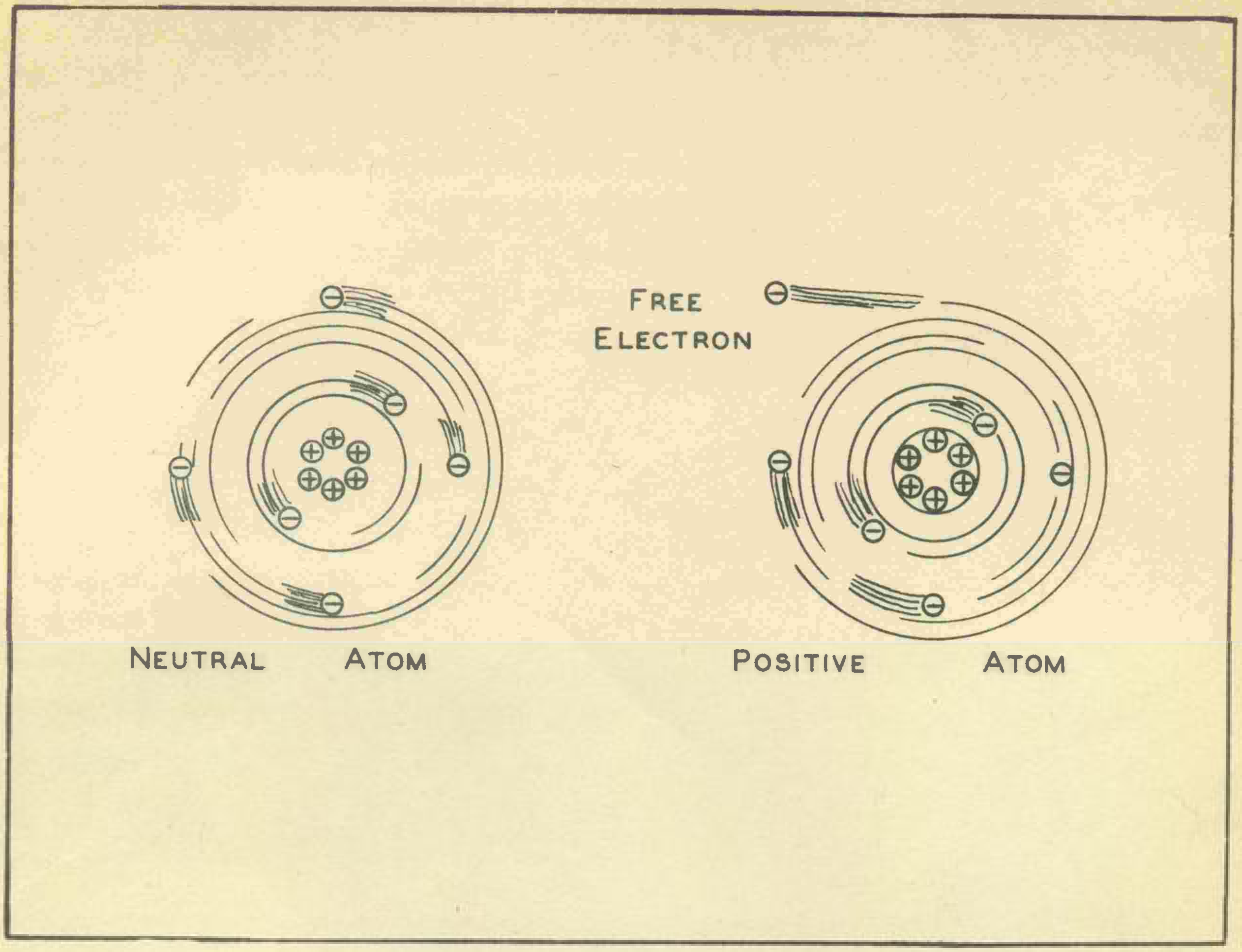

LESSON 2 R

ELECTRICITY IN RADIO TUBES AND WIRING

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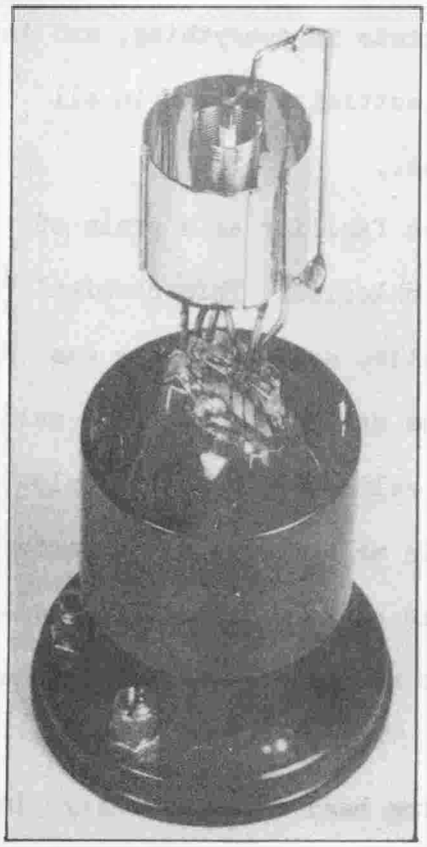
ELECTRICITY IN RADIO TUBES AND WIRING

In the preceding lesson we talked about nearly everything that goes into radio apparatus. Now we are ready to commence examining each of those parts and their behavior. Because it is the tubes and their circuits which allow present-day radio to do such remarkable things, it is these parts which we shall discuss first.



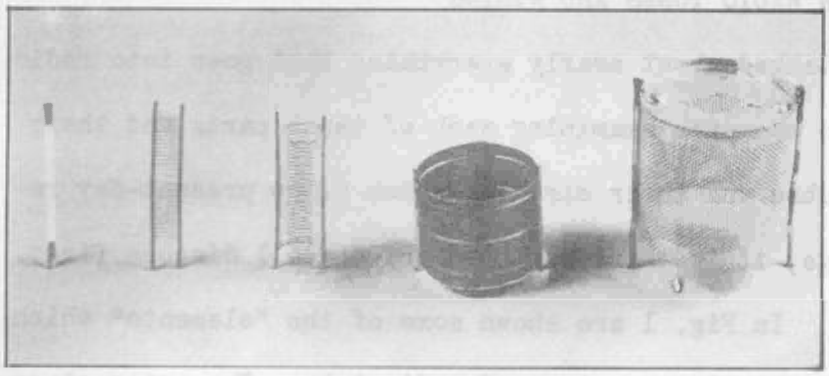
The tube is broken open to show the plate, cathode, and grid.

FIG. 1.

In Fig. 1 are shown some of the "elements" which are inside one type of radio tube. The outer glass envelope or bulb has been broken away and a few parts have been removed to give a clear view. The outermost metallic cylinder is the "plate". The innermost part: a small, white, rod-like piece, is the "cathode". Between the cathode and the plate is an open spiral of small wire called the "grid".

While the tube is in operation, the cathode is heated red hot. Heating of the cathode enables electricity to emerge from its surface, and the electricity is made to travel from the vicinity of the cathode through the grid to the plate. This travel is through the space between cathode and plate. In the complete tube this space is within the glass envelope out of which have been pumped nearly all air and other gases to leave a vacuum. In this lesson we shall investigate, among other things, the forces which make the electricity flow through the vacuum.

Electricity that flows through the space inside of the tube has to come to the tube and into the cathode through wires and other conductors, and has to leave the plate and go out of the tube through other conductors. A tube is useless without the conductors and other parts which are in the circuits connected to the tube. In this lesson we shall investigate the forces which drive electricity through the



Some of the elements found in tubes. From left to right; a cathode, two types of grids, a plate, and a shield.

FIG. 2

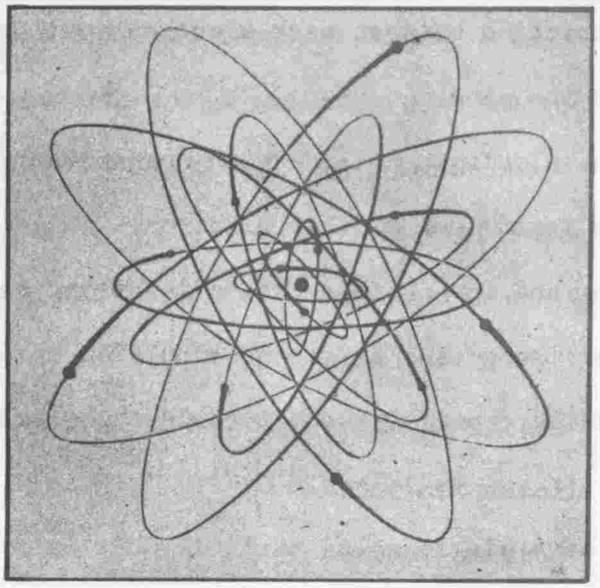
circuit connected to the tube.

Evidently our first concern is to learn a few facts about electricity itself: what electricity is and what makes it flow in conductors and spaces. Electricity exists in everything, and it exists everywhere except in absolutely empty space. Electricity exists in all solids, in all liquids, and in all gases — at all times.

To check these statements let's consider something so familiar as a grain of table salt. Table salt is a chemical compound, sodium chloride. This chemical name tells us that the salt is formed from the metal called sodium and the gas called chlorine. No matter how finely you pulverize the salt you still have salt, or sodium chloride. The smallest possible particle of salt would be a <u>molecule</u> of sodium chloride. By chemical means we can split this molecule into two parts; one of which will be an <u>atom</u> of sodium, and the other an <u>atom</u> of chlorine. Chemistry cannot divide these atoms into smaller parts, yet most atoms consist of many parts.

Atoms are small. In a solid substance the size of the head of an ordinary pin there are almost six billion, billions of atoms. If you could lay atoms in a straight line, close together, it would take about 40 millions of them to extend an inch. With the most powerful microscope ever made with glass lenses no one ever has seen an atom, nor have they come anywhere near seeing one.

But supposing that we could magnify an atom until it appeared a mile in diameter. The atom would appear somewhat as shown by Fig. 3. Most of the atom would be empty space, just as our solar system with the sun at its center and the planets around it is mostly empty space. Like the sun in the center of the solar system there would appear in the center of the magnified atom a "nucleus" about 5/8 inch in diameter. Whirling on orbits centering around the nucleus would appear particles about the size of a small pea. These whirling particles are <u>electrons</u>. They are the electric particles which, when they escape from atoms, flow through the spaces in tubes and flow also through conductors.



Electrons, which are electricity itself, whirl around the nucleus which is at the center of the atom.

FIG.3.

ELECTRONS

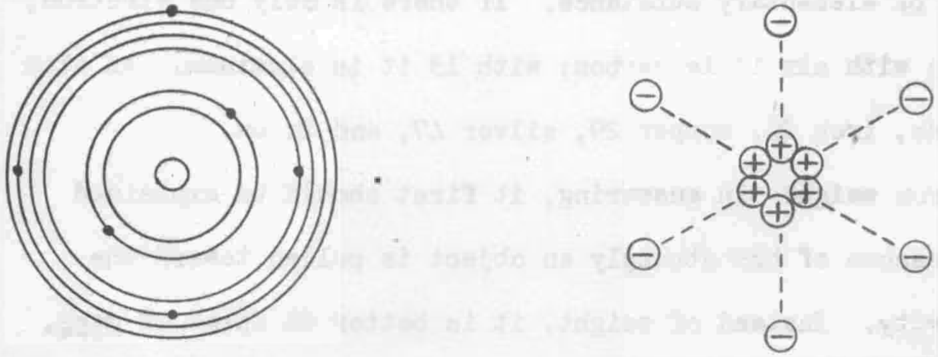
All atoms of all substances are of approximately the same size. All atoms have but a single central nucleus, but the number of their electrons may be anywhere from one to 92. The number of electrons determines the kind of elementary substance. If there is only one electron, the substance is hydrogen; with six it is carbon; with 13 it is aluminum. An atom of sulphur has 16 electrons, iron 26, copper 29, silver 47, and so on.

How much does an electron weigh? In answering, it first should be explained that weight is merely a measure of how strongly an object is pulled toward the earth by the force of gravity. Instead of weight, it is better to speak of <u>mass</u>, which is a measure of the quantity of matter in an object without reference to gravity. Then the answer to our question is: Electrons have mass. But to collect a mass of one ounce of electrons we would need about 31½ billion, billion, billions, of electrons. Compared with the electrons the nucleus of atoms has great mass; it is about 1,840 times as great as the mass of an electron.

The electrons whirl around the nucleus of the atom at tremendous speed. A thousand miles an hour would be comparatively slow. Then, you ask, why don't the electrons fly away from the nucleus and out of the atom? They don't fly out of the atom for the same reason that the earth doesn't fly off its orbit around the sun and go shooting off through limitless space. In the one case there is such strong attraction between earth and sun as to keep the earth within the solar system. In the other case there is such strong attraction between each electron and the nucleus as to hold the flying electrons in the atom.

Here is another question: Why don't the electrons collide with one another? The answer is that every electron strongly repels every other electron. While there is great attraction between electrons and the nucleus, there is strong repulsion between electrons. For that matter there also is strong repulsion between every nucleus and every other nucleus, and they would fly apart could the electrons be gotten out of the way.

The nucleus of an atom is not composed of a single solid particle, but is made up of many particles. Of the several kinds of particles in the nucleus the kind which interest us most are called *protons*. They interest us because they are the particles which attract the electrons and hold the electrons in the atoms.



A carbon atom has six negative charges (electrons) and six positive charges (protons).

FIG. 4.

We say that each electron has a *negative charge* and that each proton has a *positive charge*, or, we may say that an electron *is* a negative charge and that a proton *is* a positive charge.

With only what we now know about the behavior of negative electrons and positive protons we may state one of the great laws of electricity. The law may be stated in three parts, thus: (1) Negative charges repel each other, (2) positive charges repel each other, but (3) negative and positive charges attract each other.

ELECTRIC CHARGES

Now let's consider the structure of an atom in more detail. We shall take an atom of carbon, because it is one of the simplest. The general facts applying to the carbon atom apply as well to all other atoms.

A complete atom of carbon has six electrons, as indicated at the left in Fig. 4. Two of them are near the nucleus and the remaining four are farther out. Each electron is a unit negative charge, which means, in this case, the smallest quantity of charge; much as the cent is the smallest unit of our money. Then in the complete carbon atom there are six units of negative charge.

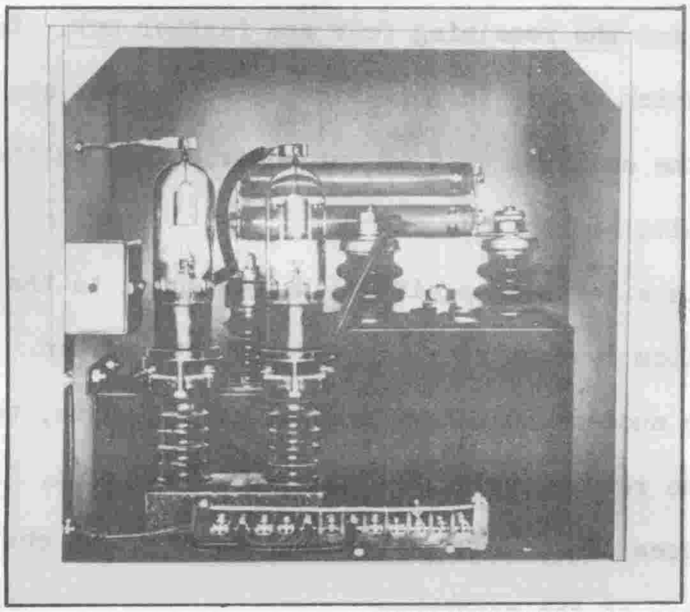
In the nucleus of any atom there is a total of positive charges equal to the number of negative charges when the atom is complete. In the complete carbon atom the total positive charge of the nucleus must have a value of six units, which exist in the six protons. This may be represented as at the right in Fig. 4. Broken lines in the diagram indicate forces of attraction between the positive charges of the nucleus and the negative charges of the electrons.

We indicate positive charges by the plus sign(+) and indicate negative charges by the minus sign(-). The words positive and negative are used simply to indicate that the two kinds of charges have opposite characteristics and effects. The terms have no other significance, and originally were chosen quite arbitrarily. They are like the terms hot and cold, wet and dry, high and low, light and dark, and hundreds of others which indicate nothing more than opposite properties. Were everyone to begin saying that it is light during the night and dark during the day, the meanings of light and dark would be reversed and then everything would be as easy as now. Were everyone to agree on reversing the meanings of positive and negative, it would be just as easy to talk about electricity as it is now. It is only a matter of attaching certain words to certain ideas.

What we have called a complete atom is more correctly called a neutral atom. A neutral atom is one in which the positive and negative charges are balanced, in which there are the same number of unit positive charges as of unit negative charges.

EXPERIMENTING WITH ELECTRONS

Now we are going to detach some electrons from their atoms and see what happens.



This unit, containing tubes, resistors, and a transformer, produces electric charges of great intensity or strength.

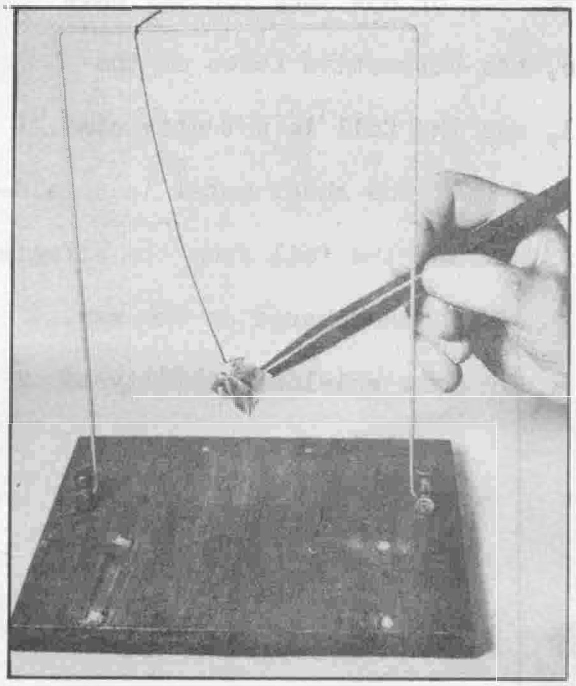
FIG. 5.

To get electrons out of atoms it is necessary to add energy to the electrons. In our experiments the energy will come originally from muscular work. When energy is added to electrons, they whirl faster and faster. Finally, one of the outer electrons in some of the atoms goes so fast that it leaves the atom -- to become a free electron. These free electrons can move about by themselves, either in space or in conductors. The positive charge, which is in the nucleus of the atoms, stays in the atoms. Unless the atoms themselves can move, there is no flow of positive electricity.

In solid substances, such as most conductors and insulators, the atoms don't move about. In liquids and in gases the atoms or molecules have movement in relation to one another, and, under certain conditions, we have what amounts to flow of positive charges as certain atoms move through liquids and gases. In radio we are but little concerned with electric flow in liquids. But in some kinds of tubes, which have gas in their envelope, the movement of positive charges inside the tube envelope is important. For the present, however, we are concerned only with flow of negative charges, or electrons, in conductors and in spaces.

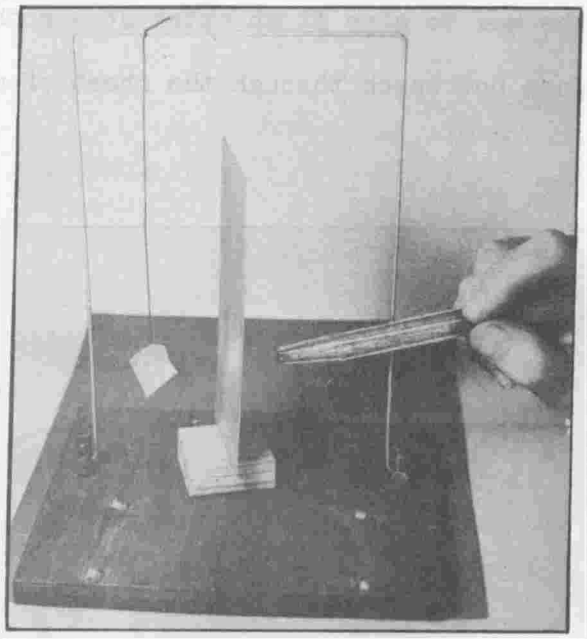
For our experiments with free electrons we shall use a stick of sealing wax such as may be had from any stationery store, and a piece of woolen or silk cloth. When you rub the sealing wax briskly with the cloth, the rubbing gives extra energy to electrons in the atoms of the cloth. One electron of each of many electrons then escapes from the cloth and goes over onto the wax. The electrons are negative charges. The wax acquires a strong negative charge, because it has acquired negative electrons greatly in excess of the positive charges in all of its atoms.

The negative charge on the wax now may be used to cause attraction and repulsion.



The metal foil is attracted by the charged sealing wax.

FIG.6



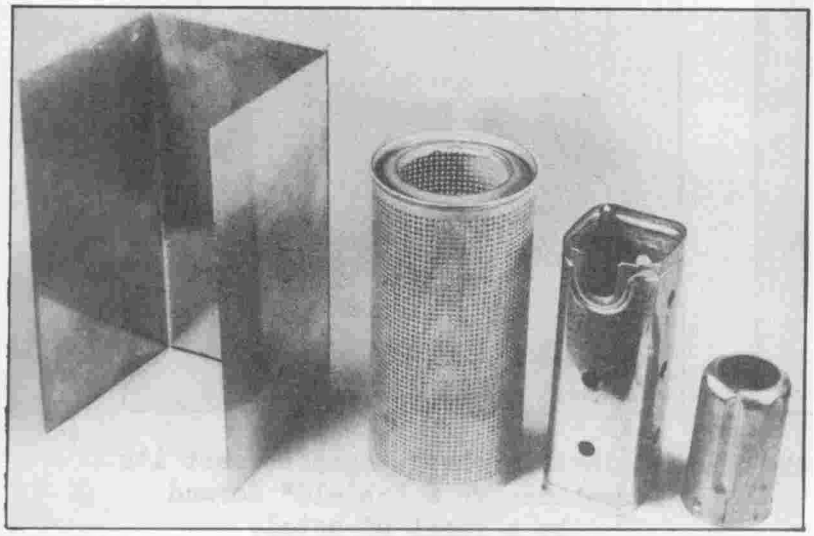
An electric charge cannot exert its force through a "shield" formed by a sheet of metal.

FIG.7

In Fig. 6 a piece of tin foil is hung from a thread. A small, light piece of any other metal would do as well. When the end of the charged wax is brought toward the foil, the foil swings over to the wax. If a fairly large area of foil comes into close contact with the wax, the foil then will swing away from the wax.

Why is the foil first attracted to the wax and then repelled from the wax? At first the foil is neutral; in it are equal positive and negative charges, with a portion of the negative charges existing as free electrons in the metal. The negative charge on the wax repels these free negative electrons, they move away from the side of the foil which is toward the wax, and that side of the foil is left with a positive charge. Then attraction between this positively charged side of the foil and the negative charge on the wax pulls the two together. If the foil makes good contact with the wax, many of the excess electrons which form the negative charge on the wax rush into the foil. Then the foil has a negative charge due to these excess electrons which enter it. The negative charges in the foil and the wax now repel each other, and the foil swings away from the wax.

In Fig. 7 a sheet of metal is supported between the suspended tin foil and the end of the charged sealing wax. No matter how briskly or how long you may have rubbed the wax to give it an extra strong charge, the attractive force of the charge does not reach through the sheet of metal, and the foil is not attracted.

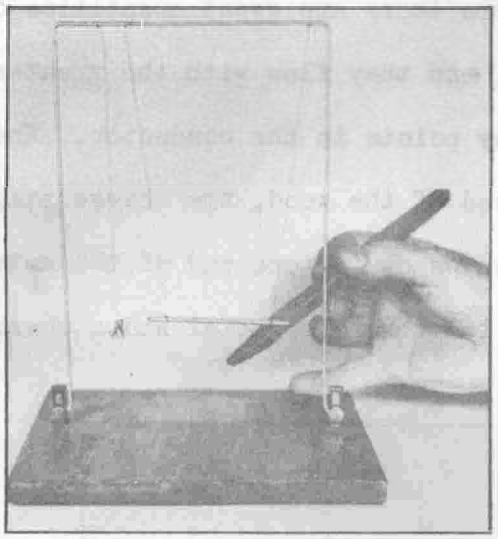


Here are some shields used in radio apparatus.
FIG. 8.

The sheet metal is shielding the foil from the effects of the charge on the wax. This shielding ability of metal is put to practical use in radio by enclosing some of the coils, tubes, and other parts in shields which commonly are called "cans". Several such radio shields are pictured in Fig. 8. We looked at shields or cans for intermediate-frequency transformers in the preceding lesson. Although you may not have noticed it in those earlier pictures, a small transformer which is in the oscillator circuit is mounted underneath the chassis of our radio receiver. Thus this transformer is shielded from the effects of charges originating in parts on top of the chassis.

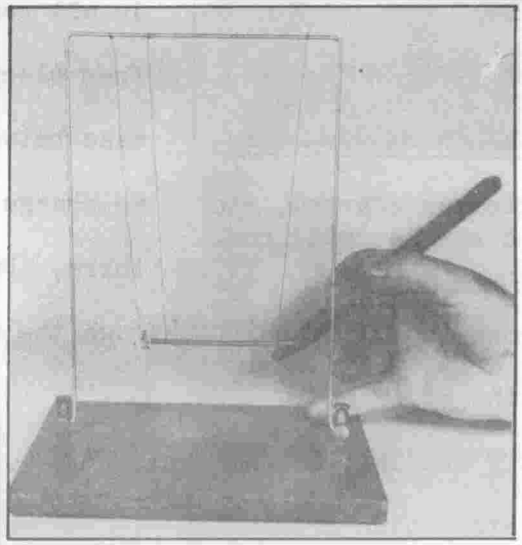
To continue our experiments with electric charges we now shall use the set-up of Fig. 9. Toward the left is a piece of metal foil, and toward the right is a metal rod about three inches long, both hanging from thread. The foil is a fraction of an inch from one end of the metal rod.

After the sealing wax has been rubbed with the cloth to give the wax a negative charge, the end of the wax is brought toward the end of the metal rod that is farther away from the foil. The charge on the wax drives free electrons away from its end of the rod and they go all the way to the end toward the foil; getting as far as possible from the charge on the wax, and forming a negative charge on the end of the rod toward the foil. This charged end of the rod then acts toward the foil just as does the charged wax in Fig. 6, and the foil swings into



The charged sealing wax is brought near one end of the metal rod.

FIG. 9.

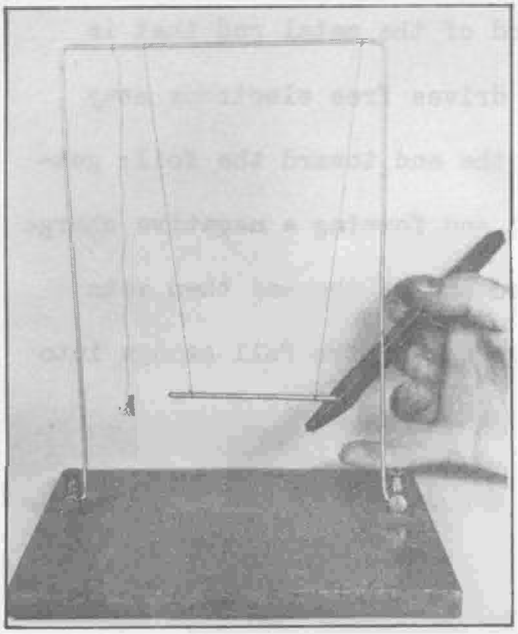


The metal rod becomes charged, and attracts the metal foil.

FIG. 10.

contact with the rod as in Fig. 10. The foil immediately takes a negative charge from the rod and swings away from the rod as in Fig. 11 -- because now both the foil and the end of the rod near it have negative charges.

In Fig. 12 we have substituted a piece of wood for the metal rod. With the wax charged as before, and brought near the end of the wood which is farther from the foil, nothing at all happens to the foil. The negative charge on the wax does induce a small positive charge on the end of the wood toward the wax, by pushing a few electrons farther from their atoms in that end of the wood. But there are very few free electrons in wood compared with the number in metal, and none of them are moved all the way to the end of the wood that is toward the foil. Consequently, that end of the wood becomes neither negatively nor positively charged, and it has no effect on the foil.



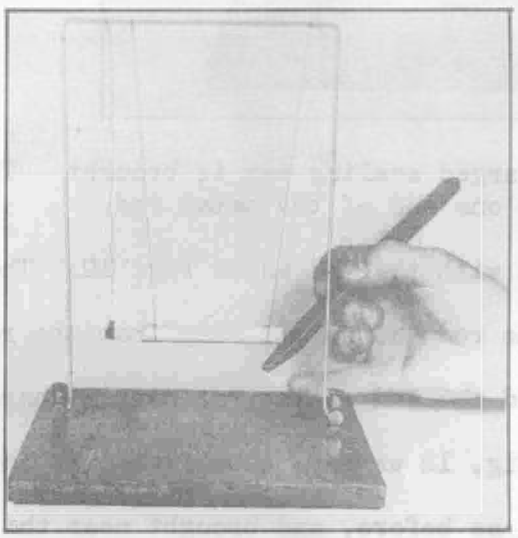
The foil becomes charged, and is repelled by the metal rod.

FIG. 11.

The metal rod is a conductor. The piece of wood is an insulator. The difference between <u>insulators</u>, such as the piece of wood, and <u>conductors</u>, such as the metal rod, is this: In any insulator there are but few free electrons, and these few cannot readily be made to flow from one place to another in or on the insulator. But in all conductors there are great quantities of free electrons, and they flow with the greatest ease between any points in the conductor. When we charge one end of the wood, the charge stays there. But when we charge one end of the metal rod, electrons instantly shift through the whole length of the metal and a charge appears at the other end.

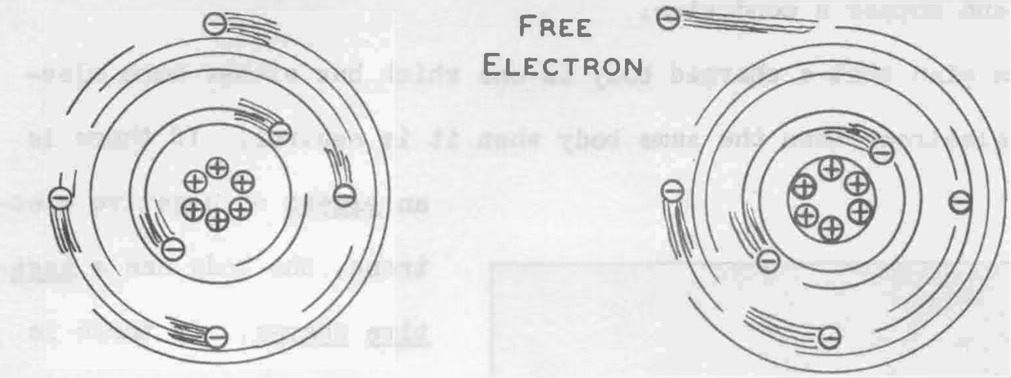
MORE ABOUT ELECTRIC CHARGE

When an atom which originally is neutral loses an electron, as in Fig. 13, that atom is left with one more unit positive charge than unit negative charges -- because the positive charges which are the protons stay in the atom. Then the atom has a net positive charge or it is a positive atom. When this happens to many billions of atoms in a body, and when the free negative electrons are removed from the body, the body as a whole has more positive charges than negative charges and the body is said to have a positive charge or to be positively charged.



Electrons do not flow through the wooden rod to produce charges.

FIG. 12.



When an electron leaves an atom, the electron becomes a free electron, and the atom becomes a positive atom.

FIG.13.

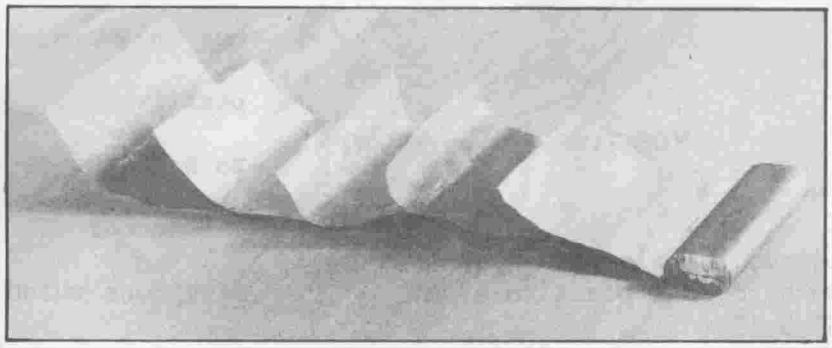
More than its normal number of electrons do not enter any atom, because the atom has only enough positive charge to hold the normal number of electrons which make it a neutral atom. But electrons can be added to a body considered as a whole. The added electrons simply increase the number of free electrons in the body. Then the body has more negative charges than positive charges, or it has a net negative charge. The body then is said to have a negative charge or to be negatively charged.

In a conductor, even though it be electrically neutral, there always are countless free electrons. This comes about because atoms continually are losing one of their electrons, which temporarily becomes a free electron. The loss of an electron leaves the atom with an extra positive charge, and any free electron which comes too close is pulled into the atom. The atoms continually are picking up free electrons which have escaped from other atoms, even while they are losing some of their own electrons.

Electrons in a conductor, or at least one electron of most of the atoms, always have nearly enough energy to escape from the atoms. Then slight shifts of energy within the conductor will release many electrons, which become free electrons.

In an insulator practically all of the electrons are tightly held in the atoms. Only a few electrons can escape to become free electrons. The sealing wax used in our experiments is an excellent insulator. Copper is one of the best conductors. For every single free electron in a given volume of sealing wax there are in an equal volume of copper about 7½ billions of free electrons. This is why sealing wax is an insulator and copper a conductor.

We should keep in mind that a charged body is one which has either more electrons or else fewer electrons than the same body when it is neutral. If there is an excess of negative electrons, the body has a negative charge. If there is a deficiency of electrons, the body has a positive charge. When a neutral body loses electrons, that body becomes positively charged; when it gains electrons it becomes negatively charged.



A paper type capacitor partly unrolled to show the layers of paper and of metal foil.

FIG. 14.

All of the capacitors used in radio are devices for receiving electric charges in their metal plates, and for giving up these charges at certain instants. The charges on one plate do not escape to adjoining plates because the plates are separated by insulation through which electrons do not flow. In some capacitors, such as tuning capacitors, the insulation between plates is air. In other types the insulation may be paper, fibre, or mica. A paper type capacitor partly opened is pictured in Fig. 14. Starting from the left there is first a layer of paper, then metal foil, followed by two more layers of paper and a second metal foil. All of these are rolled together as at the right, leaving the two metal foil plates separated by intervening layers of paper.

MEASURING QUANTITIES OF ELECTRICITY

When we talk about the numbers of electrons which move from place to place, and which are in electric charges, we always are speaking of "billions and billions" or some such astronomical figures. The use of such numbers would be most inconvenient, and so we have a practical unit of quantity of electricity. This unit is called the coulomb. One coulomb of electricity is equal to about $6\frac{1}{4}$ billion billions of electrons, or to 6,280,000,000,000,000,000 electrons.

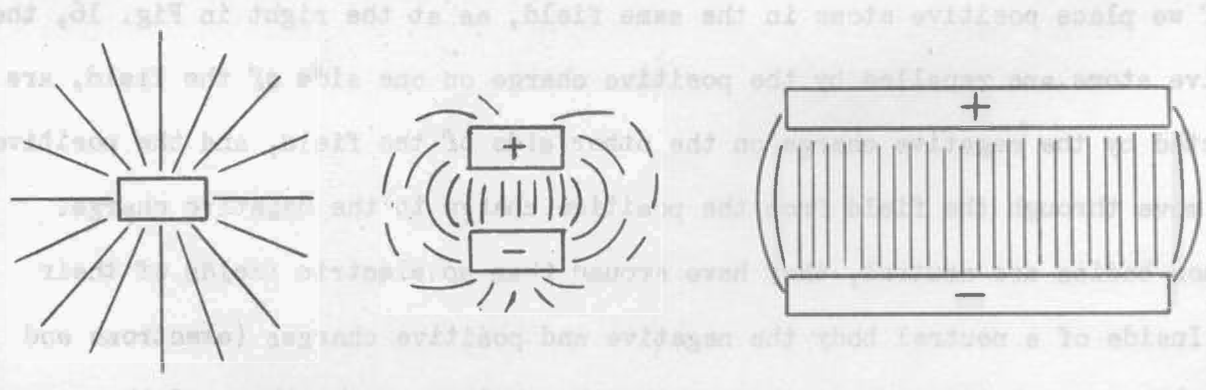
A negative charge of one coulomb means that the charged body has this number of electrons in excess of the number in the same body when it is neutral. A positive charge of one coulomb means a deficiency of this number of electrons in comparison with the number in the same body when it is neutral.

ELECTRIC FIELDS

In our experiments with electric charges and the tin foil the metal foil moves toward the charged metal rod while there still is a space between the foil and the rod. The attractive force which arises in the electric charge of the rod reaches out through space. By experimenting with the charged metal or the charged sealing wax and a piece of foil suspended from a thread you will discover that the force reaches through quite a distance.

Any space or region in which an electric force is acting is called an electric field. Extending outwardly from every electric charge is an electric field in which forces of attraction and repulsion exist. It is the invisible force in the region called the electric field that causes attraction between charges that are not alike, and that causes repulsion between charges that are alike.

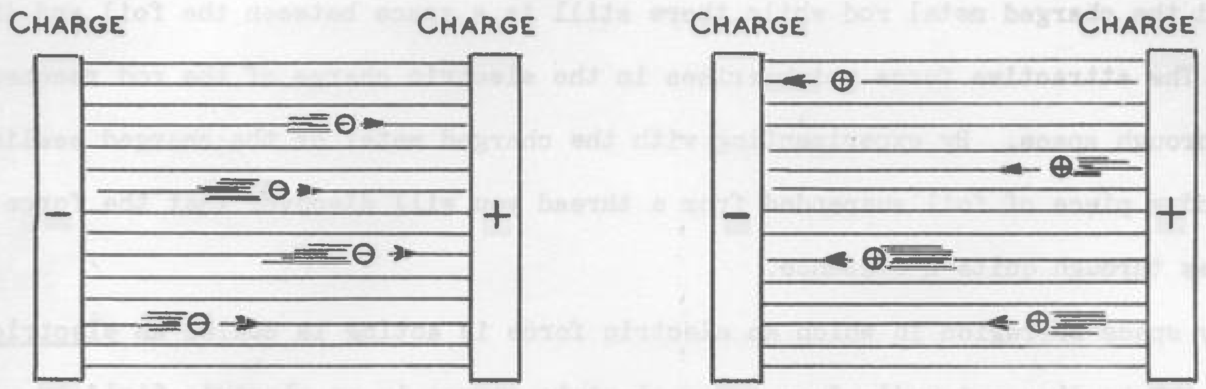
Electric fields in the space around charges usually are represented by straight or curved lines on diagrams. The lines show directions in which the electric forces act. These lines have no real existance in electric fields, but are merely for convenience in drawing diagrams.



The electric fields around and between charged bodies.

FIG.15.

If, as at the left in Fig. 15, a charged body is not near other bodies, the field extends in all directions from the charged body. Should a positive charge and a negative charge be near together, as at the center, most of the fields and electric forces are concentrated in the space between the charges. If charged bodies are long and wide, and the space between them is not too great, nearly all of the electric field is in the space between the bodies. This is shown at the right.



How negative electrons and positive atoms are caused to move by attraction and repulsion in electric fields.

FIG. 16.

Supposing that we get any number of free electrons into the field between unlike charges, as at the left in Fig. 16. The electrons are negative charges. They are repelled by the negative charge on one side of the field, are attracted by the positive charge on the other side, and the electrons move through the field from the negative charge to the positive charge.

If we place positive atoms in the same field, as at the right in Fig. 16, the positive atoms are repelled by the positive charge on one side of the field, are attracted by the negative charge on the other side of the field, and the positive atoms move through the field from the positive charge to the negative charge.

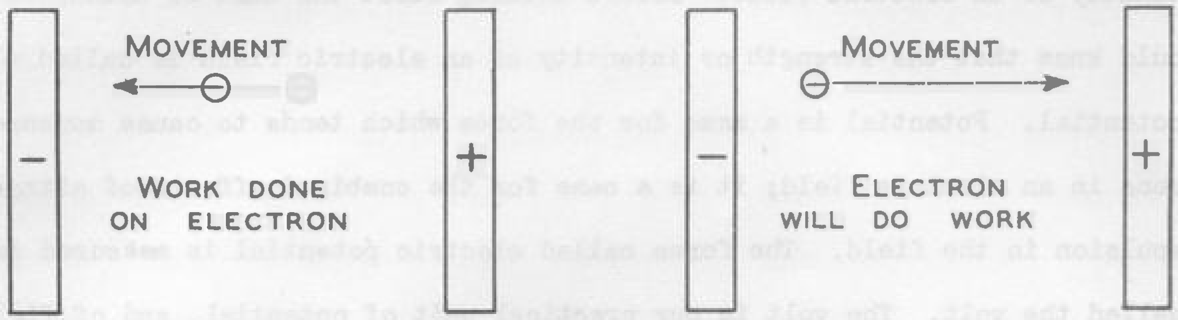
When bodies are neutral, they have around them no electric fields of their own. Inside of a neutral body the negative and positive charges (electrons and protons) are equal in number and strength; they balance each other and there remains no unbalanced electric force to form a field outside of the body.

Just as we needed a practical unit for measurement of quantity of charge, and found it in the coulomb, so we need a practical unit for measuring the strength or intensity of an electric field. Before talking about the unit of measurement, we should know that the strength or intensity of an electric field is called electric potential. Potential is a name for the force which tends to cause movement of electrons in an electric field; it is a name for the combined effects of attraction and repulsion in the field. The force called electric potential is measured in a unit called the volt. The volt is our practical unit of potential, and of field intensity or strength.

Now we know what it is that a volt measures, but still we do not know how much force is represented by a potential of one volt. To get an understanding of the meanings of potential and of the volt we must begin with an understanding of the meaning of work. All of us feel that we know the meaning of work only too well, but now we are going to talk about the precise technical meaning of work. Work, in the technical sense, is done only when a weight, or mass, is moved. You may get all tired out pushing against a stone wall for hours, but you will have done no work unless you succeed in moving the wall.

You do work when you lift a weight against the force of gravity. If you lift through a height of one foot a stone having a mass (weight) of one pound, you have done a definite amount of work. You have done one foot-pound of work. The foot-pound is the practical unit of work. If you lift the one-pound stone through a height of ten feet, you have done ten foot-pounds of work, and if you lift a ten-pound stone through a height of one foot, you likewise have done ten foot-pounds of work. The number of foot-pounds of work is equal to the product of the distance in feet by the mass or weight in pounds, or to the number of feet times the number of pounds.

Now look at the left-hand diagram of Fig. 17, where is represented an electron in the field between charges. The electron wants to move to the right, from the negative charge toward the positive charge. But let's say that we are applying a force that makes the electron move to the left. We then are moving the mass of the electron against the electric force in the field, just as you move the mass of



Work must be done on an electron to move it from positive to negative in a field, and the electron will do work when moving in the opposite direction.

FIG.17.

a stone against the force of gravity. The electric force in the field space near electric charges is similar to the force of gravity in the air space around the earth. When we move a body against the force of gravity, we do work on that body, and when we move an electron against the field force, we do work on the electron.

When work is done on a body, energy is put into that body. When you lift the stone, you give the stone energy, which is the ability to do work. If you let the lifted stone fall against some other body and that other body is moved, work is done by the stone. When an electron is made to move against the forces of attraction and repulsion in an electric field, work is done on the electron and the electron gains energy. If the electron is made to move all the way from the positive charge to the negative charge at the left in Fig. 17, a definite amount of work is done on the electron, and the electron has acquired a definite amount of energy.

In the right-hand diagram of Fig. 17 the electron is being allowed to move back from the negative to the positive charge under the influence of the forces of attraction and repulsion. As the electron moves in this direction, it will give up energy and do work. By the time the electron gets all the way from the negative charge to the positive charge it will have lost all the energy put into it while moved from the positive charge to the negative charge.

Now for the definition of a volt of electric potential. When 0.737 foot-pound of work has to be done on one coulomb of electricity to move that much electricity all the way through a field against the forces of attraction and repulsion, as at the left in Fig. 17, that field has a potential of <u>one volt</u>. More correctly we should say that the potential is one volt greater at one side of the field than at the other side, and that there is a <u>potential difference</u> of one volt between opposite sides of the field and between the charges on the opposite sides.

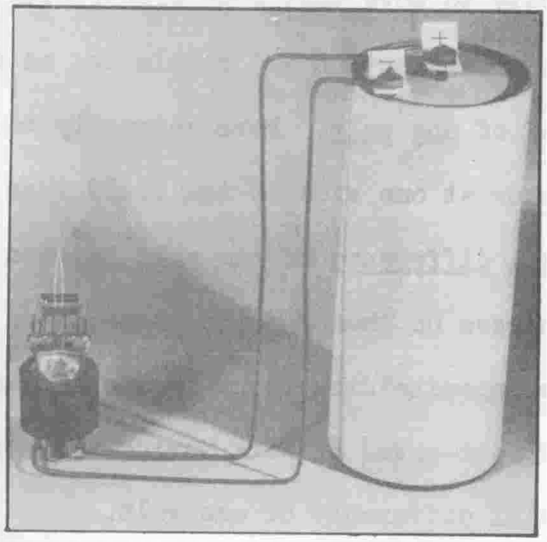
If one coulomb of electricity moves in the opposite direction, from negative to positive, and if the electricity does 0.737 foot-pound of work during this travel, the electricity has moved through a potential difference of one volt.

We may state these facts in a more general way as follows: There is an electric potential of one volt between any two points when 0.737 foot-pound of work is required to move one coulomb of electricity <u>against</u> the field forces existing between the two points. Also, there is a potential difference of one volt between any two points when 0.737 foot-pound of work is done by one coulomb of electricity moving <u>with</u> the field forces existing between the two points. The two points may be any two points in any circuit.

ELECTROMOTIVE FORCE

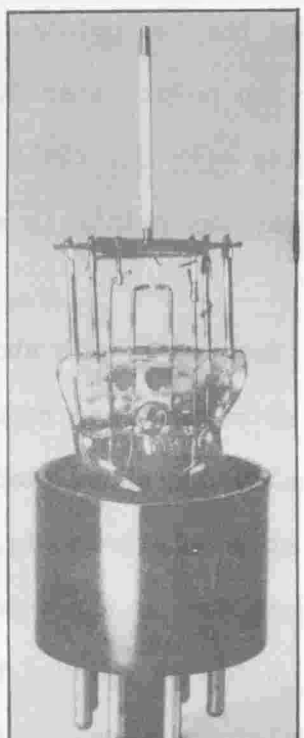
Now let's talk about the force that makes electrons move <u>against</u> the forces of attraction and repulsion. This force is called <u>electromotive force</u>, a name which usually is abbreviated to <u>emf</u>. It is electromotive force that makes electrons move as at the left in Fig. 17: away from a positive charge and toward a negative charge. Electromotive force acts against the forces of attraction and repulsion.

A few paragraphs back we learned that the combined forces of attraction and repulsion are called electrical potential, and we learned that potential is measured in volts. It is only natural that the opposing force, called electromotive force, also should be measured in volts. Both of the forces which act to move electrons are measured in volts: in volts of potential when the electrons move with the field forces, and in volts of electromotive force or emf when electrons are moved against the field forces.



A circuit consisting of the heater used in a tube, a source which here is a dry cell, and conductors connecting the two.
FIG.18.

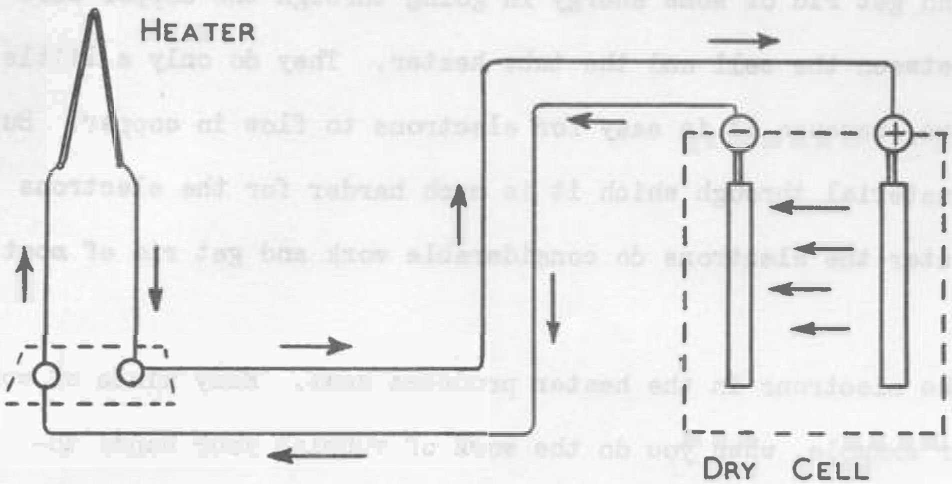
To see how the opposing forces act in the same circuit we shall look at the circuit of Fig. 18. At the left is a tube from which have been removed all of the parts except the base, the supports for the elements, and the heater. The heater is the thin, white conductor of inverted V-shape extending upward from the supports on the tube base. To the base pins that connect with this heater we have attached two wire conductors which lead to the terminals of the dry cell at the right. A dry cell often is called a battery, although the word <u>battery</u> really means two or more cells working together.



Here is a cathode within which is a heater.
FIG.19.

In the complete tube the heater is enclosed within a tiny cylinder which is the cathode of the tube. Fig. 19 shows a cathode within which is a heater. The cathode is the small white cylinder extending upward from the supports. When the heater is made red hot, it transfers enough heat to the enclosing cathode to make the cathode red hot. The cathode, when red hot, lets electrons emerge from its surface into the surrounding vacuum which is within the envelope of the complete tube. The heater is used only to raise the temperature of the cathode. The heater conductor is covered with insulation so that no electrons pass from the heater into the cathode, nor do electrons emerge from the heater into the tube space.

The electric circuit which includes the heater, the dry cell, and the conductors between them may be represented as in Fig. 20. Inside the dry cell are chemical compounds which will separate while giving up energy. The chemicals in the cell break down to produce electromotive force. The electromotive force makes electrons move through the parts in which this force appears. In the case of the dry cell the emf causes electrons inside the cell to move from the right-hand positive(+) "electrode" and terminal over to the left-hand negative "electrode" and terminal of the cell. This direction of electron movement is shown by arrows.



A diagram of the heater circuit.
FIG. 20.

We may note that the word electrode is a name given to any part at which electricity or electrons pass from one substance or medium into a different one. The parts which stick down into the interior of the cell are electrodes which are attached to the cell terminals. The cathode of a tube is an electrode because electrons pass from the cathode surface into the tube space. The plate is another electrode because electrons pass from the space into the plate.

The result of the electron movement within the cell is to produce an excess of electrons (a negative charge) at the negative electrode and terminal, while causing a deficiency of electrons (a positive charge) at the positive electrode and terminal.

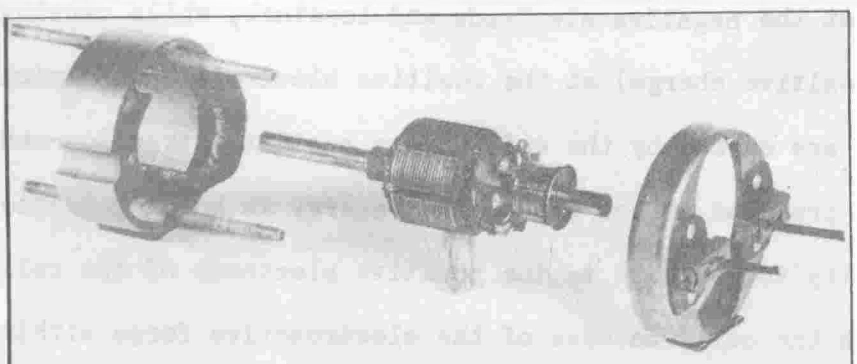
When electrons in the cell are caused by the emf to move against attraction and repulsion of the charges being produced at the electrodes, energy is being put into the electrons. The electrons try to get back to the positive electrode of the cell. They cannot go backward through the cell, because of the electromotive force within the cell, and so they get back to the positive electrode by flowing through the external circuit which includes the heater. The path of the electrons through this external circuit is shown by arrows.

Between the time at which the electrons leave the negative terminal of the cell and the time at which they get back to the positive terminal, the electrons do work and get rid of the energy that is being put into them by the emf. The electrons have to do some work and get rid of some energy in going through the copper wire conductors which are between the cell and the tube heater. They do only a little work in these conductors, because it is easy for electrons to flow in copper. But the heater is made of material through which it is much harder for the electrons to flow, and in the heater the electrons do considerable work and get rid of most of their energy.

The work done by the electrons in the heater produces heat. Many kinds of work will produce heat. For example, when you do the work of rubbing your hands together you can feel the heat being produced. The electrical energy which is being produced from chemical energy in the cell is changed to heat energy in the heater, and the heater gets red hot.

POLARITY

The cell terminal at which there is maintained a positive charge is called the positive terminal, and the one at which there is maintained a negative charge is called the negative terminal. Formerly the positive terminal was called a positive pole, and the negative terminal a negative pole. From this practice came the word polarity. When any point in a circuit is positive with reference to some other point, we still say that the first point is of positive polarity. Then the other point, which is negative with reference to the first one, is of negative polarity.



A generator changes mechanical energy into electrical energy.

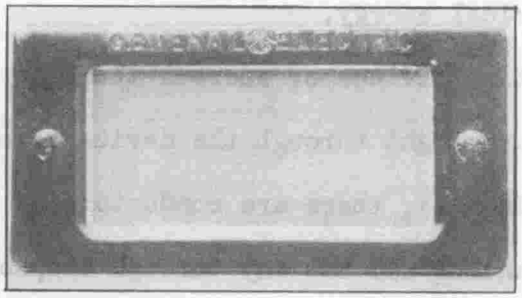
FIG. 21.

ENERGY SOURCES

Any device in which

electrical energy or electromotive force may be produced from other kinds of energy is called a source of electrical energy, or, more commonly, is called simply a source. The dry cell is a source because, in it, chemical energy is changed to electrical energy and emf. A storage cell, such as one of the cells in an automobile battery, is another source in which chemical changes produce emf.

Another kind of source is an electric generator or dynamo, such as the small one whose principal parts are pictured in Fig. 21. The armature, shown in the center, goes into the opening through the field poles shown at the left. The brush holder at the right is mounted so that carbon brushes bear on the cylindrical commutator, which is at the right-hand end of the armature. When the armature is rotated by mechanical power, emf's are induced in the armature windings and the emf's cause electron flow in these windings. The electron flow goes through the commutator and brushes to an external circuit. The generator changes mechanical energy into electrical energy.



A photocell changes light energy into electrical energy.

FIG. 22.

Fig. 22 is a picture of a photocell which changes energy in light into electrical energy. When light falls on the window of this cell, an emf is produced in the parts of the cell, and electron flow will take place in a circuit connected to the cell.

Still another energy converter, or source, is shown by Fig. 23. This one is a thermocouple which changes heat energy into electrical energy. The particular thermocouple shown is used in electric meters. Electricity to be measured flows in the straight wire inside the bulb, and heats that wire. The other two wires are of different metals, joined together where the joint can be heated by the straight wire. An emf appears at the joint, and

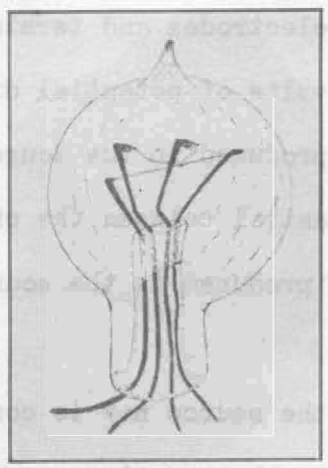
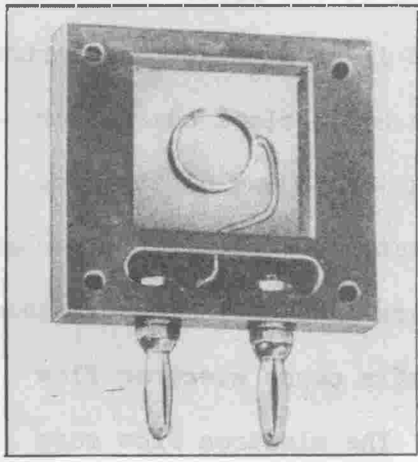


FIG. 23.

A thermocouple will change heat energy into electrical energy.

electron flow passes to the connected meter.

Fig. 24 shows, in its mounting, a crystal made from the mineral quartz. When a quartz crystal is cut or shaped in a certain manner, it will, when placed in an electric field, become alternately thicker and thinner, or longer and shorter, in time with the frequency at which the field strength changes. If the same crystal is subjected to changes of pressure at or near the frequency for which the crystal is cut, the crystal will produce alternating emf's at this frequency. Thus the quartz crystal, which is one kind of piezo-electric crystal, will translate the energy of varying pressure into electrical energy.



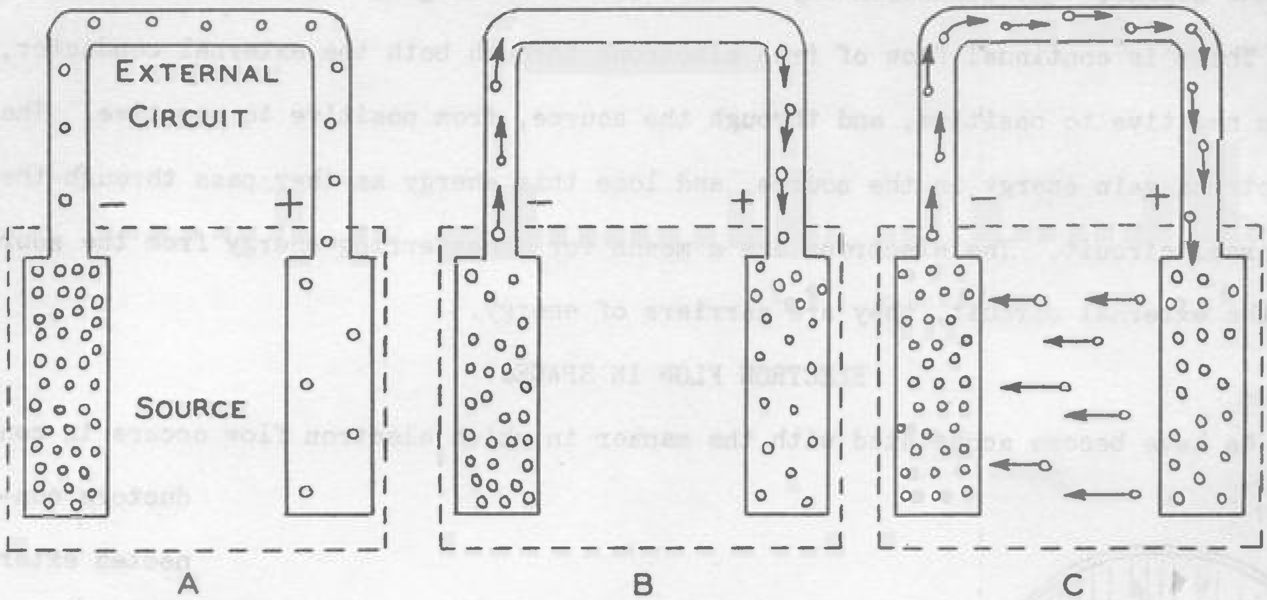
A quartz crystal will change pressure into electrical energy.
FIG. 24.

In all energy-converting devices or sources there is a complete conductive path right through the device, from terminal to terminal. That is, there are conductors of one kind or another extending all the way through the source. These conductors in the source are full of free electrons which are caused to move by the emf produced in the source. Emf's may act also where there are no conductors; they may act in space. But for an emf to cause movement of electrons there must be electrons where the emf exists, whether in conductors or in spaces.

If the terminals of a source are not connected to any external circuit, the emf will cause electron flow inside the source only until charges are built up at the source electrodes and terminals. When these charges reach values at which the number of volts of potential difference between them is equal to the number of volts of emf produced in the source, then the flow will stop. The flow ceases because the potential between the charges is equal in volts, and opposite in direction, to the emf produced in the source.

ELECTRON FLOW

If the source now is connected to a complete external circuit, electrons will flow from the negative terminal (or charge) through the external circuit around to the positive terminal (or charge). This electron flow commences at practically the same instant in every part of the circuit, but for purposes of explanation we may consider that the electron flow begins at the positive terminal of the source.



How electron flow commences and continues in a source and an external circuit.

FIG. 25.

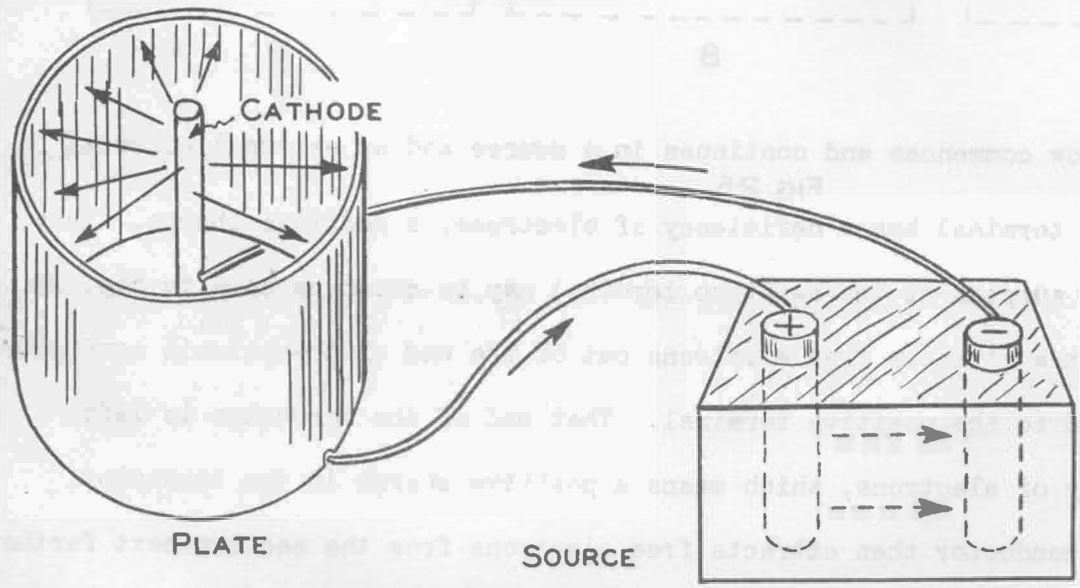
The positive terminal has a deficiency of electrons, a positive charge. This, and the electron surplus at the negative terminal may be shown as at A in Fig. 25. The positive charge attracts free electrons out of the end of the circuit conductor, which is attached to the positive terminal. That end of the conductor is left with a deficiency of electrons, which means a positive charge in the conductor. This end of the conductor then attracts free electrons from the section next farther from the source terminal. This action extends quickly through the whole conductor until, at the end attached to the negative terminal of the source, electrons are taken away from the negative charge (surplus of electrons) existing at that terminal. The conditions might be represented as at B in Fig. 25.

Electrons from the circuit conductor have been added to the positive electrode of the source, making that electrode less positive. Electrons have been taken away from the negative electrode, making that electrode less negative. The emf acting in the source instantly commences taking away electrons which are coming into the positive electrode, driving the electrons through the source, and adding them to the negative electrode, which is losing electrons to the conductor. Thus the emf acts to maintain the charges and the difference of potential between the terminals of the source. The condition may be represented as at C in Fig. 25.

There is continual flow of free electrons through both the external conductor, from negative to positive, and through the source, from positive to negative. The electrons gain energy in the source, and lose this energy as they pass through the external circuit. The electrons are a means for transferring energy from the source to the external circuit, they are carriers of energy.

ELECTRON FLOW IN SPACE

We have become acquainted with the manner in which electron flow occurs in conductors connected externally to a source. Now let's discuss electron flow through space. In Fig. 26 are represented the plate and the cathode of the tube first pictured in Fig. 1. The plate is shown connected to the positive terminal of a source, and the cathode is connected to the negative terminal of the same source. The plate and cathode, also any other elements used, are enclosed within the vacuum inside of the tube envelope.



Electron flow from cathode to plate in a tube, and through the connected circuit and the source.

FIG.26.

The emf acting in the source produces charges at the source terminals. The positive charge at the positive terminal draws free electrons out of the conductor connected to that terminal, and this conductor draws electrons out of the connected plate. The plate acquires a positive charge because of losing electrons. At the same time the negative charge at the negative terminal of the source repels some of its free electrons into the conductor connected to that terminal. These extra electrons continue through into the connected cathode, and the cathode is given a negative charge. Now we have a positive charge on the plate and a negative charge on the cathode.

If the cathode now is heated red hot, electrons emerge from its surface. These electrons are repelled by the negative charge being maintained in the cathode, and they are attracted by the positive charge being maintained in the plate. Consequently, the electrons flow through the space between the cathode and plate, continually leaving the vicinity of the cathode and entering the plate. From the plate the electrons flow continually through the conductor to the positive terminal of the source, through the source, and from the negative terminal through the other conductor back to the cathode, where they again emerge into the tube space under the influence of heat.

MEASURING THE RATE OF ELECTRON FLOW

Just as we have units in which to measure charges, potentials, and emf's, so we have a convenient unit in which to measure the rate of electron flow through conductors and through spaces. The unit of rate of flow is based on a flow of one coulomb per second. We may speak of a rate of flow of electrons or electricity as being so many coulombs per second, just as we speak of a rate of flow of water as being so many gallons per second.

The term "coulombs per second" is a rather long one. In practice we specify rates of electron flow in the unit called an <u>ampere</u>. A rate of flow of <u>one coulomb per second</u> is a rate of flow of <u>one ampere</u>. The term "coulomb per second" and the word <u>ampere</u> mean exactly the same thing. It would be incorrect to speak of a flow rate of so many amperes per second, because the one word <u>ampere</u> indicates both the quantity flowing (one coulomb) and the time required (one second).

The ampere is a rather large rate of flow. Many electron flow rates in radio apparatus are so small that we specify them in <u>milliamperes</u>. One milliampere is equal to 1/1000 of an ampere. Still smaller flow rates are specified in <u>microamperes</u>. One microampere is a flow rate of 1/1000 milliampere, or is a rate of 1/1,000,000 ampere.

SPEED OF ELECTRON FLOW

Contrary to popular belief, electrons flow very slowly in conductors. This is easily proven by a little arithmetic. You may follow the computations if you desire. Here they are:

The rules of the Fire Insurance Underwriters state that the maximum permissible flow rate in copper wire of number 14 gage is 15 amperes. This is a rate of 15 coulombs per second, or 900 coulombs per minute. Multiplying this number of coulombs by the number of electrons per coulomb shows that the flow rate per minute is 5,652,000,000,000,000,000,000 electrons.

Scientists say that there is approximately one free electron per atom in solid conductors. In a cubic inch of copper this means a number of free electrons equal to 64,500,000,000,000,000,000,000.

Then there will be our flow rate per minute, 5,652,000,000,000,000,000,000 electrons in 5,652/64500 cubic inch of wire. This volume of 14 gage wire will make a length of 27.15 inches (because the cross sectional area is 0.003225 square inch).

It follows that the maximum permissible rate of electron flow is 27.15 inches per minute, much less than one yard per minute, and a speed of only about one-half inch per second.

In view of this "crawl" of electrons in conductors, how does it happen that when you turn on a switch at one end of a room an electric lamp at the other end lights instantly? It happens because the action explained in connection with Fig. 25 occurs in the most minute fraction of a second throughout an entire circuit. So far as we can measure, the forces of attraction and repulsion act at the far end of a circuit during the same instant that they act in the near end, and electrons commence to move at the same instant in the whole circuit. But the electrons which are at one end to start their journey may take many minutes to get through the circuit.

This is like turning on the faucet at one end of a long hose which already is full of watef, as the conductofs are full of electrons. The instant that you open the faucet, water squirts from the far end of the hose, although it may be quite some time before watef originally at the faucet gets to the nozzle end of the hose.

What about electron speed in space; especially in a space which contains a vacuum such as inside of a radio tube? The answer is astonishing. Were there a complete vacuum inside the tube, were there no other elements between cathode and plate, and were the potential difference from cathode to plate to be, for example, 200 volts, the speed of electrons through the tube space would be about 1,640,000,000 feet per minute or 18,660,000 miles an hour.

In the tube pictured in Fig. 1 the distance from the cathode to the plate is about 5/16 inch. Were this tube operated undef the conditions specified in the preceding paragraph, it would take an electron less than one-billionth of one second to go from cathode to plate.

Often you heaf it said that electricity travels at the speed of light. We have seen that such a statement is far, far out of line when talking about electficity in conductors. Even in the tube we have discussed, the speed of the electrons is only about 1/36 of the speed of light. Radio waves in space do travel at the speed of light, but thefe are no electrons and no electricity in the radio waves that fly thfough space between transmitters and our feceiving antennas.

DIRECTION OF ELECTRIC FLOW

The mistaken ideas which are held by some people with feference to the speed of electron flow do no one in the fadio business any pafticular hafm -- so long as we ourselves hold the correct ideas. But there once was a mistaken idea that has femained to bother everyone in the fadio and electric businesses through all of the years that radio has existed. This is the idea that electficity, or the electric current, flows through an external circuit from the positive to the negative terminal of the source.

The only kind of electricity that can possibly move in solid conductors is electrons. Electrons, being negative charges, can move only from a negative charge (or terminal) to a positive chafge (or terminal) in a circuit external to a source.

Nothing can move the opposite direction.

The scientists who first concluded that electricity flows from positive to negative, in an external circuit, knew nothing about electrons and their actual behavior. Those men simply were mistaken in their conclusions. But before their mistake was discovered, a great electrical industry had grown up in the power and lighting divisions. All of the older text books, instructions books, circuit diagrams, and everything explaining electricity were based on a non-existant flow from positive to negative in those circuits. So electrical men talked about flow from positive to negative, even after they knew it is the reverse that is true. In the power and lighting branches of the electrical industry most men still talk that way, and instruction books are written that way.

To make things less confusing many people have tried explaining that the electric current flows from positive to negative while electrons flow from negative to positive, or they have explained that some electricity flows one way while other electricity flows the opposite way. There is no way of reconciling the two ideas, for one is correct and the other is incorrect-- a mistaken, outdated idea which we should ignore other than making allowances for those who still hold to it.

The flow of electrons or electricity in conductors and spaces usually is called the electric <u>current</u>. We have a current of electricity or electrons in conductors just as we have a current of water in rivers, pipes, and through space when the water comes from the nozzle of a hose. In later lessons we shall do a great deal of talking about electric current, and we always mean electron flow when we sa, current.

Since the electric current and electron flow are one and the same thing, and since electron flow always is from negative to positive in a circuit external to a source, the electric current always flows from negative to positive and never from positive to negative in such a circuit.