500	78.0	86.0	150.0	.....	.....	......
100,000	91.0	100.0	193.0	.....	.....	......
102,500	108.0	121.0	245.0	.....	.....	......
105,000	137.0	159.0	283.0	.....	.....	......
107,500	190.0	227.0	345.0	.....	.....	......
110,000	290.0	325.0	410.0	.....	.....	......
112,500	398.0	430.0	500.0	.....	.....	......
115,000	500.0	550.0	600.0	.....	.....	......
117,500	600.0	650.0	700.0	.....	.....	......
120,000	700.0	750.0	800.0	.....	.....	......
122,500	800.0	850.0	.....	.....	.....	......
125,000	900.0	950.0	.....	.....	.....	......

stance, in the coil referred to in illustrating the winding formula, there are 10,000 feet of No. 24 wire. This wire has a resistance of about 26 ohms per 1,000 feet, or a total of $26 \times 10 = 260$ ohms. The current this coil carries is equal to its circular mils divided by 1,000, or

$$\text{Current in coil} = \frac{\text{circular mils}}{1000} = 0.4 \text{ amperes, as found previously.}$$

The number of watts wasted are equal to:

$$\text{Ohms} \times \overline{\text{amperes}}^2 = 260 \times 0.4 \times 0.4 = 41.6 \text{ watts.}$$

Temperature Formula

The formula for calculating the temperature is as follows:

$$\text{Degrees F.} = \frac{100 \times \text{watts wasted}}{\text{sq. in. of radiating surface}}$$

The watts wasted in this case are approximately equal to 41, and if the square inches of radiating surface equal 100, the total rise of temperature in degrees F. would be

$$\text{Degrees F.} = \frac{100 \times 41}{100} = 41 \text{ degrees.}$$

This is not an excessive temperature rise and can be allowed.

The important point is the influence of an increase or decrease in the radiating surface upon the temperature of the coils. The amount of heat generated in a coil due to the resistance and current is about constant under ordinary circumstances. If the means by which this heat can escape are limited the temperature rises. On the other hand, if the radiating surface of the coil is large, the heat readily escapes and the temperature may remain constant. The problem is largely one in physics, where the heat is limited in quantity but the surface through which the heat escapes can be made larger or smaller, in which case the temperature drops or rises. If, for instance, the heat of a candle is concentrated at a point, that point would rise to a very high temperature. On the other hand, the heat, if imparted in its entirety to a large body of large radiating surface, would produce but a low temperature. The temperature of the body, therefore, is as much a question of the radiating surface, its character and extent, as of the amount of heat it has absorbed. In the case of a coil, the temperature should not rise much above 100 degrees F. If the coil develops a temperature of its own of 41 degrees and the surrounding air is at 60 degrees, then the total temperature would be 60 + 41 degrees or 101 degrees. If a coil of this kind is used in a place unduly heated, or, if it be put into operation in the tropics, then the temperature of the coil would become excessive. The surrounding atmosphere must be considered in the design of magnet coils, particularly when they constitute parts of dynamos in use in engine rooms, where the temperature is generally very high. The resistance of a winding is increased by its own heat, and this to some extent cuts down the flow of current.

The Magnetization Curve

The curve which shows the internal condition of the iron is called the magnetization curve. It is obtained by plotting a curve whose elements consist of ampere-turns per inch length and the number of lines of force they produce at each successive stage of magnetization. Such a curve is shown in Fig. 30. The value of such a curve in practical work is easily seen when the rise and direction of the curve is noted. The rapid rise of the curve with a very small magnetizing force shows how sensitive the iron is to magnetic influences when its reluctance is low and its permeability high. The result is a curve which rises with a slight inclination and then begins to bend. The bend of

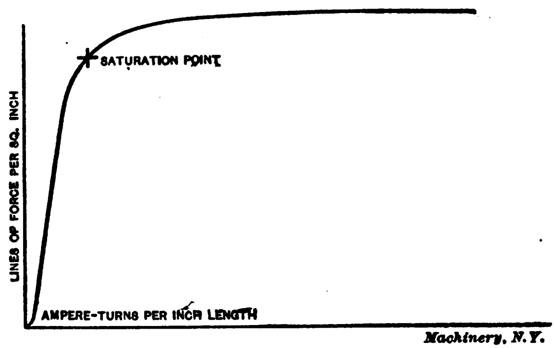


Fig. 30. The so-called Magnetization Curve

the curve indicates a distinct change in the permeability and consequently the reluctance of the iron. Following the curve for a short distance it is seen to bend with a greater and greater tendency to the horizontal plane, and, when reaching a horizontal direction, it begins to move constantly in this direction. At the critical point, where the bend originally begins, it will be noted that a given magnetizing force in ampere turns does not produce the effect it did before. In fact a little beyond this point it takes a comparatively great magnetizing force to produce a little additional magnetic field. This point is called the saturation point and is considered in practice the economical point at which to operate the iron. Beyond this point magnetism is obtained at too great an expense in wire and power. It is about 100,000 lines of force per square inch for wrought-iron and about 80,000 lines of force per square inch for mild steel, of which two metals the majority of dynamo cores are made.

In the curve the base line represents the ampere turns per inch length, and the vertical line, the magnetic lines per square inch of cross-section.

CHAPTER III

ELECTROPLATING

Electrolysis is a department of electricity which treats of the effect of a current upon a chemical compound. By this is meant, that water, for instance, will succumb to the influence of electricity and be divided into its actual constituents, the two gases oxygen and hydrogen. The same is true of many other forms of chemical combinations. The action of a current is said to decompose the original body, and overcome in part or wholly the chemical affinity which exists between the elements of which it is composed. It is impossible to pay the proper attention to the effect of a current upon a solution within which are placed electrodes, unless the modern aspect of this branch of practical science is correctly presented. It must, therefore, be stated that the chemical theory previously accepted has been supplanted by the electro-chemical theory, and this theory is based upon the assumption that all elementary forms of matter possess charges of electricity.

Such a conclusion was necessary on account of the quality of *valency* possessed by atoms and molecules. By this is meant the peculiar choosing power, of oxygen, for instance, for two atoms of hydrogen, or of hydrogen for chlorine, etc. In other words, the elements, when in the form of atoms, have strange likes and dislikes which manifest themselves in the form of certain affinities for each other. Through these fixed affinities, the elements form chemical combinations, as in the case of water or acids. This choosing power inherent in the atoms, given by chemists the name of valency, is by the electro-chemist, attributed to varying charges of electricity. Thus the combination of oxygen and hydrogen is due to the electrical attraction of oxygen for hydrogen. On this basis, either one or the other must have a positive or negative charge. This charge, if powerful enough to form so intimate a combination, must be highly concentrated, because of the exceedingly small dimensions of the atoms and molecules themselves. In the case of water, it is a well-known fact that a current of electricity will decompose it into oxygen and hydrogen; and the curious phenomenon presenting itself under these circumstances will be that of the oxygen always clinging to the positive pole of the battery and the hydrogen to the negative. Placing two copper plates in a slightly acidulated solution, connected to a source of electricity, as shown in Fig. 31, will demonstrate this principle. The great mass of bubbles at the negative pole will serve to prove that twice as much hydrogen as oxygen is evolved. As water contains two atoms of hydrogen to one of oxygen, the quantity of the gases collected is in harmony with this proportion. As far as the practical application of this principle is concerned, the amount of gas evolved by this process can be calculated with mathematical certainty. Not only is this true, but if the two poles of a battery, which when employed for electrolytic work are called electrodes, are used in connection with a metal salt solution, such as water and sulphate of copper, a coating of copper will be deposited upon the negative electrode, the quantity of which also can be estimated beforehand with the greatest accuracy. The estimates made in the case of the gas refer to the quantity of it which will be evolved per unit of time. In the case of the copper the same holds true. In both cases certain values must be known:

1. The strength of the current in amperes.
2. The time in seconds during which the current flows.

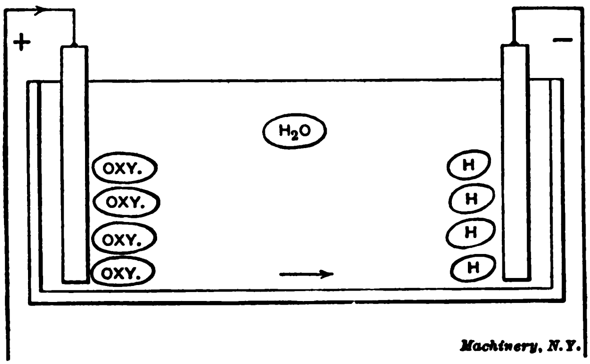


Fig. 31. Graphical Illustration of the Decomposition of Water into Oxygen and Hydrogen

The two battery terminals, called electrodes, are also named with reference to the poles they represent. The positive pole is called the *anode*, the negative pole the *cathode*.

The Grotthus Hypothesis

According to the hypothesis framed by Grotthus, when metals are being deposited, a curious transference of metal is taking place within the solution. Take, for instance, the case of copper being deposited from a solution of sulphate of copper, as indicated in Fig. 32. The chemical formula for copper sulphate is $CuSO_4$. This is divided up into two groups of atoms, one of which is positive and the other negative. The sub-divisions are those of the copper on the one hand, and the oxygen and sulphur on the other, as follows:

Copper ($= Cu$) moves toward the cathode.

Oxygen and sulphur ($= SO_4$) moves toward the anode.

According to this idea the electrolytic bath with the two electrodes immersed is traversed by two streams of atoms, one going to one pole, and the other to the other pole. But according to the Grotthus hypothesis, the solution of copper sulphate and the two streams of traveling atoms act in a very interesting manner toward each other. The solution of copper sulphate, for instance, permits a copper atom to leave the copper anode from which it has been electrically removed; it seizes it, but sends on its own atom of copper in place of the first to its destination, the cathode. The same process is carried out with respect to the oxygen-sulphur molecule. Thus the solution acts as an intermediary, whose strength will remain unaffected as long as the anode replenishes the lost atoms. An exchange goes on continually, with the result that the copper anode will gradually become lighter and its metallic equivalent will be found at the cathode, or on the objects placed there to receive it. These two oppositely moving streams of electrified particles have been designated streams of ions. If the

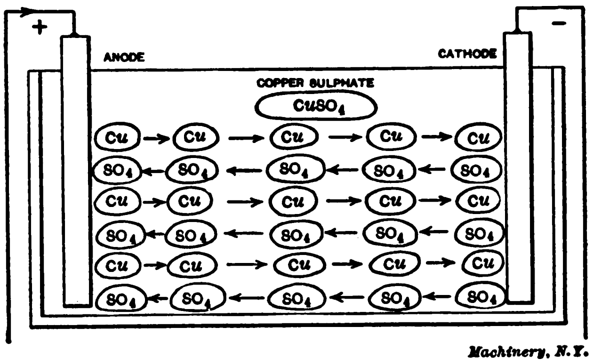


Fig. 32. The Process of Electroplating Graphically Illustrated

anode is of a neutral metal, for instance, or of carbon, then the solution used in this experiment will continually weaken.

The Electro-chemical Equivalent

The carriers of electricity being the ions, it may be questioned whether or not these ions carry equal quantities of electricity in the electrolytic experiment. To satisfactorily settle this question, a series of baths of silver solution, copper solution, etc., were prepared with electrodes of the proper character. The current sent into each was carefully measured, and the time during which this current flowed correctly gaged. It was found that in each case different results were obtained, although the current was preserved at a uniform value. The amount of silver deposited, for example, was different from that of copper, etc. In other words, a broad principle was discovered, a principle which showed that each particular metal was unique in this respect, that its ions or charged atoms were each the carriers of only a specified amount of electricity which was different with every different form of matter tested. The metals, particularly, displayed such differences that a table was made, called the table of electro-chemical equivalents, giving the exact weight of metal carried over by one ampere in a second. The table supplied herewith gives the name of the element, its atomic weight, its valency, its chemical equivalent, and its electro-chemical equivalent.

The definition of the electro-chemical equivalent of a metal is as follows: The weight of the metal in grams carried over by one coulomb of electricity, that is, one ampere-second. On this basis, the weight of any metal, such as gold, silver, copper, lead, etc., carried over by a certain current in a certain time, can be readily ascertained by a simple calculation.

Calculating the Weight of Metal Deposited

In practical electroplating the judgment and experience of the plater is employed to its fullest extent in the determination of the amount of metal deposited on an object being plated. The weight of metal can,

TABLE OF ELECTRO-CHEMICAL EQUIVALENTS*

Elements	Atomic Weight	Valency	Chemical Equivalent	Electro-chemical Equivalent in Grams per Ampere-second
Electro-positive				
Hydrogen	1	1	1	0.000010384
Potassium	39.03	1	39.03	0.0004053
Sodium	23	1	23	0.0002388
Gold	196.2	3	65.4	0.0006791
Silver	107.67	1	107.67	0.0011181
Copper	63.18	2	31.59	0.0003281
Mercury	199.8	2	99.9	0.0010374
Tin	117.8	4	29.45	0.0003058
Iron	55.9	3	18.64	0.0001935
Nickel	58.6	2	29.3	0.0003043
Zinc	64.9	2	32.45	0.00033698
Lead	206.4	2	103.2	0.0010716
Electro-negative				
Oxygen	15 96	2	7.98	0.00008286
Chlorine	35.37	1	35.37	0.0003673
Iodine	126.54	1	126.54	0.0013140
Bromine	79.76	1	79.76	0.0008282
Nitrogen	14.01	3	4.67	0.00004849

* From S. P. Thompson's "Electricity and Magnetism."

however, be calculated from a knowledge of the time in seconds and the strength of the current in amperes, as follows:

Weight in grams = weight per second per ampere × current in amperes × time in seconds.

Reduced to symbols, the formula reads:

$$W = E \times C \times T$$

in which W = weight of metal deposited in grams,

C = current in amperes,

T = time in seconds,

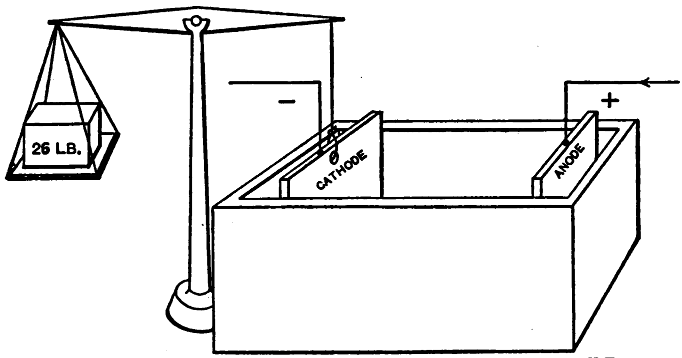
E = the electro-chemical equivalent (that is, the weight of metal due to one ampere in one second, or one coulomb.)

To illustrate this formula, suppose a current of 100 amperes is employed for copper plating for 100 hours; then as the electro-chemical equivalent of copper is 0.0003281, as given in the accompanying table, the total weight of copper deposited would be $0.0003281 \times 100 \times 3600 \times 100 = 11{,}812$ grams = 11.8 kilograms = 26 pounds of copper.

In the above calculation the 3600 is the number of seconds in one hour. In Fig. 33 is shown how this calculation may be checked by a practical experiment.

Anions and Cathions

The atoms carried forward to the negative plate or cathode are called cathions and those passing the anode are called anions. The metals all move toward the cathode and are therefore termed cathions. The gas hydrogen also moves toward the cathode, and thus betrays the properties of a metal in an electrical sense. The anions are oxygen, chlorine and other elements moving toward the anode. This peculiar



Machinery, N.Y.

Fig. 33. Weighing the Copper Deposited

qualification has led to the conclusion that the natural charge possessed by atoms determines their position in the electrolytic bath as anions or cathions. The so-called anions, or ions with an attraction for the positive electrode, are regarded as negatively charged and are called "electro-negative." The cathions are positively charged, and called "electro-positive." This is the influence causing discrimination between the ions for either anode or cathode in electrolysis. When copper plating is done the Cu and SO_4, or copper and so-called sulphion, divide, the copper depositing on the cathode and the sulphion forming sulphuric acid by combining with hydrogen giving H_2SO_4, and thus intensifying the acidulation of the solution.

Electric Meters Based on Electrolysis

The idea of employing an electrolytic meter to determine from the increased weight of the electrode, the amount of current consumed by customers, is based entirely upon the electro-chemical equivalent. The original Edison Illuminating Company of New York used thousands of zinc sulphate meters, composed of two electrodes of zinc in a zinc sulphate solution, and receiving a shunted current from the customer's mains, as shown in Fig. 34. Each month the meters were replaced by new ones and the added weight of the cathodes of the old ones carefully ascertained. The number of ampere-hours were thus determined on the basis of the electro-chemical equivalent. The final estimates were based upon the number of milligrams of zinc deposited.

The Deposition of Metals

The general process of depositing metals by means of electricity has developed into an industry represented by several distinct branches. Each of them is of importance in the commercial world and covers the following fields:

1. Electroplating.
2. Electrotyping.
3. Electro-metallurgy.

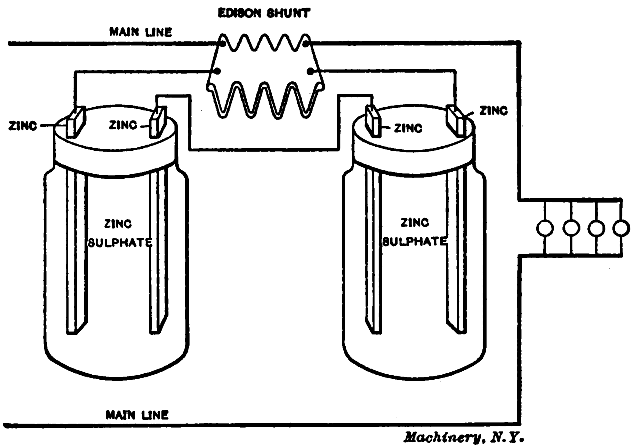


Fig. 34. The Principle of the Edison Meter for Electric Current based on the Deposition of Metal

Electroplating might be defined as a process in which a thin layer of metal, such as copper, nickel, gold or silver, is deposited from appropriate solutions called plating baths, upon some other metal, by means of electricity. The thickness of metal deposited is carefully gaged in the case of those metals that are termed precious, as gold and silver, and in consequence expressions are used such as triple or quadruple plate, etc.

The process of electrotyping is employed in all printing and publishing houses in connection with the duplicates of photo-engravings, used so extensively in this class of work. An electrotype is the exact duplicate, or as some term it, *fac-simile* of such master cuts or engravings as would be worn out by use in printing. These fac-similes are obtained by a plating process, although certain important preliminary processes are necessary. The name was probably derived from the practice of taking a wax impression of type and plating this impression with copper—hence the term electrotype.

The refining of copper and other metals cannot be better done than by means of the electric current. Instead of delicate preparations being made for the deposit of a thin film of metal, as in electroplating and electrotyping, the current is utilized for the purpose of separating the pure metal from all impurities and depositing it in thick plates at the cathode. The anode would therefore be the crude ore, probably in the shape of a block, dipping of course in the correct solution. It is evident that this process does not differ essentially from either of the two previously mentioned, although the skill required in each case is of an entirely different character. The last process is associated with

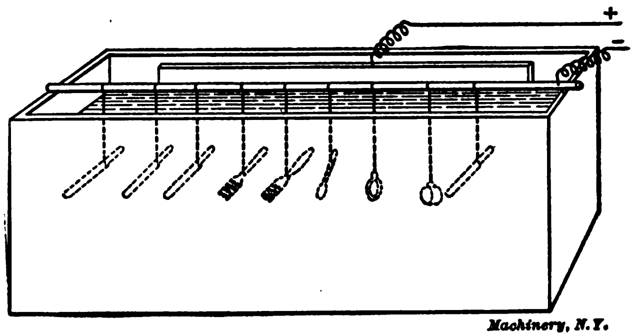


Fig. 35. Electro-plating of Small Articles

mining plants, particularly of copper ore, while both electrotyping and electroplating are fine arts.

Principles of Plating

The principles of plating embrace questions of correct current, electromotive force, solution, and certain preparatory processes. In other words, the current must not be too strong, and in addition the electromotive force must be capable of carrying the metal over. Cleanliness is an important item in this process, as the presence of oil or grease in any form will prevent the cathode from receiving its proper coating. The principal requirements of plating can therefore be best defined as follows:

1. Current of the proper strength per unit area of cathode.
2. Voltage suitable for the metal to be plated.
3. A solution electrolytically correct for the deposition of the metal.
4. A perfectly free surface at the cathode, with no traces of oil or grease.
5. A uniform current and electro-motive force.

In all arts, human skill, which is the direct result of extensive experience, is rarely if ever limited in its exercise by set rules. In electroplating, skill of this character has developed to a high point, and it may be considered as relating to two important features of the work as follows:

1. Skill in the mixing and preparation of solutions.
2. Skill in the adjustment of the amperage and voltage employed.

The dynamo has displaced the battery in the art of plating and electrotyping, though small equipments can be purchased which are only operated by a few cells. A shunt-wound dynamo is generally employed the voltage of which can be varied from 10 or 12 volts to 3 or 5 by means of a rheostat in circuit with the field winding. By this means the pressure can be adjusted to suit the metal to be plated.

The plating solutions mostly used to-day are gold and silver, copper, nickel and brass solutions. The basis of these solutions are metallic salts manufactured with reference to the object in view and therefore called plating-salts.

Copper Plating Solution

Too great a density in the copper solution must be avoided, or the deposit will be brittle and crumbling and in addition very slow in making its appearance. A strong, tough deposit is obtained by a current of about 15 amperes per square foot of cathode surface. This solution may be made up either acid or alkaline. If acid, the deposit cannot be had upon iron or any other metal affected chemically by the acid. The following is the method for preparing an acid solution as given in Urquhart's "Electrotyping": "Prepare a saturated solution of copper sulphate by pouring hot water on the crystals of nearly the bulk required; add to this for each gallon of solution, a quart of water, and finally stir in for each gallon of solution four ounces of sulphuric acid. In the preparation of the solution it should be noted that by 'saturated' solution is signified that state of the liquid when it will not dissolve any additional salt. The crystals may be dissolved in a separate vessel and then poured into the depository trough, or the trough may be nearly filled with warm water and the crystals dissolved into it from a few muslin bags suspended in the liquid. The water used must be either distilled or filtered or at least the solution filtered when complete. This solution is well adapted for most purposes of the electrotyper, and has been tested repeatedly. It will deposit well upon metals or upon blackleaded moulds, and will be found to dissolve the anode freely when the current is passing. Some electrotypers use a large percentage of sulphuric acid, but this is seldom required except in very cold weather."

An alkaline copper solution suitable for deposits upon iron, zinc or pewter, quoted from the same source, is as follows: "Prepare a solution of copper sulphate, and also one of cyanide of potassium; add the latter to the former when a copious deposit of copper cyanide will take place. The liquid should be poured off and the residue washed, when it may be finally dissolved in a fresh solution of cyanide of potassium (two pounds to the gallon), to form the depositing liquid. As the cyanide of copper is not freely soluble in the potassium cyanide, it should be desolved to saturation. Free cyanide should be afterwards added to the extent of two ounces per gallon. This will promote rapid working, but there is also a stronger tendency to give off hydrogen at the cathode, the deposit at which may contain large quantities of gas. This solution works best at a temperature of 100 degrees F."

Nickel Solution

The double nickel salts are generally purchased in commercial form ready for solution according to these directions: "Dissolve the compound in hot water to saturation; afterwards dilute with water. The proportions are three-quarters of a pound of salts to one gallon of water. The solution should be neutral or nearly so, that is, neither acid nor alkaline. To ascertain this, test it with blue litmus paper; if the paper turns red increase the alkaline by adding ammonia sulphate. If red paper be turned blue, increase the acid by adding nickel sulphate until the mixture is as nearly as possible neutral. If there is a tendency to either side in working, it is better to have it alkaline."

Brass Solution

The method of making brass solution, the components of which are copper and zinc salts, is given by the following formula: "Dissolve in 1000 parts of water, 25 of copper sulphate, and 25 to 30 of sulphate of zinc; or 12½ of acetate of copper, and 12½ to 15 of fused chloride of zinc. Precipitate the mixture by means of 100 parts of carbonate of sodium dissolved in plenty of water and stir the mixture. Wash the precipitate several times by adding water to it, stirring and allowing the precipitate to subside, pouring the clear liquid away. Add to the washed precipitate a solution composed of 50 parts of bisulphide of sodium dissolved in 1000 parts of water, and while stirring, add a strong solution of ordinary cyanide of potassium until the precipitate is just all redesolved; then add three parts of free cyanide. This solution is used warm or hot. A current of about 12 volts must be employed, and an anode of brass. When the deposit is white it can be attributed to too strong a current, and if the deposit is red it is due to too weak a current. It is a simple matter to experiment with a small bath of solution, and a small anode and cathode, before attempting heavier work. A strong deposit of brass is a very handsome form of plating, which wears well and is not very difficult to obtain."

Slow Deposits and Unclean Anodes

The slow rate of deposit observed in plating is due to the employment of a weak current. This is frequently the case when an attempt is made to get a deposit upon a black lead surface. In this case the resistance is naturally very great, and in consequence, very little current passes. The remedy for this is a higher pressure, the use of which will hasten the process of deposition.

Absolute cleanliness is a guarantee of success in plating or electrotyping, and the reverse simply invites failure. Unclean anodes, on the surface of which dirt and oil or grease may be present, will greatly interfere with the work of plating. Some of this dirt, which is called by a certain philosopher, "matter in the wrong place," has been analyzed by a chemist and found to consist of particles of a great many different kinds of metals in the proportions in one particular instance of tin, 33; copper, 9; antimony, 9; arsenic, 7; silver, 4; sulphur, 2; and nickel, 2. A certain amount of organic matter also was found present, which militated against successful plating. Thorough cleansing is the effective means of disposing of this, such as washing in an alkaline bath.

Electrotypes of Coins or Medals

The surface of a coin or medal to be electrotyped is put through a preparatory process by first varnishing the back with beeswax or some rapidly drying insulating solution. The face to be plated must be cleaned thoroughly and then rubbed over with turpentine in which a little beeswax has been dissolved to avoid absolute adhesion between the electrotype and original. The use of small trays is recommended, with a connecting wire attached. These depositing trays hold the coin securely, and assure perfect contact between it and the cathode. When a dry, clean surface is first placed in the solution, the liquid may not take hold, due to a minute film of air on the surface. This must be removed by wetting the coin until the signs of this defect entirely disappear.

The intaglio or impression of a coin in wax is obtained by cleaning it thoroughly, and then dusting its surface very carefully with plumbago, leaving only a delicate film. It is then placed flat upon the wax plate of composition and pressure applied in the electrotyper's press. If a good impression has been obtained, the surface is dusted over with plumbago, by means of a soft camel's hair brush.

To obtain a conducting surface without the use of plumbago, the following formula is recommended: "Dissolve phosphorus in pure alcohol until a strong solution is obtained, and wash the mould with the mixture. A silver solution is prepared by dissolving nitrate of silver in aqueous ammonia to saturation. It is to be poured evenly over the surface of the mould, and allowed to float over it for a few minutes; the solution is poured off and the mould allowed to become partly dry, when it is again floated with the mixture. Spots that do not appear to take the solution readily must be wetted with it by means of a soft brush." A surface prepared in this manner is actually covered with a film of precipitated silver, highly conductive, and by some considered far superior to the old-established plumbago process.

The degree of saturation of the solution, and the strength of current, are always related to each other in a manner that can only be ascertained experimentally. Thus, if a saturated solution of copper is employed, the deposit is crystalline. If the solution is diluted with from two to four times its bulk of water, the metal is deposited in a malleable state, and a still further dilution will invite deposits of a granular character. A weak solution and a strong current will cause a black, spongy coating to appear, associated with hydrogen bubbles. Under conditions which remain uniform, a definite deposit per second, per minute and per hour, is assured. An ordinary electrotype takes about five hours to become thick enough for service.

Pewter vessels are first copper-plated before undergoing the gilding or silvering process. The process of gold plating requires the use of the salts called the double cyanide of gold and potassium, and silver plating the double cyanide of silver and potassium. In plating with either of these solutions, the above mentioned precautions are necessary as regards absolute cleanliness, etc. When silver is being plated, too heavy a current, which forces the deposition, will give rise to a gray and crumbling coating. Bisulphide of carbon in a minute quantity, will make the deposited silver bright if introduced into the solu-

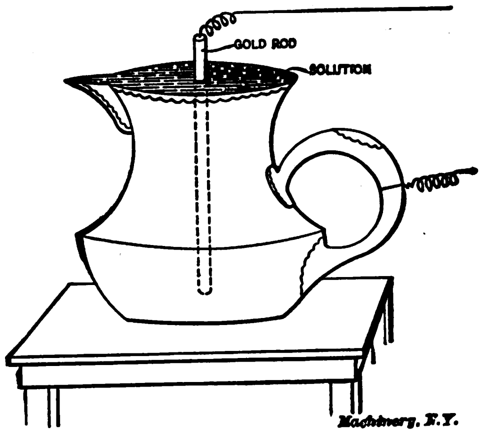


Fig. 36. Method of Gilding the Inner Surface of a Pitcher

tion. In gold plating, generally performed in the insides of silver plated utensils, as shown in Fig. 36, the gold solution is poured into the vessel, and a gold anode suspended in the center from the positive pole of the dynamo, the negative being attached to the article itself.

Treatment of Plated Articles

The two courses of treatment to which the electroplater subjects articles undergoing plating may be classified as, first, that before plating for the purpose of securing electrical cleanliness, and second, that after plating in the nature of finishing. The following indicates this classification:

Before plating: Article may be washed in water, pickled in acid or scoured in lye.

After plating: Article may be scratched, buffed, polished or burnished.

Although cleanliness is above all the primary consideration, it is only obtained with respect to the surface of the metal by the use of vats of water, caustic soda and dilute acid. The surface of the article to undergo plating may have to be polished; it is then dipped in the hot lye solution to remove all traces of grease, then into the acid to remove any film of oxide present, and finally it is well washed in clean water.

When silver plating, one of the most prevalent platings in vogue, the copper surface is treated with mercury to secure a good foundation. A diluted solution of nitrate of mercury is applied, which forms a metallic precipitate suitable for the rapid and effective deposition of silver.

The scratching, buffing and polishing of plated articles are purely mechanical processes. Their object is to remove metallic projections, smooth the entire surface, and finally to give the high finish looked for in plated articles. The scratching is done by means of a wheel of brass wire projecting radially, which when rotating at a high speed acts as an effective scratch brush. The buffing is accomplished by the use of canvas wheels, composed of disks of canvas held at the center with the edges free. Buffing paste or powder is applied, and the marks of the scratching removed. The polishing is done by means of rouge or other fine polishing powders. The wheel may be of leather or walrus hide, by means of which a mirror-like surface is readily obtained.

Coloring Copper Surfaces

A copper plating can be rendered artistic by the following means: To obtain a rich brown color, the object must be dipped into a very diluted nitric acid solution, and gradually heated. By this process any shade of brown can be reached, which will possess great permanency. A fine black finish can be obtained by dipping the article into a weak solution of platinum chloride. This shade may be regulated by the strength of the solution and time of dipping.

Cause of Stripping or Peeling

One of the reasons why a dip into an acid bath is so necessary, or, as it is called, why pickling is employed, is to remove the oxide film which settles upon the surface of many metals and acts as a partial conductor to the current. Even when the conductivity of the surface is good, still there is no intimate contact between the coating and the cathode. Such a plating can easily "strip," that is, be peeled off. The removal of the oxide by polishing or by chemical means will insure a good deposit of metal. The pickling is always preceded by the lye solution, which, if hot, removes grease, and after washing, the acid solution follows.

Vats for Nickel Solution

The nickel solution is frequently poured, after being made up, into wooden vats lined with lead. The lead joints are not soldered but burnt together. Nickel can be deposited on copper, iron, brass and steel by a solution in which the crystals of the double sulphate of nickel and ammonium have been dissolved, according to the directions previously given. The vats are about 3 feet wide, 6 feet long and 30 inches deep, although the dimensions vary according to the work. Enameled vats are preferred by some platers because they possess strength, durability and insulating properties because of the coating. They are made of many sizes—from 1, 5, 10, 20 gallons, etc., up to 50 or 100 gallons capacity. All vats must have a rim of wood around the upper edge raised above the vat proper. The copper rods supporting the anodes and cathodes extend across, resting on this support.

Silver Salts and Solution

Effects of a most artistic nature are obtained by a proper handling of a silver bath in electro-plating. The silver salts may be considered as represented by the chloride, nitrate, cyanide, acetate, sulphide and oxide of silver. The cyanide of silver solution is used almost exclusively for silver plating and is made in the following manner: A solution of cyanide of potassium is carefully mixed, the preparation being made with well filtered or distilled water. A solution of nitrate of silver is also carefully prepared in the same way. The cyanide solution is then added slowly to the silver nitrate solution until a thick white precipitate is obtained at the bottom of the vessel. This white flocculent mass is washed with pure water several times until thoroughly cleansed. A new solution of cyanide of potassium is prepared and introduced gradually into the precipitate. The result of this operation will be the redissolving of the white mass and a new solution, to which is given the name "double cyanide of silver and potassium."

Successful silver plating can only be accomplished by patience and a strict adherence to the rules of cleanliness. Extreme cleanliness with respect to the solution makes it possible to use the same solution *for years*, if it is occasionally filtered or a little new cyanide added to replace or strengthen the old solution, and make up for the losses due to evaporation. Besides the question of cleanliness, attention must be paid to the current. A rough, gray or black silver plating results from the use of too much current.

Distance between Anode and Cathode

If an object suspended from the cathode has many projecting parts presenting an irregular surface to the anode, there should be considerable distance between the anode and cathode. The advantage of this is a more uniform distribution of the current and consequently a more uniform coating of silver. The edges are apt to take on a rough deposit even under the best of conditions. The larger surfaces will plate very smooth and even unless very much curved. If the object being plated is curved, it will be best to use an anode curved as far as possible in the same manner to obtain a fairly uniform series of paths through the liquid. In the plating of pitchers, sugar bowls, etc., the plating is only successful when special care is taken in this respect. The process of evenly plating statuettes or busts without destroying their contour is also a question of preserving equal current paths between them and the anode.

Iron Plating or Steel Facing

For the steel facing of electrotypes or other objects, a coating of pure iron may be deposited from a solution made up as follows: "To each gallon of water dissolve one pound of carbonate of ammonium, and dissolve iron into the solution by passing a strong current from an anode of iron until a deposit appears upon a clean copper cathode. A few ounces of carbonate of ammonium should be stirred into the bath once a week. The anode, which should be large in proportion to the work, must be cleaned occasionally." Another solution employed for the steel facing of plates, and given by Urquhart, is made up as follows: "Prepare a solution of sulphate of iron, and another of carbonate of ammonium. Add the latter to the former until the iron is precipitated; pour off the liquid portion and wash the precipitate. Take a bulk of sulphuric acid equal to the volume of the solution required, and dissolve the iron precipitate in it to saturation. If there should be any free acid it will retard the working; it is therefore usual to evaporate the solution a little." From either of these solutions good iron can be obtained by a current of from three to four volts. The anode is of iron, and the cathode of copper. According to Urquhart, the anode should be from five to eight times larger than the cathode to prevent the solution from becoming acid. It is also advisable to have the anode in the solution when not in use and to connect it by a wire to a cathode of platinum or copper to prevent the formation of acid and to keep the bath as dense as possible. The metal obtained is usually *as hard as steel*, but becomes soft and malleable after heating. It is very important to have a solution which yields a crystalline and very hard coating of iron. A coating obtained from a solution of sulphate of iron and chloride of ammonium yields an exceedingly hard deposit of the purest iron, and it is thus well suited to the coating of small and very fine electrotypes of steel engraved plates. All solutions made from sulphate of iron simply, are very troublesome and are constantly acted upon by the air, thus spoiling the solution. The salts in these solutions pass to a higher state of oxidation by absorption. Oxygen is rapidly absorbed and may appear in combination with the coating at the cathode. Charcoal iron is the purest to use as an anode and ordinary wrought-iron is the next best metal. If the solution is slightly heated, it will act much better in plating work. Acid and ammonium carbonate can be added occasionally to compensate for the oxidized salts. This must be so carefully done that the general composition of the bath is not changed. When attempted by beginners, this form of plating is full of holes, due to too much free acid in the solution and too heavy a current. Acidity can be held in check by the use of litmus paper for testing for this condition, and when it is found to be present, by neutralizing it. An oxidized solution may be deoxidized by passing a current through it for some hours between an iron anode and copper cathode. A little glycerine may serve to protect the solution from the effects of the air, but is rather objectionable.

Other Uses of Electricity

The application of electricity to produce electro-chemical changes is not limited to its use for the plating process alone. It is employed as the agency by means of which refining processes are carried out, germ laden masses of matter and infected water rendered innocuous, and new compounds produced. It is to be noted that electro-chemical changes are those in which a transposition of atoms occurs without any other outward signs than perhaps those due to bubbles of gas. On the other hand, the use of electricity for the manufacture of new in-

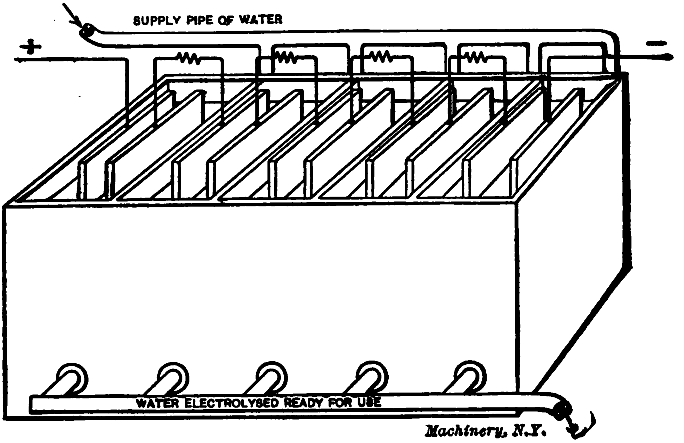


Fig. 37. Method of Purifying Water by Electricity used by a Large Packing Plant

dustrial products, such as aluminum, carborundum or calcium carbide, is attended by the development of intense heat.

Aluminum, the light, silvery looking metal, can only be cheaply obtained by means of electricity. It is distinctly an electrical product in a commercial sense, derived from the electric furnace by the melting of aluminum bearing ore. The heat of the furnace and, to some extent, electrolytic action, makes it possible to obtain the pure metal, The calcium carbide product, from which acetylene gas is obtained, is due to the coalition of lime and carbon in the electric furnace. Carborundum is also obtained in a similar manner by the conjunction of two foreign bodies fused by heat into an industrial product. Thus aluminum, the metal, calcium carbide, the gas producing chemical, and carborundum, a substitute for emery, and superior to it, are the first practical yield of the electric furnace. Of late the electric furnace has also found a distinct field in the metallurgy of iron. In the electric furnace, the high heat is due to the current passing through high resistances caused by imperfect contacts, and a rising temperature.

Electro-sterilizing

It has been proposed on many occasions by scientists and inventors to sterilize the drinking water of large cities during plague periods by electricity. The germs of typhoid are peculiarly active in water. Other germs may be transmitted in a more or less malignant form through the medium of water. Hence, it is required as a measure of protection that the water be pure. To secure this end, it may be

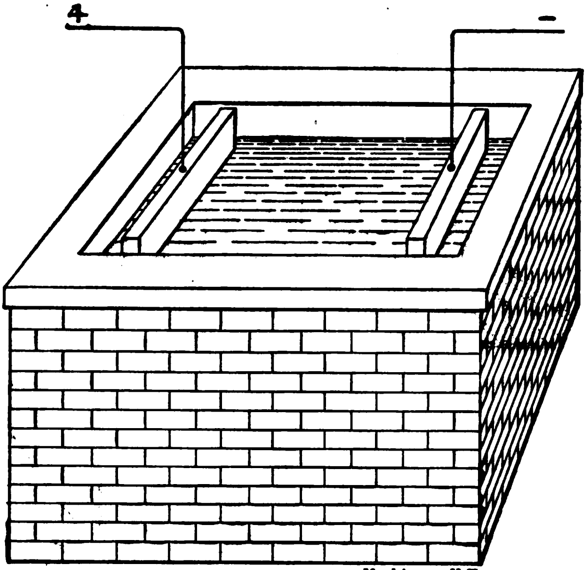


Fig. 38. Destruction of Germs in Water by Means of Electricity

subjected to the effects of a current of electricity, the influence of which is destructive to animal life. That this method renders the water under suspicion free from active germs has been substantiated in many cases. Although not deemed a practical process on a large scale, electricity has been employed to destroy the virility of germ life in sewage or other refuse utilized in many instances for reclaiming ground. The process is called filling in, and was carried out extensively at Riker's Island near Hell Gate, where the refuse was thoroughly treated before used for filling.

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