ELECTRO-MECHANICAL ANALOGIES

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PREFACE

It is a well established fact that most beginners in the study of electricity and the electric phenomena have considerable difficulty in comprehending the meaning and significance of electrical terms and actions or of the reason for these actions.

In view of this fact, we have endeavored to explain, by drawing hydraulic and mechanical analogies, such terms and actions as we have been able to find references and analogies for.

We have endeavored to write them in such terms that the average non-technical person can easily grasp their meaning. Especially have we endeavored to write this so that it might be used to make things clearer for the average beginner in the study of the electrical phenomena than it was for us when first attempting to grasp the meaning of abstract terms.

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ELECTRO-MECHANICAL ANALOGIES

AMMETER. In measuring the strength of the current flowing in a line use is made of what is termed an ammeter or measurer of amperes. This does not by any means necessitate that the entire current shall flow through it as an examination of Fig. 1 will show.

The action is similar to that of a meter in a water main where A of Fig. 1 is the ammeter and M of Fig. 2 is the water meter. Only part of the current passes through the water meter. By an examination of Fig. 2 we see that, since pipes A and B have definite proportions, they have a certain definite ratio to each other and, therefore, the meter can be so calibrated as to give the total water passing instead of merely that going through the meter. In the same way the ammeter may be calibrated to give the full current passing in the line at the time. However, a variation of this is often made use of. By knowing the ratio of the resistance in the meter itself to that of its shunt S of Fig. 1, and knowing that the currents are inversely as the resistances in the lines, we may make use of what is termed the meter constant to multiply the meter reading by in order to get the full line current or, the meter can be so arranged with multiple scales that, by reading on a certain scale when a certain shunt is used, the reading may be had direct. This enables us to make use of the same meter for various strengths of current by merely using a different shunt. This would be analogous to being able to vary the size of pipe A in Fig. 2, and would give the same results in that case if we knew the ratio of the cross sections of the pipes or if the meter were equipped with multiple scales. This last is an impossibility in the case of the actual water meter as we know them today and it is very doubtful if one could be so equipped without great trouble which would not be awkward to handle and use.

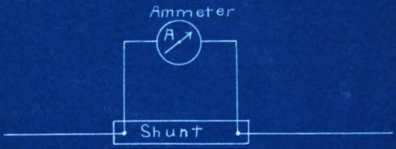

Fig. 1.

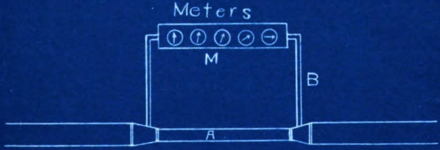

Fig. 2.

CHARGING CONDENSERS. Charging is nothing more or less than causing a state of strain in the insulating medium between two conductors.

Suppose we take the pulleys P and P' carrying the endless cord C as an illustration of the conductors, the disks at D as the medium, and the weight W as the force causing motion. Fig. 3. We would then have a parallel to the electric circuit. If we wish to insert an infinite resistance it would be only necessary to clamp the cord. This would parallel the electric circuit which was open or incomplete. If we take the actual circuit, we will suppose the disks to be fixed to their supports and to simply impose friction to the passage of the cord which would be similar to the action of resistance in the electric circuit. The only result that could possibly occur would be the generation of heat caused by the friction of the cord as it was drawn through the disks.

However, if we suppose the disks to be attached rigidly to the cord and to have an elastic support we would have the action of the condenser or Leyden jar while being charged. The elastic supports would then give as shown in Fig. 4, that is the medium would be under strain. When the force was removed the disks would spring back to their original position. They would not stop just when it was reached however, but would go a little beyond it and would then reverse. This reversing or vibrating would be kept up for some little time until the position of rest was reached which would correspond to the discharged condition of a condenser.

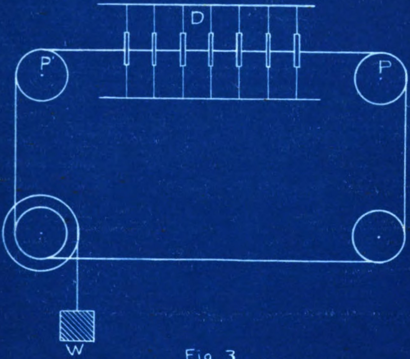

Fig. 3.

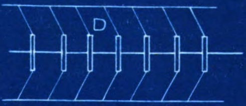

Fig. 4.

CHOKE COIL. To protect the machinery on the line from the damaging effect of lightning discharges some form of lightning arrester is used. This often takes the form of a choke coil which makes use of the inductive action of a current flowing through a coil of wire. The coil must be made of only a few turns of very heavy wire in order that the passage of currents of commercial frequency may not be impeded. On the side of the Coil C from which the discharge is expected, is placed a spark gap S, Fig. 5, long enough so that normal current cannot arc across.

If we suppose our choke coil to be a heavy block of metal such as an anvil, capable of transmitting pressure but, on account of its mass, not responding readily to sudden forces, we would have the action of the coil. If we lay a piece of soft metal on the anvil we can transmit pressure through it up to a certain limit without deformation. In the same way the spark gap pays no attention to the passage of ordinary currents. If, however, we should strike the block a heavy blow, which would parallel the effect of the lightning discharge on the line, the metal would flatten, since the heavy block is slow about taking up the force of the blow and, according to the fundamental laws, we cannot destroy energy but can only transform it. Therefore, since it cannot pass on, it must go into the work of deforming the metal. In the same way the high frequency lightning discharge (100 000 cycles per second) cannot go on and, as it must go somewhere, it breaks down the resistance of the spark gap and so passes to the ground.

Or, suppose we call our coil a very crooked, winding stretch of smooth road. If an automobile came along the straight road, which would represent the line, at a reasonable rate and struck this crooked road it would have little difficulty in passing it in safety. On the other hand, however, suppose the driver were "hitting it up" and struck the crooked part at a high rate of speed, which would correspond to the high frequency of the lightning discharge. The chances are very strongly in favor of his going into the ditch on account of not being able to hold the road. In the same way a lightning discharge is "ditched" through the spark gap, not because it cannot follow the wire but because its high frequency builds up an opposition in the coil which it cannot move against and, since because of its own momentum it must go somewhere, it follows the path of least resistance which is through the spark gap.

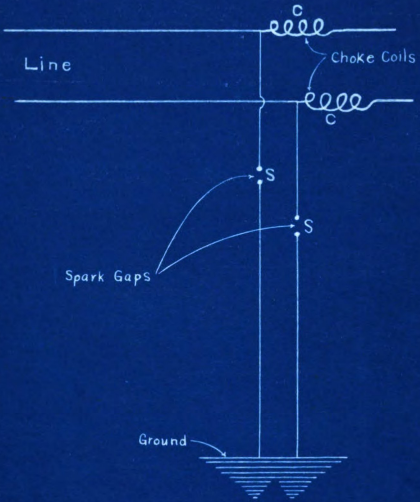

Fig. 5.

CIRCUIT BREAKER. As a safeguard against overloading the line, circuit breakers or fuses are used. The fuse depends for its action upon the heating caused by the current as it passes through the conductor. If the current rises above a certain definite, predetermined value, the temperature of the conductor rises above the melting point of the fuse and the fuse gives way, or as it is termed, "blows". With the circuit breaker, the action is dependant upon the increase in strength of an electromagnet as the strength of current increases, that is, the more the current the stronger the magnet. In use we have the circuit breaker having its arm held in place, when closed, by a latch which opposes the action of a spring which tends to open the line. As the line becomes overloaded an electromagnet becomes strong enough to draw a small trip lever which trips the latch and allows the spring to open the circuit.

A parallel to this action is the action of a safety valve on a boiler. The load on the line would, in this case be represented by the boiler pressure. As it becomes too high for safety the safety valve rises from its seat and allows the pressure to drop to a safe working value. The resistance to the action of the steam may be either a spring, or a weight and lever, depending on whether the valve is of a modern design or one of the older types. There is one great difference between the safety valve and the ordinary circuit breaker, however, and that is, that, while the action of the safety valve is only temporary, that is, it will return to its seat as soon as the excessive pressure is relieved, the action of the circuit breaker is permanent, that is, it will remain in the tripped or open position until some outside force operates to close it again. We might add however, that special self setting circuit breakers paralleling the reseating action of the safety valve can be purchased.

CLASSIFICATION OF CURRENTS. There are, in electrical terms, three kinds of currents; (1) constant or steady, (2) pulsating, and (3) alternating. The first two fall under what is termed direct current or D.C. while the last falls under what is commonly known as A.C.

The first may be said to strongly resemble the steady, normal flow of a river or any other stream which does not vary perceptibly during a moderate interval of time.

The second resembles the blood flow through the arteries in the human body. It varies from instant to instant, depending upon the time interval since the last heart beat, but at no time does it ever come to zero or stop. It continues always in the same direction but in varying quantities. It also resembles the flow of water from a pump not equipped with an air chamber. The flow is kept up by the action of the plunger, but due to the necessity of the plunger constantly reversing, a pulsating action is necessarily present. The flow does not stop in this case either, but it does vary from instant to instant the same as the pulsating electric current. More current may flow at one instant than at another but, so long as the circuit is complete, the flow will continue.

These two currents are found in D.C. work only. The first is probably strictly true only from a storage battery and may possibly not be absolutely true even there owing to irregularities within the battery itself. Under ordinary conditions the pulsating would be more liable to exist as can be easily seen by watching for a few moments a meter connected in an electric line.

About the best analogy for the alternating current is the ebb and flow of the tide in a tidal river or estuary. As the tide rises the water flows up and away from the sea, then, as the tide reaches its maximum, it ceases, reverses and begins to run out as the tide falls, again reversing as the tide rises once more. In the same way the alternating current increases, reaches a maximum, ceases for an infinitesimal instant of time, then reverses its flow, passes through zero to a maximum in the opposite direction, again ceases and reverses itself, to repeat the process indefinitely so long as the cause producing it exists and continues to act.

COMPASS DEVIATION. It is an often noted fact among surveyors and among others as well that the compass does not always point to the true North: in fact it almost invariably deviates somewhat from the true line. This is due to the fact that the magnetic action of the earth is disturbed by outside influences and also to the fact that the magnetic poles do not coincide with the axial poles. This is equivalent to saying that the poles of the earth magnet are off center which in fact they are. Even if they were coincident with the axial poles the compass would still deflect and the reason is easily seen.

Suppose we stretch elastic bands from pole to pole of the earth in the direction in which the magnetic force acts. Also, let us apply similar bands to our compass needle. Since the lines of force around a magnet are not straight from pole to pole but form curves, we would have the magnets surrounded by sets of curved, elastic, roughly parallel lines. Now, if the compass be inserted in the earth's field, we would have the elastic bands of the two fields interfering. The earth's bands being of course the stronger, would overcome those of the compass and would turn the compass until its bands were parallel to those of the earth. Now, if an electric wire or some other strong magnet were brought near the compass, we would have still another set of elastic bands stronger even than those of the earth and the result would be that the earth's bands

and those of the compass would tend to become parallel to those of the strong magnet. In reality they would not but each would give more or less according to the strength of the bands, the strong magnet the least and the compass the most, until a state of equilibrium was reached when they would remain fixed unless some further disturbance occured.

The magnetic action of the earth and of the various electric circuits that exist is exactly the same. When a compass approaches a conductor, the field of the compass pulls the compass needle around until its field coincides with the combined field of the conductor and the earth. Of course, the nearer the compass is to the magnet the more will the field of the magnet predominate in the combined field.

CONDENSER. Use is often made in electrical work of a series of thin plates of a conducting material seperated by thin sheets of a non-conductor, the alternate conductors being connected together i.e., 2, 4, 6, etc., in one group and 1, 3, 5, etc., in the other. When so arranged the apparatus is termed an electrical condenser. Now if an electrical impluse is sent through it by connecting the two groups to opposite sides of some electrical generator as in Fig. 6 we find that we have an electric charge on the surface of the plates or, as it is termed, the condenser is charged. Conversely when the electric pressure is removed, the charge is released and current flow reverses or, as we say, the condenser discharges.

Suppose, now, for the electric pressure E we substitute a pump P and for the condenser C a cylinder containing an elastic diaphragm D. We would then have the arrangement of Fig. 7. Further, let us place valves V and V' to serve the purpose of the key K in the electric circuit. Now, if the plunger of the pump is displaced, it is evident that the diaphragm will be stretched sinee there is no way for the fluids in the pipes to get through. When the plunger reaches the end of its stroke and reverses, the diaphragm will be at its maximum stretch and will be stretching at the maximum rate. On the other hand, when the plunger is at the middle of the stroke it will have its maximum velocity while the diaphragm will be at zero stretch and will be changing its direction of elongation. A little study will disclose the fact that the pump reverses itself when the diaphragm is at its maximum extension and that the diaphragm reverses itself when the pump has its maximum velocity or, in other words, they are ninety degrees apart. Now, suppose that when the diaphragm were more or less fully extended the valve V were to be closed. The flow would at once stop and the diaphragm would retain its position. This is equivalent to opening the key and breaking the electric circuit. The diaphragm would then be stretched or, in the electrical case, the condenser would be charged. Now, if the valve V' be opened the diaphragm would tend to force the extra liquid from one side to the other and so equalize the pressure on the opposite sides. This would be the same as discharging the condenser through the by pass of Fig. 6. It would not stop when the pressure was equalized or, to be exact, when the diaphragm was in the neutral position but, due to the inertia of the moving water, it would go somewhat beyond this and would then surge back and forth exactly as in the electric circuit until the neutral position was reached and all stress was removed.

Or, suppose we compare the charged condenser to the filled tank of Fig. 8. We can easily see that, if we open the valve between the tanks, there would at once be a flow of water from the full to the empty one until there was a balance of pressure due to their both being at the same level. However, the action would be the same in this case as well, and they would not at once come to the same level but, owing to the inertia of the flowing water, the water would oscilate back and forth from one to the other, each oscilation being less than the one before it until the balance of pressure existed and the water came to rest. This is due to the fact that the flowing water would more than come to its level and would go a little above it in the second vessel on account of the pressure due to its velocity of flow. In the same way, it would go above its level on the return and would continue to do this until the pressures were finally balanced. If there were no friction this surging would continue indefinitely but, due to friction there is a certain definite limit to it.

In the same way the surges in the condenser will have their definite limits due to the resistance in the wires forming the circuit, though there will be surges back and forth in the same way that there were in the pipes connecting the two tanks and the changes of pressure on the condenser in the same way that there were changes in water level in the tanks as they alternately received and discharged the water before it finally came to rest.

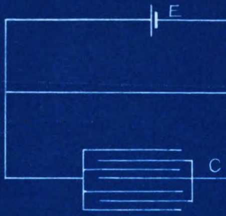

Fig. 6.

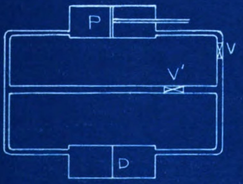

Fig. 7.

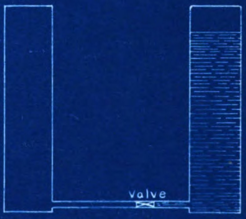

Fig. 8.

CYCLE AND FREQUENCY. In alternating current work we often run across the terms cycle and frequency and many persons ask what the meanings of these terms are. A cycle is the interval between the passage of the electric wave through any given current or voltage value and its next passage through an equal value in the same direction. Frequency is the number of these cycles in unit time.

To thoroughly understand this action, suppose we compare the changing values of the electric current or voltage to the surface of a wave on some body of water under the influence of the wind. We can see that a bubble for instance or, better still, a fairly large body that is not easily affected by the wind does not move forward with the wave but moves up and down in a certain time imterval. The interval of time betweem the time it is on the crest of one wave for instance and the time it is on the crest of the next succeeding wave would be the time of one complete cycle for that object and so would measure the time of the cycle of the wave. We see from this that the frequency would be the same as the number of waves that the body would clear in a unit time interval, usually the second, or that it would be the number of times it passed through the same point while going in the same direction in the same time interval.

In electricity this would be the same as saying that the number of times per second that the current passed through the zero point going in the positive direction, that is, gaining in strength, for instance, would be the number of cycles or frequency.

DIFFERENCE OF POTENTIAL. When a state exists between two electrically charged bodies such that there is a tendency for electricity to flow from one to the other, a difference of potential is said to exist.

This property of electricity may be illustrated by the action of liquids. We must keep in mind, however, that electricity is not a liquid. Among electrical people it is sometimes termed "juice" but this is in a slang sense only. We do not know what it is exactly but it is probably a form of strain or the effect of a vibration in the ether surrounding a conductor. Electricity cannot be directly perceived by our senses as can liquids or gasses. It is only by its various actions that we may know of the presence of electricity.

We may take for an example, two vessels of water of different levels. Now if these vessels were connected together by a hose or pipe, we know from ordinary experience that water will tend to flow from the vessel of higher level to that of lower. This flow is caused by the difference of level which causes a pressure or motive force measured by the difference of level or potential between the water in the two vessels. If the water in the two vessels were at the same level no water would flow. This analogy may be used to illustrate the flow of electricity between two charged conductors. One of the bodies is supposed to hold a positive charge and the other a negative one or none at all, and the flow is considered as from the positively charged to the negatively charged body. Now if we consider that the body with the positive charge is at a higher electrical level than the body with the negative charge we may say that the flow of electricity is caused by the difference of electrical level or electromotive force. No flow of electricity will or can occur if the bodies are at equal electrical levels.

The terms "positive charge" and "negative charge" indicate the one body is at a high r potential than the other, that is, that electricity will flow from one to the other if they are put in contact or if connection is made by means of a conductor. Thus we may have several charged bodies one of which is negative to some and positive to others, just the same as we may have several vessels, one of which may be lower in level than some and higher in level than others.

The earth is considered to be at zero potential or level in the same way that the average height of the sea may be considered as the zero level from which to measure the heights of various levels of water. By refering to Fig. 9 the relative potentials of bodies may be illustrated. We may take the line O O as the zero level or the surface of the sea. The two tanks A and B will then be at a positive potential because they are of higher levels while C and D will be negative since they are below zero level. Thus when we say that an electric charge is "positive" it

is meant that the charge is of a potential which is higher than that of the assumed zero, while an electric charge is "negative" when its potential is lower than that of our assumed zero level.

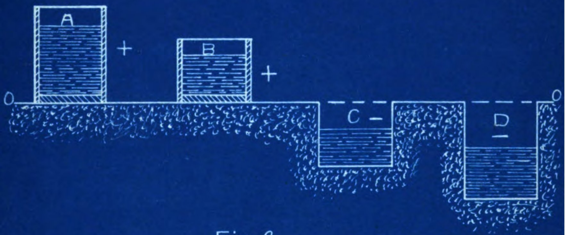

Fig. 9.

DRY BATTERIES. For ordinary use in telephones and for similar work we often make use of what are termed dry cells or batteries. Strictly speaking they are not dry as there must be some moisture in order that the electrical action may take place. These are sometimes connected in parallel and sometimes in series, depending upon whether a large current or a high pressure is desired for the particular work at hand. Many people cannot see the reason for this but if we look at Figs. 10 and 11 for a few moments the reason should be easily understood.

Suppose for our parallel cells we substitute a series of pumps connected in parallel to the line as in Fig, 10. We can see at a glance that the pressure in the line will n not be increased by this arrangement but that the quantity of water pumped will be, since it is equal to the total discharge from all the pumps and, further, the more pumps the greater will be the quantity of water handled.

Now, suppose, for our series cells, we use the pump arrangement of Fig. 11. We see at a glance that the pressure of the liquid leaving the second pump is equal to the pressure of the liquid leaving the first pump plus what the second pump added to it. For the third pump it will be the pressure of the first two plus the added pressure of the third and so on for any number of pumps. At the same time it will be seen that the quantity delivered will be the same as the delivery of any one pump since the same liquid passes through all of them successively.

In the dry batteries the action id the same. Parallel connections give large currents but low voltages while series connections give high pressures but smaller currents. Sometimes, too, combinations of the two connections are used. This would be equivalent to connecting up pumps in series and then paralleling these series sets. These combinations are used where both a larger current and a higher voltage are desired than can be secured by either series or parallel connections alone.

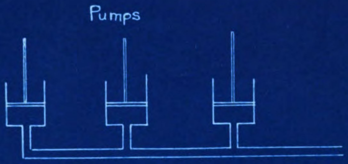

Fig. 10.

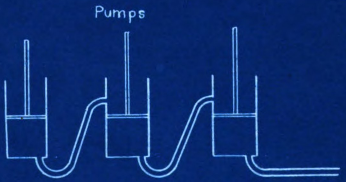

Fig. 11.

ELECTRIC DOUBLER. If we take two tin cans and place them on insulated stands as shown in Fig. 12 and suppose each to have a small initial charge, say C a positive and D an equal negative, we will have the foundation of an electric doubler. Now if we place between them two insulated balls made of a good conductor, some of the lines of force running between the cans will converge upon the balls and the balls will have a certain charge induced upon them, B being positive and A negative. Now if A be carried over and into D and B be inserted into C the charges on the balls will be given up to the cans, the lines of force connected with them will be transfered to the respective cans and there will be just that many more lines strung between the two cans than there were at first. If this process be repeated several times it will be found that light threads hung over the sides of the cans will begin to rise from a vertical position and stand out horizontally. This shows that our metal cans have begun to show a considerable charge. If the operation be repeated often enough the potential that can be produced is very high. If the number of lines in the first case were only ten and only half of them were transfered the potential would be multiplied by one and a half and a little multiplication will show that the increase will be very rapid from then on increasing as the number of cuttings increases. In fact, starting with these conditions and operating under this supposition, the charge after sixty repitions will be a-

bout one hundred billion times the original charge providing there is no leakage through faulty insulation.

A parallel to this action would be to suppose the lines of force to be elastic bands capable of being cut and reattached. In this case it is at once evident that if we cut a certain percent of the lines the pull between the two cans will increase and that the more the cutting and attaching goes on the stronger will be this attraction. If the cutting were to continue long enough it is also evident that the cans would finally be under such strain that they would be no longer able to keep their places and would be drawn toward each other. The electric action is the same except that the cans are not drawn but the charges on the cans are. When the charge reaches a certain value which is higher than the insulation of the air can hold out against there will be a discharge in the form of a spark from one can to the other which will tend to equallize things and put them back in their original state once more.

Another way of producing much the same thing is to make use of the method shown in Fig. 13. If we have a hollow conductor B seperated from a plate A by the insulation of the air and the point P kept at a higher charge than the plate by a small battery and use the ball C to transfer the charge we may get practically the same results. If we touch the ball to the point we get a certain charge on the ball. By carrying it up into the hollow cylinder as shown at (c') we transfer the charge to the conductor as seen at (d). The ball may then be brought back for another charge. This differs slightly from the first in that instead of cutting a certain percentage of the lines each time we cut a certain definite number so that the increase is at a steady rate. In the first case we had a geometric progression since the rate of increase increased as the transfer progressed while in the last case we had a mathmetical progression since only a definite amount was added each time and the amount was fixed.

In this last case the analogy would be to substitute rubber bands an the same way as in the first case but to suppose them hooked over the point and capable of sliding along A. Then if the ball had some meand of picking up a part of them and carrying them over to B and transfering them each time we would get similar results. As the transfer continued B would be drawn over against A by the increased tension. In the same way as the charge on B increased the tension in the air between would finally become so great that there would be a discharge between the two in the form of an electric spark.

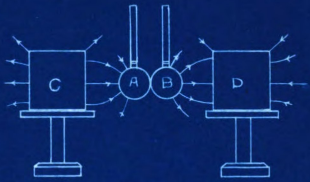

Fig. 12.

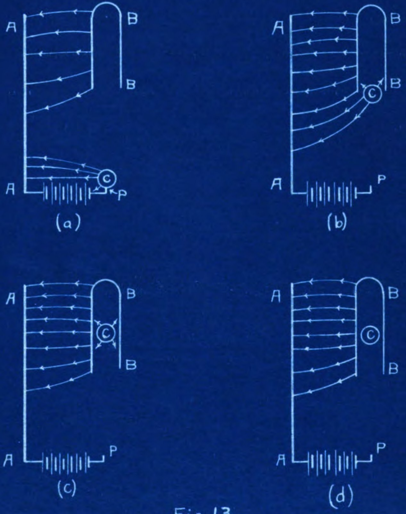

Fig. 13.

ELECTRICAL MACHINES. What are known as dynamos and motors are nothing more nor less than machines so constructed as to feed power out onto a line or to take power from a line and convert it into the work of every day life. Fig. 14.

Suppose we had a pump, Fig. 15, forcing water or some other fluid into a pipe line at the other end of which was an hydraulic motor or a machine of some sort which was capable of using the fluid in some way to perform useful work. This would parallel the action of the generator and motor shown in Fig. 14. The pump or generator forces the medium, either water or electricity, out into the line while the motor uses the medium as a means of doing useful work.

Another analogy is the ordinary leather or rubber belt with the driving and driven pulleys of Fig. 16.

Ordinarily we speak of electricity as "generated" but this is in the figurative sense only. In the case of the leather belt we could not speak of the drive pulley as a "leather generator". That would be absurd. We could speak of it as a "mover of electricity" however. When we speak of "doing it electrically" or driving by electricity how many of us ever stop to think that somewhere back of the electricity there is a machine which drives the electricity in the same manner that the drive pulley drives the belt? In the same manner that the belt drives the driven pulley the electricity drives the motor. We must have a circuit in the belt or it cannot act. It would be as absurd to try to drive a pulley by a belt which merely touched that pulley and another without completing the circuit and forming an endless loop as to try to drive a motor without completing the electric circuit either by connecting up to two or more wires or by using the ground for a return wire by what is termed "grounding" one side of each of the motor and generator.

Another point that is generally understood is that an electric machine is reversible. By this is meant that if a motor is driven it will generate electricity and that a generator will supply power if supplied with electricity.

This is what would happen if we had two engines so connected that when one turned over it would carry the other with it. Then if one were supplied steam it would drive the other and the second would act as a pump. Then, again, if we feed the steam into the second it would drive the first as a pump and we can see that the conditions are reversed. In the same way the electrical machines would be reversible.

There is one significant difference however. With the engines, they would of necessity be coupled up so that one would be running backwards whichever were driving or there would be trouble with the valves not working. If one were running backwards, though, the valve action would be reversed and therefore the engine could act as a pump. With the electric motor and generator just because the functions of the machine are reversed and the motor runs as a generator or the generator as a motor does not necessarily imply that the machine will run backward in the one case to what it will in the other. In some cases this will be so but in others the direction of motion is the same no matter whether the machine is being used as a generator or motor.

Another point that should be noted in this connection is that it is not always good practice to run a motor as a generator or vice versa as the case may be just because there is no generator or motor at hand. Just because the machine is reversible is no sign that it is highly efficient in the reversed condition any more than in the case of the engines. A good engine does not necessarily make a good pump nor a good pump a good engine. In the same way a good motor does not necessarily make a good generator or a good generator a good motor. In fact it may go by opposites and a very efficient motor may turn out to be a very poor and inefficient generator or the generator a poor motor.

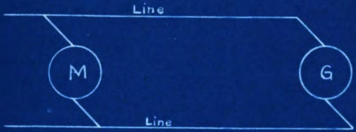

Fig. 14.

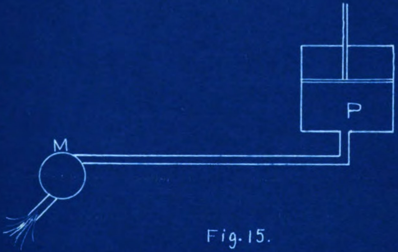

Fig. 15.

Fig. 16.

ETHER VIBRATIONS. In the wireless telegraph and telephone, use is made of the known phenomena of the vibrations that are set up in the ether by the discharge of an electric spark. The receiver catches these vibrations on its sensitive apparatus and magnifies them so that they can be understood.

Imagine the ether to be replaced by a still pond and the receiver by a light float. Then if a stone or some other object be thrown into the pond, waves will be set up and these waves will cause the float to move or vibrate as they reach it. By this means signals could be transmitted for limited distances but, as can be easily noticed, only a very small portion of the wave set up ever affects the float. Therefore it is evident that to transmit messages to a greater distance a much more powerful source of disturbance is necessary. This explains why such a powerful electric source is necessary to affect an electric receiver only a few miles away.

Suppose, however, that two or more singals were being transmitted at one and the same time. We at once see that the waves will interfere and that no intelligible message can be sent. However, if we add to the float a spring which will force the float to vibrate at a certain predetermined rate it is evident that waves which do not have this particular rate of vibration will not affect the float but that if a message is sent with this particular wave rate it will be received in spite of the other vibrations which will be automatically discarded.

This is what is actually done in wireless work by what is called "tuning" of the receiver or sender which is, by an electrical apparatus, brought to the same rate of vibration or wave length as that of the station with which it is desired to talk. When this is done it is easily understood that messages may be sent and received regardless of any other messages that may be passing in the air at the same time but with a different wave length or frequency.

GENERATORS IN PARALLEL. Many people wonder why we can have two generators in parallel on a line and not have them of the same capacity as far as generation is concerned. This is not at all necessary but the voltage between terminals must necessarily be the same and this necessity is vital to successful operation. If the voltage were not the same it is evident that there would not be enough resistance to the E.M.F. of the other machine to prevent its sending part of its current through the lower pressure machine and, in addition to wasting that current as far as doing any good on the line was conserned, render extremely probable the damaging of the second machine.

If we had two steam engines feeding power onto the same shaft we would not for an instant think of saying that they must both have the same power in order to be able to work together any more than we would say that two men pulling on a rope to move some object must both pull with the same amount of force in order to produce motion. The only essential in the case of the engines is that the speeds shall be the same. When they are both connected to the same shaft in the manner of a multi-cylinder engine they will of necessity run at the same rate. However, for efficient running they must be designed for this rate. We could use two engines having different sized cylinders and operating from the same source of steam generation if the engines were designed for the same speed at full load and had about the same general characteristics throughout the whole range from no load to full load and get good results. Or, we could have two engines having the same or different size cylinders and operating at the same or different pressures and still get good results providing they were designed to operate under the same conditions as regards speed.

Now, if we compare speed to voltage, we will see that we have the same rule in effect in the parallel connected generators. With the same voltage in each case neither can send current through the other which would be equivalent to having the higher speed engine pull the lower speed engine along with it as it turned over. All power must then go into the line in the same way that all power in the case of the engines must go into the shaft. There is no other outlet. In the case of any number of generators the same considerations hold in exactly the same way that they would with any number of engines or men. If all worked at the same speed they would unitedly pull the load they were working on or put all the power onto the line. If any one, or any number, tried to work at a lower or higher rate there would be friction and power would be lost in the struggle between the units which would each be struggling to run at their own particular speed the same as it would with the generators in the attempt of each to put its own particular voltage out onto the line and the consequent confusion that would result if there were several different voltages or even two only.

GENERATORS IN SERIES. Generators in series are commonly used where it is desired to boost the line voltage over that which could be supplied by one acting alone.

This case is similar to the condition we would have in a pumping station where it was found that the pressure carried would not deliver the amount called for. If, however, we put in the line somewhere, another pump having the same pumping capacity, we could help out the main pump and so relieve it of considerable strain that it would otherwise feel in trying to keep up the pressure to what it should be. Since the same amount of water must pass through all of the pumps it is evident that they must be of the same capacity. They need not, however, be of the same speed. If one were of half the speed but had twice the displacement of the other they would have the same capacity and could consequently be operated in series without any trouble. If, however, they were not of the same capacity one would either be pumping water faster than the other could take it or else would be pumping water out of the line faster than the other could force it in. Consequently it would be pumping against a vacuum for a part of the time.

In the case of two or more generators in series on the line we have the condition that they must all be designed to deliver the same current since the total line current must flow through all of them in succession. They need not, however, be of the same pressure so long as they can put the same strength of current through their respective armatures. If one or the other produced a stronger current, the other would immediately begin to draw current out and to act as a motor and of course would be useless as far as increasing the line voltage was concerned. The fact that the voltage is not the same makes not the least particle of difference any more than it would in the case of the pumps if each individual pump required a different pressure to produce the same pumping capacity. The fact that there are a number of generators in the line has no effect upon the proposition providing they are built to give the same current to the line. In actual use the generators would not be bunched together in one building necessarily but would be scattered so as to get the best results by increasing the pressure where it showed the greater inclination to drop below that which was allowable on that particular line.

HYSTERESIS. In the actual magnetisation and demagnetisation of iron as it occurs under the action of the reversing current in the field of an electric machine, it will be found that the actual magnetisation of the iron lags behind the current which produces it, caused by what is termed the hysteresis of the iron or its tendency to remain in one state of magnetisation indefinitely unless affected by some outside cause. The curve showing the relation between the force causing the magnetisation and the magnetisation produced would be the hysteresis loop as shown in Fig. 17.

Suppose, now, we had a body of considerable mass and inertia which was held in a central position on a smooth plane by springs capable of acting either under tension or compression. This arrangement is shown in Fig. 18. If we were to impose upon this body a force F, we would cause the body to be displaced a certain distance from its central po position. If the force were now removed, however, the body would not at once return to its central position owimg to the friction between it and the plane upon which it rests, but would still have a certain displacement D remaining which would call for a negative force F' to overcome the friction in order to bring the body back to its central position. If the curve showing the relation between the force and the displacement were to be plotted we would have a figure similar to the hysteresis loop of Fig. 17 showing that this action is similar to that of the iron under the

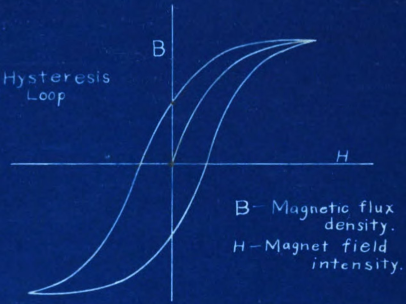
B
Hysteresis
Loop
H
B- Magnetic flux
density.
H-Magnet field
intensity.

Fig. 17.

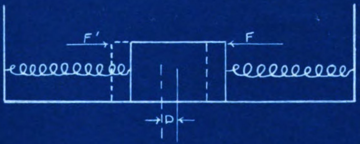
F'
F
D

Fig. 18.

action of the alternating magnetising current of the magnetic field.

IGNITION. The use of the electric spark for the ignition of the charge in the cylinder of a gas engine is a simple phenomenon commonly known to nearly everybody. It is usually, in fact nearly always, accomplished by the use of a spark gap and condenser in some form or other, the condenser storing up the electricity over a comparatively long period and then releasing it suddenly through the gap in the form of a spark.

Parallels to the action of the condenser and spark gap are fairly common.

Since man first began to think he has more or less conciously tried to find ways and means of multiplying his muscular powers, of storing up energy over a long period, and of using this stored up energy to do work through a short period.

For this purpose there are two great devices; mass-velocity and spring deflection. The charging of a condenser is similar to the deflection of a spring, while the creation of a magnetic field bears a strong resemblance to the acceleration in the mass-velocity. The mechanical spring device which mathmatically, most resembles the condenser, is an air chamber into which more air can be forced by increasing the pressure. The amount of air Q is proportional to the pressure P and the energy stored in it is proportional to the square of the pressure, so long as the air remains in the gaseous state and the compression is at a constant temperature.

The ordinary expressions denoting the amount of energy stored up in each of the four mediums; mass-velocity, spring, magnetic induction, and electrostatic capacity are in order;

(1)	$MV^2/2$	(2)	$QP^2/2$
(3)	$LI^2/2$	(4)	$CE^2/2$

where

M	mass	Q	quantity
V	velocity	P	pressure
L	inductance	C	capacity
I	current	E	E.M.F.

It will be seen that the first and third and likewise the second and fourth areclose parallels. There is one thing that should be noted in this connection, however, and that is that no energy can be stored in any one or all of the four mediums without the action of some active outside element.

In some respects a magnetic field may be said to resemble a spring, particularly if the medium opposing the action is in the form of an air gap. Lines of force in air resemble rubber bands which tend to shorten, collapse and disappear, losing their energy as the coercive force is removed. The presence of iron in the magnetic circuit increases the magnetic inductance and so stores up more energy. By increasing the iron and at the same time reducing the air gap more and more energy may be stored up but at the same time there is no gain in the released energy. The greatest release of stored energy is when that air gap is used which gives the greatest range from maximum to the residual fluxes.

For ignition purposes it is not desirable to use so small an air gap on account of the slowing up effect of the iron. In this sense, if it is without iron, an inductive coil or spark coil resembles a spring such as an archer's bow, so stiff that it requires considerable pull to deflect it even a small amount or like a spring without any great stiffness and with great flexibility if there is a large amount of iron and no spark gap. An intermediate degree of stiffness that gives a large deflection for a given pull and has a large returning moment is nearest like the spark coil with a properly proportioned amount of iron and length of spark gap.

INDUCTANCE AND CAPACITY IN PARALLEL. If we connect up a parallel circuit with a condenser in one branch and an inductance coil in the other as in Fig. 19 we find that the amount of current that will flow in the two branches will vary with the frequency of the current. If the frequency is low most of the current will go through the inductance coil and, in fact, if the frequency is zero so that we have direct current all of it will flow through the inductance. If the frequency is high, however, most of it will pass through the other branch of the circuit. In between, then, there will be a point where the amount passing in each branch will be exactly the same. This point is called the critical frequency and it will be found that at this frequency the pressure in the branches will be out of all proportion to that in the line and may even build up so high as to disrupt the instruments.

Suppose we take the arrangement of spring and weight shown in Fig. 20. If we move the handle very slowly the spring S will not be affected and the motion will be transferred to the weight W. If we move the handle rapidly, however, the inertia of the weight will hold it stationary and the spring will take up the motion. If the critical frequency is found and the handle moved back and forth at this rate it will be found after a time that the motion of the handle will be very small in comparison to that of the lever ends. If, now, the motion of the handle were to be

stopped altogether, the motion of the spring and weight would go on for some little time on the momentum they had gained before the stoppage of the active outside force. If, however, the motion of the handle be kept up, the added force will, in time, be so great that the mechanism will be beyond control and something will have to give.

In the electric circuit this action is the same. The induction builds up a high pressure which it will transfer to the condenser if it has a chance and the condenser will promptly return it, to receive it again on the return. Now, if the outside force is at the same time adding more force it is easily seen that, after a short interval of time, the force built up between the inductance and the capacity will be much higher than the outside pressure and will keep on growing just as long as the line keeps feeding in more and more current and keeps the condenser and coil passing the force back and forth between themselves.

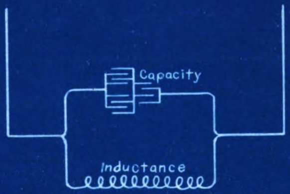

Fig. 19.

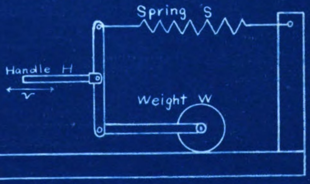

Fig. 20.

INDUCTANCE AND CAPACITY IN SERIES. It is common knowledge among electrical people that if an electric current be sent through an inductance coil a current in the direction opposing the current flow tends to appear. This action is in addition to that caused by any resistance that the circuit may posses. Fig. 21.

Suppose we take as an illustration of this a pump handling water and connected to a chamber having in it a heavy weight which is free to move with the water but which will not let any water pass it. Shown in Fig. 22. As the piston P moves, it forces the water into the chamber containing the weight M and causes it to move. At low frequency of the piston P, it is evident that the inertia of the weight will not enter in any great degree into the resisting force but that as the rate of motion of the piston increases, the force will have to overcome not only the resistance of the pipes to the flow, but the inertia of the weight as well and, finally, at high speeds, the inertia of the mass will be the predominating factor.

Or, take the case of the spring S carrying a weight W and having one end fixed as in a vise. Fig. 23. When the spring is bent very slowly to and fro most of the force will go into the bending of the spring. At high speed the force will go into overcoming the inertia of the weight. There will be an intermediate speed, however, where the inertia of the weight will bend the spring and the outside force will merely have to supply the force necessary to overcome the outside resistance.

In the electric circuit, the outside force would be the A.C. current. At low frequency most of it would have to be used in overcoming the resistance of the circuit but at high frequency it would have to overcome what is termed the counter E.M.F. set up in the induction coil of Fig. 21.

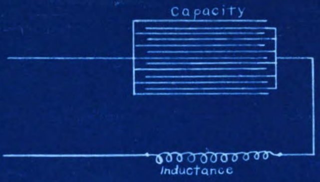

Fig. 21.

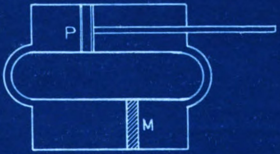

Fig. 22.

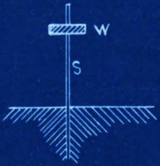

Fig. 23.

INSULATION. In the electrical field we find that if some means is not made use of to keep the current from straying from the path we wish it to follow we can do little. To prevent this we make use of some substance that will not conduct electricity which we call an insulator. Strictly speaking, there is no such thing in nature as a perfect insulator any more than in an air line we can have absolutely perfect air tight joints throughout the entire length of the line.

We might compare our insulator to the walls of a channel or pipe in which a liquid of some sort was flowing. We know that we are almost certain to have a leak somewhere in the line either large or small and furthermore we may have seepage through the walls of the container itself especially if we are carrying a very high pressure. At the same time the walls will keep the liquid in its proper channel and deliver it where we want it to go.

The action of the insulator in the electric circuit is exactly the same. It confines the electricity to the wire or whatever it is flowing along. It cannot confine the lines of force of the magnetic field, however, as they will pass through any insulator no matter what it may be or in what condition we may find it. This is tantamount to saying that we cannot keep the liquid in our pipe line or channel from transmitting pressure to the walls surrounding it. It would be as foolish to try to do so as to try to keep the lines of force from penetrating the walls of the insulator. In fact, use is made of the lines of force as they do escape, as in the transformer for instance. We might make use of the fluid pressure in the same way and, in fact, we do make use of this very principle in the hydraulic press, the air locks on lathe jigs, air and water drills and rammers and many other similar appliances.

LOOSE AND CLOSE COUPLING. When we have two circuits connected inductively as in Fig. 25 we say that they are coupled. By the terms loose and close we mean the relative amount of connection if it might be so expressed. When we have the coils close together, either by actually so placing them or by putting in an iron core and so keeping the energy from getting away into the surrounding medium, we say that they are close coupled that is, there will be little loss of energy by leakage. When, however, the coils are seperated more we have the loose coupling where there is considerable tendency for the lines of force to get away from the coils.

Suppose we had the two cars S and P of Fig. 24 held in a neutral position by the springs as shown and connected by the lever L L' carrying the weight W. We would then have the machanical analogy of the coupling. Suppose the weight to be of considerable mass in comparison to that of the small cars. When either car was set to vibrating, the weight, on account of its mass would remain nearly stationary while the other car would vibrate in unison with the first one but in the opposite direction at all times. In this case the weight would act as a pivot for the cars to act about. It is evident that there would be very little loss of energy due to the motion of the weight and that practically all of the energy would go into the vibrations of the cars.

Again, if we had the weight comparatively light, the cars and weight would all vibrate in the same direction at the same time and would reverse at the same time. In this case there would be considerable loss of energy due to the acceleration and deceleration of the weight.

The first case would be the analogy of the close coupling while the second would be the analogy of the loose coupling.

If, now, we examine the motion we find that there are four possible variations that might exist in the cars and weight;

(1) they might vibrate at the same frequency but in opposite directions while the weight remained nearly stationary,

(2) they might vibrate at the same feequency and in the same direction carrying the weight along with them,

(3) the car P might be held fast while the weight and car S vibrated,

and (4) the car S might be held stationary while the weight and car P vibrated.

In the electric connections the first would correspond to the case of the close coupling in a transformer with the oscillations of the primary and secondary opposite in phase and at high frequency; the second would correspond to a low frequency vibration in a transformer with the two currents in phase; the third would correspond to the secondary vibration if the primary were suddenly opened; and the fourth would correspond to the primary vibration with the secondary open.

The most common type of vibration is a combination of the third and fourth cases where the primary oscillates and then hands its energy over to the secondary and comes to rest. The secondary then hands back the motion to the primary and comes to rest itself. This handing back and forth of the motion continues until the resistance to the motion gradually brings the cars to a state of rest.

In order that all the energy may be handed back and forth the cars must be adjusted to the same vibration rate. This corresponds to the "tuning" in the electric circuit especially in wireless work. If they are not adjusted the vibrations will not be at the same rate and there will be two motions at the same time. The weight will then show a good deal of energy lost in its movement.

In the older wireless work the quenched spark was used to a great extent. That is, the primary vibrations were transfered to the secondary and then the primary circuit was suddenly broken. This is illustrated by the case which would exist if the cars were set to vibrating and then car P were suddenly seized and held.

If it were car S that were to be seized and held we would have the analogy of what would happen when the secondary is suddenly opened or broken.

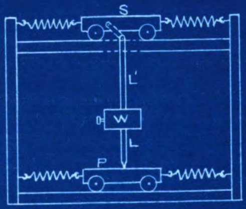

Fig. 24.

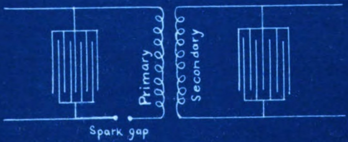

Fig. 25.

MAGNETS. It is common knowledge that if we bring the like poles of two magnets together or near each other some little force will be necessary to bring them into actual contact but that if the poles be unlike they will spring together of themselves if they are brought near each other. Soft iron or steel will act in the same way and so, in fatc, will any iron or steel body. The explanation of this lies in the fact that iron or steel in a magnetic field becomes a magnet. However, question is often asked, "why the repulsion or attraction and why do not all poles act alike and all attract or all repel?"

Supppose each magnet to be a hollow tube fitted internally with a pump and immersed in a tank of some fluid. When the pump is operating there will, of course, be an intake at one end and a discharge from the other. Also, the fluid from the discharge end must curve around and reenter the intake end. The paths taken by the particles of the fluid are similar to the paths taken by the lines of force of an electric field. If we bring another and similarly equipped tube near the first one with the discharge ends opposite it will at once be apparent that there must and will be a repulsion between the two streams similar to that which occurs between the like poles of two electromagnets.

Now, if we reversed one of the tubes, the suction of the intake would quite naturally draw the other tube up close to it the same as occurs with unlike poles of the magnet.

The only way of throroughly explaining the repulsion of the magnets whenever like poles are brought together is to suppose two opposite streams of different liquids passing through the pipes in such a way that neither mingles or interferes with the flow of the other in the slightest degree. In our original arrangement there would have been a strong attraction between the suction ends if they were brought together whereas in the magnet there would have been a strong repulsion in the like instance. If there were two opposite streams, however, neither of which interfered with the free passage of the other, then when the like ends came together they would interfere and repel but when unlike ends came together they would pass, the action being exactly the same as in the electromagnet.

Another way of explaining this phenomenon, and perhaps a better way, is to replace the lines of force emanating from a magnet by elastic bands under tension. Since the bands cannot go straight to the end of the magnet it follows that they must curve around the sides. Further, since they are thickly crowded together, some will be pushed sideways and will be longer and under a greater tension than others will. Now, if we suppose the ends of the bands attached to any pole have the property of being able to attach themselves to any other pole of a like kind that may happen to be in the neighborhood if they so desire, we have a very good example of magnetic action. The bands, being always under tension, tend to shorten and if by attaching themselves to some other pole they could shorten their length they would most naturally do so. This is what occurs when unlike poles approach. The bands of each attach themselves to the other and, by contracting, draw the poles together. Some of the bands, of course, will not be able to find a place to attach themselves and so will remain in the original position or nearly so. Others will be forced loose and will attach themselves to other loose elastic bands extending between extreme ends of the two magnets.

But, if like poles are brought together it is evident that the bands will remain fixed in their positions and the result will be that force will be required to compress the elastic mass in order that the magnets may be brought into contatc.

PHASE. When the force producing an electric current and the current produced do not reach corresponding points at the same instant of time we say that they are out of phase and that when they do they are in phase.

Suppose, now, we liken the current to the flow in a tidal channel and the force causing the current to the ebb and flow of the tidal action itself. It may be seen that the two are parallel. For instance, if the channel is smooth and straight, the tide in the channel will closely correspond to that in the ocean outside. It will rise with it, turn with it, and fall with it. The two are then in phase if it were to be expressed electrically. But, suppose the channel were crooked and obstructed with rocks, logs, and various other objects. It is at once evident that the obstruction to the flow would be considerable in this case. It is also apparent that the tide at the head of the channel might be considerably behind the tide in the sea. It would reach its maximum of ebb or flow later and might even flow in the opposite direction for a short time after the tide in the sea itself has reversed its direction. This is analogous to being out of phase in electricity. There is one slight difference however. In an electric sense the current may either lead or lag, that is, it may be either ahead of or behind the force producing it, while the tidal analogy can only follow the tidal action of the sea and in this sense it always lags.

RESISTANCE. When we have several wires carrying electricity from one place to another we find that the wires tend to oppose the passage of the current. The wires may be placed end to end in what is termed series connection, Fig. 26, or side by side in what is known as parallel connection, Fig. 28.

To illustrate the series connection, suppose for the wires AB, BC, CD, of Fig. 26, we substitute the pipes AB, BC, and CD, of Fig. 27 connected end to end in the same manner as the wires. We would then have a mechanical example of the series connection. It is at once evident that there would be a greater total friction in the pipes and also that the total friction is equal to the sum of the frictions in all the pipes. In the same way the electric resistance in a circuit increases as more conductors are connected in in series with those already in the circuit.

Or, say we have several conductors connected in parallel as in Fig. 28. If, now, we substitute as before and put pipes A, B, and C in place of the corresponding conductors of Fig. 28, we have the example of the parallel circuit as shown in Fig. 29. It is easily seen that more water can pass through the several pipes in the same interval of time than through one alone, and, therefore, for the same amount of water, the friction must be less. In the same manner, if the several electric conductors are placed side by side the resistance offered by them taken together is less than that offered to the same amount of current passing through any one alone.

If, now, we combine the two connections into what is known as series-parallel or parallel-series depending upon which way they are grouped, we get such a connection as is shown in Fig. 30.

Substituting as inthe preceeding cases we have the piping arrangement illustrated in Fig. 31. We can see at once that, if we consider the parallel pipes as a unit, this unit plus the unit in series with it will offer more frictional resistance to the flow than if the pipes A, B, C, and D were all in parallel but that at the same time the friction will be less than if the pipes were all in series. From this we see that to find the total friction, we must first find the friction offered by A, B, and C in parallel and then add to this result the friction offered by the pipe D. The manner of finding the electric resistance of series-parallel connections in electric circuits is exactly similar. We must first find the resistance of all sets of parallel connections and, when these are reduced to the resistance which they would have if a single conductor were substituted, add up all these resistances to get the total resistance.

Fig. 26.

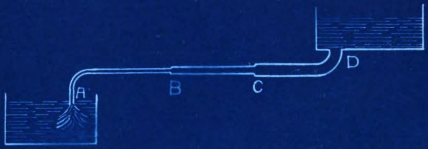

Fig. 27.

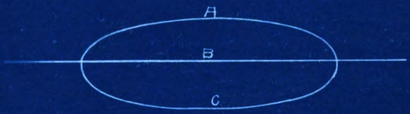

Fig. 28

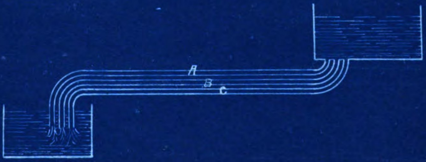

Fig. 29.

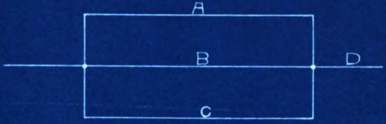

Fig. 30.

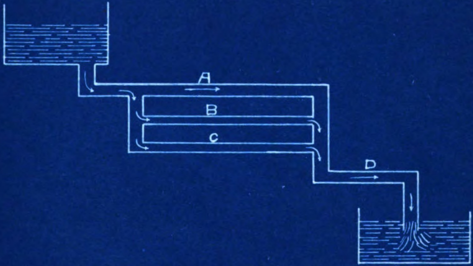

Fig. 31.

ROTARY CONVERTER. In case we desire to use the electric current or power at a different voltage than that at which the mains supply it or at a different frequency or both or even if we wish to change the number of phases, we make use of the rotary converter. This is nothing more or less than a generator which delivers electricity when driven by electricity. A brief examination of the machine will show us that the circuit from which the line current is drawn is entirely distinct from that which delivers the outgoing current.

The action of this machine is analogous to that of an air pump. We can easily see that we can deliver air at the same pressure as that of the steam driving the pump if the steam and air cylinders are of the same size, at a lower pressure if the air cylinder is the larger or at a higher if the air chamber is the smaller. In the same way we can use any sort of current we desire, either direct or alternating, single or multiple phase, to drive the converter and deliver any kind we desire. It is only a question of using the proper winding and connections for the delivery current. This would correspond to the using of the proper size cylinder for the air delivered if we wish a certain pressure in the air mains. This characteristic is often made use of where a different class of electricity is desired than that in the line and where a transformer would not deliver the electricity under the conditions desired.

STORAGE BATTERY. Where current is available within a reasonable distance for charging or for use in storing surplus energy, storage batteries are much in favor and are in common use. These take the current from the line as it is fed in and, when properly connected up, will give out the current in the reverse direction to that in which it was fed in.

To understand this action, take as an example a pump forcing water into an elevated reservoir as in Fig. 32. It is evident that the water has a definite direction of flow in the pipe. If, now, the action were reversible and the pump were used as a motor, it is apparent that the original direction of flow of the water must be the reverse of what it would now be with the pump acting as a motor.

Further, more power must be used to deliver the water than can possibly be received from the water when it is used to do work on account of the friction of the pipes against the moving column of water. This friction would cut down the amount of work regardless of that lost in the friction in the pump and motor since there is no such thing as a one hundred percent efficient motor or pump. In the same way more current is necessary to charge the battery and at a higher pressure than that which the battery can deliver on account of the resistance within the battery itself and in the line.

Another parallel is the gradual deterioration of both battery and reservoir with use unless they are kept constantly uner inspection and repair to prevent their falling to pieces with time.

We often speak of storing electricity but do we? We could not, strictly speaking, say we stored energy in the case of the pump except, perhaps, indirectly, by storing the water. In the same way we cannot store electricity except by causing chemical action in the battery which when properly connected may set up electric currents. Therefore, we must brand the expression of "storing electricity" as incorrect, not in the general meaning, for we do store it up indirrectly through the medium of the chemical action, butt as to what it would seem to imply on the face of it.

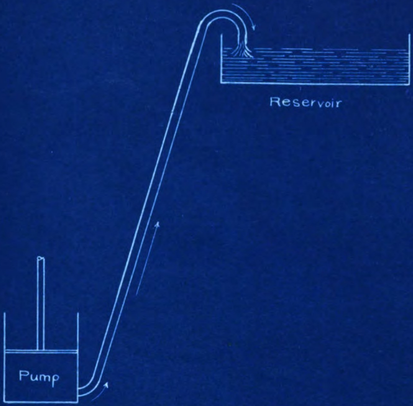

Fig. 32.

TELEPHONE. The telephone as it is used today is a highly efficient device for the conveyance of human speech over wires. This is done by means of a diaphragm controlled by electrical impulses. The strength of the current flowing is controlled by a small cylindrical container placed just back of the transmitter which is filled with finely divided carbon. When pressure is applied to this carbon it is more closely packed together and the resistance is therefore less and, consequently, more current can flow.

If a flexible pipe were taken as arepresentation of this and if it were to carry a liquid from one vessel to another we would have a liquid telephone. It is evident that if we squeeze the pipe the flow would be restricted and less water can flow. On the other hand, if we ease up on the pressure more water will flow, This is analogous to the action of the powdered carbon. It inserts a ressistance in the electric circuit which will vary with the pressure inposed by the vibrating diaphragm under the action of the vibrations of the voice. The action of the receiver disk is the reverse of this but here an electromagnet is used to cause the receiver disk to vibrate under the varying strength of the magnets caused by the varying currents.

THREE WIRE SYSTEM. Use is often made in electric distribution work of what is known as the three wire distribution system. This simply means that three wires are used to carry the current instead of two. The wiring is shown diagramatically in Fig. 33 where G, G are the generators and L, L are the lamps.

Now, suppose we substitute pumps for the generators and water motors for the lamps. We would then have the arrangement of Fig. 34 where the pumps elevate the water from one tank to the next higher one. It may be seen that there are three possible conditions;

(1) when the motors of the sets draw the same amount of water,

(2) when the upper set draws more than the lower,

and (3) when the lower set draws more than the upper.

In the first case the same water will pass through both sets of motors and, therefore, there will be no flow from pipe B into the tank, but that the flow will be from the upper tank into line A, through the motors and then back through line B to the lower tank.

In the second case the upper set will use more than the lower and, consequently, there must be a flow of the surplus from B into the intermediate tank.

In the third case, when the lower set takes more than the upper, there will, of necessity, be an outward flow from the central tank into line B to make up the deficite from the upper set of motors.

In all the cases there will be an outward flow in A and a return flow in C. Another possible condition is to have motors connected directly across from A to C. This is done where a greater pressure is desired and would give double the pressure which exists between the other lines.

The electrical connections are exactly the same and in actual practise the lamps on the two sides of the central line are kept as nearly the same in capacity as possible so that there will be as little flow in the central line as possible. The connections across between the other lines are used when it is desired to have a higher voltage over some of the machinery connected into the line. Actually it would not be necessary to have two generators as one generator cam be built with the windings so arranged as to feed all the wires from the one machine.

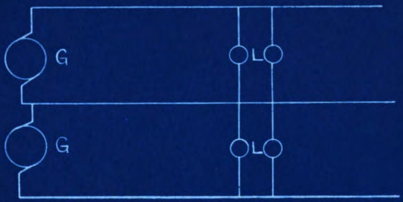

Fig. 33.

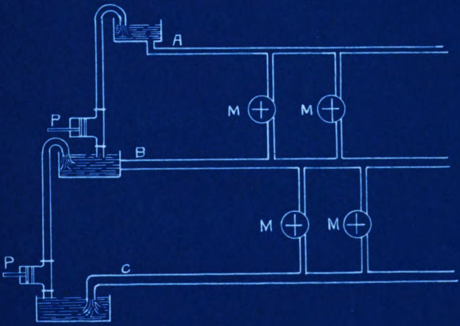

Fig. 34.

TRANSFORMERS. For distributing current through communities what are termed transformers are used at frequent intervals. These instruments take the line current at whatever voltage it may be and deliver it to the house lights at the required voltage which is usually considerably lower than that of the line.

Suppose we compare the transformer to a pump taking water at a high pressure and delivering it at a low pressure as shown in Fig. 35. We see that the water under the high pressure by acting against a piston, is able to pump more water under lower pressure by means of a large piston.

The action of the transformer is identical. Either a small current of high pressure electricity flowing in the line pumps out a large current of low pressure electricity, in which case it is called a step-down transformer, or we may use low pressure electricity to deliver high, in which case it is called a step-up transformer.

Another example is the common lever. At first it would seem that there is no connection but if we look more closely we see that the parallel is close. Suppose we take an ideal case and make our lever out of a weightless bar. Then the velocity of the ends as it moves back and forth on the central fulcrum will correspond to the primary (ingoing) and secondary (outgoing) voltages and the forces exerted by and on the ends of the lever will compare favorably with the currents on the opposite sides of the transformer. It is well known that the forces on opposite sides of the lever are inversely as the lengths of the arms. This is also true in the transformer, but here the currents are inversely as the number of turns of wire in the windings. The velocity of the forces are directly as their arms which is the parallel to the fact that the voltage are directly as the number of turns in the windings, Now, if we fix the lever and open the circuit of the secondary we would have parallel cases since no motion can occur in either case. Therefore, if the lever has more or less mass, as it would in the actual example, some force would be required to overcome this. This corresponds to the current which will leak from the transformer or be used to magnetise the windings. In the lever it is easily seen that the same forses that move the lever do not do the actual work but that it is the force generated by this force through the medium of the lever arms that does it. In the same way, the current flowing into the transformer from the line does not go out onto the house circuit. The two circuits are entirely distinct, each having its own winding in the body of the transformer.

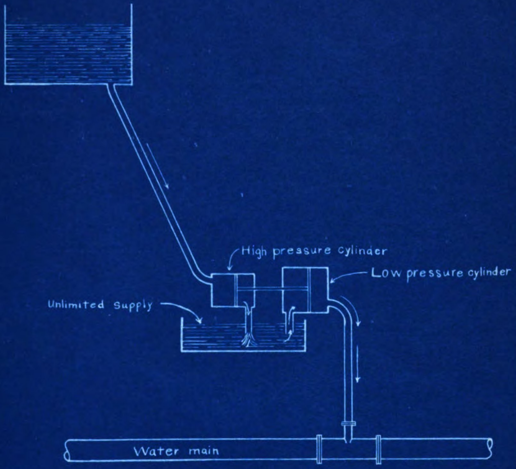
High pressure cylinder
Low pressure cylinder
Unlimited supply
Water main

Fig. 35.

VOLTMETER. For finding the difference of potential or voltage between any two points of an electrical circuit we make use of what is termed a voltmeter or electrical pressure gage. This makes use of the known law that, the resistance being constant, the greater the electric potential the more the current which will flow. This property is made to move the voltmeter coil and so move the pointer. Fig. 36.

For a parallel to this let us turn to the pressure gage as used in either a steam or air line. Fig. 37. We all know that the gage shows the pressure in the main over and above the pressure of the air outside. To do this one side of the gage must be subjected to the pressure exerted by the air and the other to that of the gas in the main. The pressure gages for gases can be so fixed as to give the absolute pressure of the gas and in this one particular it has a characteristic that is not obtainable in the voltmeter as it can only give the difference of pressure between any two points and if the pressure of the lower side rises the reading of the meter will drop the same as if the atmospheric pressure rose on the steam gage. However, there is one thing necessary in the voltmeter which would render the steam gage valueless if it were complied with in its case and that is that current must flow through it in order that the pressure or voltage may be registered. If this were done in the steam gage the pressure on the two sides would tend to become the same and the gage would become valueless. But, not considering this and considering only the way in which they operate the action is the same.

Fig. 36.

Fig. 37.

WHEATSTONE BRIDGE. For measuring very small resistances or currents we use what is known as the Wheatstone Bridge named after the inventor. This is nothing more or less than a square of conductors having the source of electricity connected across two opposite corners and a very sensitive indicator across the other two. Fig. 38 illustrates this. A, B, C, and D, are the conductors, E is the source of electricity and G is the galvanometer or indicator. If the electrical pressure is the same on the opposite sides of the indicator it is evident that the instrument will not move but that if the pressure is not the same it will show a flow of electricity from one side to the other. Then by proportion we may find the resistance of any one of the resistances if the resistances of the others at balance are known.

Now, substitute pipes carrying a liquid for the conductors and a pump of some sort for the source of pressure. It is easily seen that if the friction of the pipes in Fig. 39 are rightly proportioned there will be no flow through the cross pipe G but that if balance does not exist there will be a flow since liquids tend to flow from a region of high pressure to that of low if the way is open. This parallels the action of the Wheatstone Bridge where the electric current flows through the galvanometer when the circuit is closed and electric balance does not exist in the arms of the Bridge.

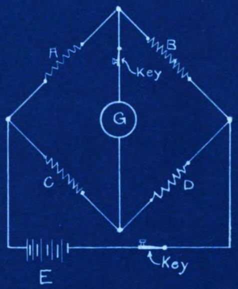

Fig. 38

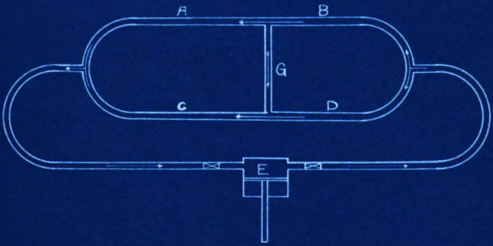

Fig. 39.