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AUTOMOTIVE DIESEL MAINTENANCE 2. UNIT XI, INTRODUCTION TO ELECTRICAL MAINTENANCE FOR OFF-HIGHWAY VEHICLES.

HUMAN ENGINEERING INSTITUTE, CLEVELAND, OHIO

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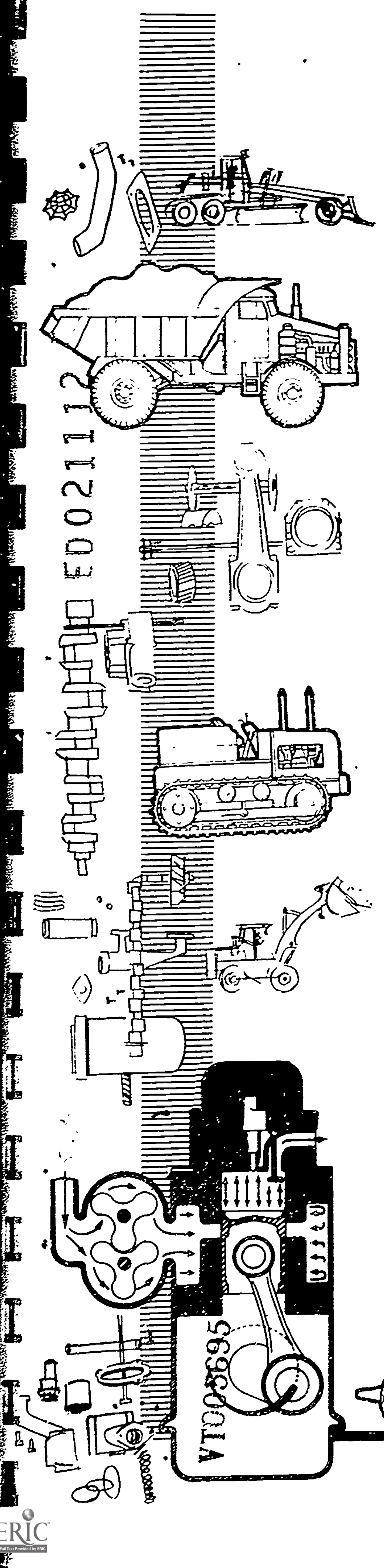
THIS MODULE OF A 25-MODULE COURSE IS DESIGNED TO FAMILIARIZE THE TRAINEE WITH THE FUNDAMENTALS OF ELECTRICITY AND MAGNETISM AS THEY RELATE TO DIESEL POWERED EQUIPMENT. TOPICS ARE (1) FUNDAMENTALS OF ELECTRICITY AND MAGNETISM, (2) ELECTROMAGNETIC FIELDS, (3) MAGNETIC FORCE ON A CONDUCTOR, (4) ELECTROMAGNETIC INDUCTION, (5) OHM'S LAW, (6) METER MOVEMENTS, AND (7) GLOSSARY OF TERMS. THE MODULE CONSISTS OF A SELF-INSTRUCTIONAL PROGRAMED TRAINING FILM "UNDERSTANDING THE FUNDAMENTALS OF ELECTRICITY AND MAGNETISM" AND OTHER MATERIALS. SEE VT 005 685 FOR FURTHER INFORMATION. MODULES IN THIS SERIES ARE AVAILABLE AS VT 005 685 - VT 005 709. MODULES FOR "AUTOMOTIVE DIESEL MAINTENANCE 1" ARE AVAILABLE AS VT 005 655 - VT 005 684. THE 2-YEAR PROGRAM OUTLINE FOR "AUTOMOTIVE DIESEL MAINTEMAMCE 1 AND 2" IS AVAILABLE AS VT 006 006. THE TEXT MATERIAL, PROGRAMED TRAINING FILM, AND THE ELECTRONIC TUTOR MAY BE RENTED (FOR $1.75 PER WEEK) OR PURCHASED FROM THE HUMAN ENGINEERING INSTITUTE, HEADQUARTERS AND DEVELOPMENT CENTER, 2341 CARNEGIE AVENUE, CLEVELAND, OHIO 44115. (HC)

STUDY AND READING MATERIALS



AUTOMOTIVE DIESEL MAINTENANCE 2

INTRODUCTION TO ELECTRICAL MAINTENANCE FOR OFF-HIGHWAY VEHICLES — UNIT XI

SECTION A	FUNDAMENTALS OF ELECTRICITY AND MAGNETISM
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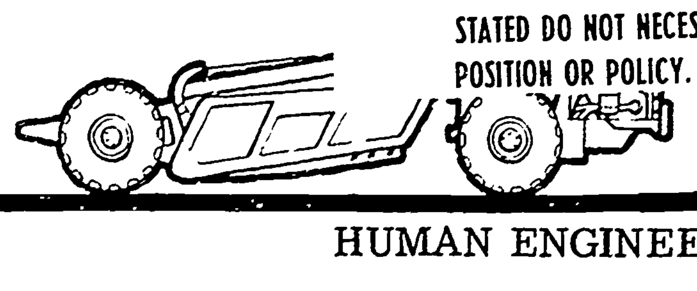


HUMAN ENGINEERING INSTITUTE

SECTION A -- FUNDAMENTALS OF ELECTRICITY AND MAGNETISM

If you are one of the automotive diesel electricians who understand fundamentals thoroughly and who have a good mental picture of the actions associated with the flow of current and magnetism, you are prepared to make your own analysis of new electrical equipment when it appears in the field. You will find that the new products merely employ new adaptations and arrangements of the fundamental principles with which you are already familiar, and you will be able to understand their operation. Without this knowledge, however, each new unit is a mystery, and the functions of each unit must be studied separately before any kind of service to the equipment can be offered.

Every unit of automotive diesel electrical equipment contains an electrical circuit through some kind of conductor. Most of the units also create a magnetic field either in air or some magnetic material. Generators, regulators, motors, coils, solenoids, and magnetic switches depend upon a proper use of electricity and magnetism for their operation. It is necessary, therefore, for those working with automotive electrical units to know something about the nature of electric current and magnetism in order to understand the design, operation, servicing and limitations of such equipment.

In recent years, scientists have developed a theory on the nature of electricity which has been widely accepted. This is known as the ELECTRON THEORY, and like any other theory, it is a statement which cannot be proved. It does, however explain more thoroughly than any other the observed behavior of the flow of electric current and magnetism.

It has been fairly well established that all matter is made up of tiny particles called MOLECULES and that molecules, in turn, are made up of two or more smaller particles called ATOMS. If we were to divide a drop of water in two and continue in the division until we got the smallest division possible that could still be called water, we would have a molecule of water. See Figures 1 and 2.

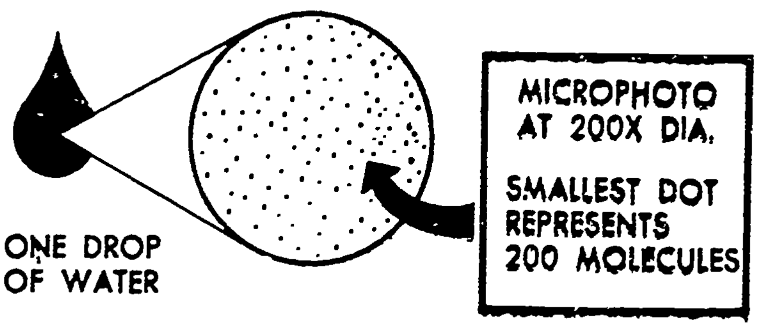


Figure 1

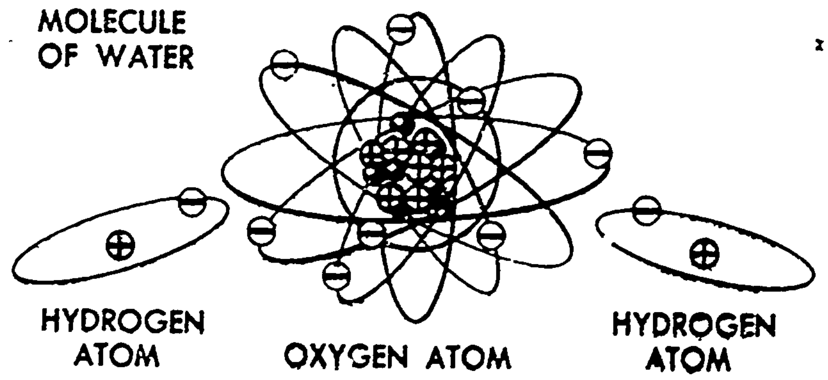


Figure 2

It is now believed that atoms themselves are still further divided into even smaller particles known as PROTONS, NEUTRONS, and ELECTRONS. These particles are the same in all matter, and the different properties of matter such as hardness, softness, toughness, fragility, liquid, solid, conductivity, non-conductivity, occur only because of the number and the arrangement of these particles. The proton has a small natural positive charge of electricity, whereas the electron has a negative charge. The neutron has no charge but adds weight to matter. See Figures 3 and 4.

Protons and neutrons form a center or nucleus in the atom much as the sun does in our solar system. Electrons rotate in orbits about the nucleus much as the Earth, Venus, Mars and other planets rotate about the sun. They carry the smallest known negative charge, and neutralize the positive charge of the protons.

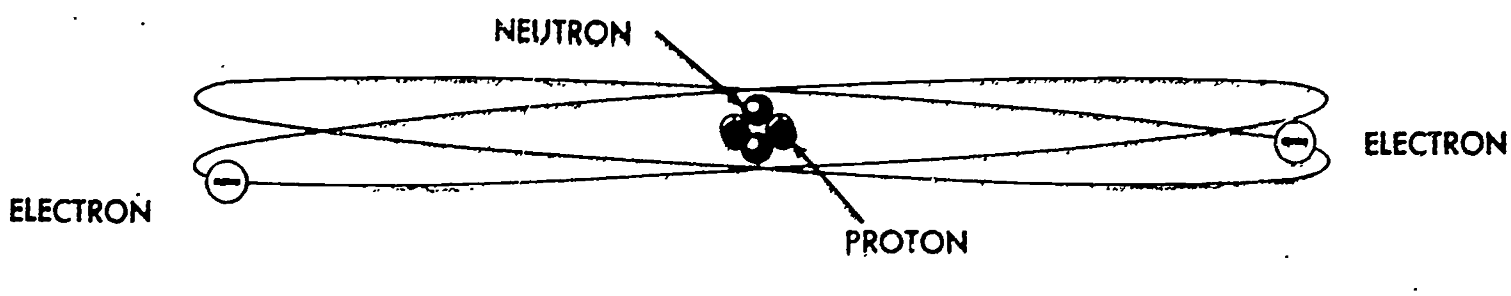


Figure 3

Any material which is composed of only one kind of atom is called an element. Hydrogen, iron, carbon and gold are elements. There are at present over one hundred known elements in the atomic scale, and each element differs from its neighbor by one additional proton and one additional electron. Uranium, for instance, has 92 protons and 92 electrons. It is number 92 in the atomic scale.

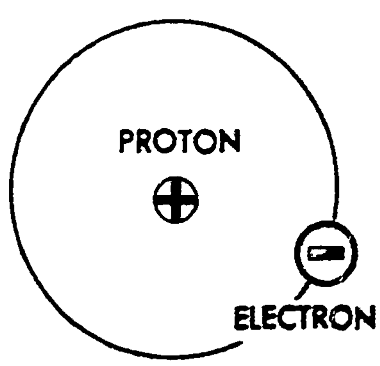


Figure 4

The HYDROGEN atom is the most simple of all atoms and is No. 1 in the atomic scale. It consists of ONE PROTON (positively charged body) and ONE ELECTRON (negatively charged body). See Figure 4. The electron moves in its orbit above the proton. This atom is used for comparison because of its simplicity.

To understand the electron theory, it is necessary that we visualize open space in materials which allow room for the movement of electrons. According to this theory, the ability of electrons to move about is the secret of electric current flow. Visualizing the existence of open space in all materials will go a long way in clearing up the mystery of electric current flow through what appears to be a solid.

From the standpoint of the automotive electrician, these thoughts should stand out: ELECTRONS ARE CHARGES OF ELECTRICITY; THEY ARE CONSTANTLY IN MOTION; THEY ARE VERY TINY PARTICLES; AND THEY HAVE A LOT OF ROOM IN WHICH TO MOVE. Actually, there is just as much room for electrons to move through solid copper wires as there is for water to flow through a pipe. See Figure 5. Until we were able to visualize the construction of matter, electricity was a complete mystery. The electron theory helps to understand why the flow of electricity is possible.

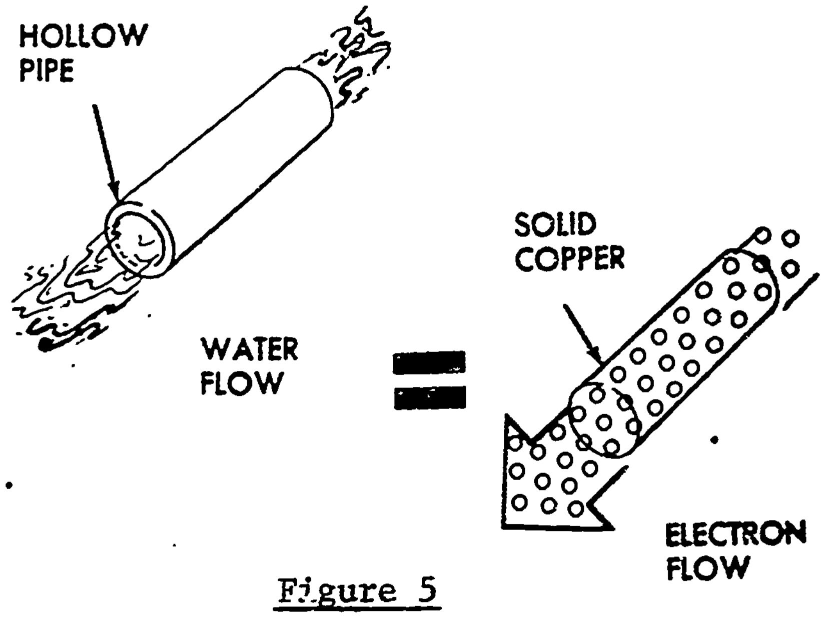


Figure 5

In the complicated atoms such as copper, iron or silicon, we find differences in construction which are important in considering electrical properties. The nucleus in most elements is composed of protons and neutrons. This nucleus is surrounded by closely held electrons which never leave the atom. These are said to be "bound" electrons; and where this type of electron predominates in an element or compound, the material is said to be an insulator or non-conductor. Glass and hard rubber are good illustrations of this kind of material.

In a few materials, the nucleus is surrounded by another group of electrons which under electrical stress (voltage) can be made to move from one atom to another. Electrons of this type are called "free" electrons. Materials having an abundance of free electrons are called conductors. Silver and copper are examples of this kind of material.

In the uncharged state each atom is neutralized with equal positive and negative charges, and the continuous electron movement is concentrated about each individual nucleus. With some disturbing force, such as an excess of electrons, in any part of a circuit, there is a drift of electrons from one atom to another. This drift we call a flow of current, and this is the basis of the present theory of electricity. When an atom loses an electron it will do the necessary amount of work to pull another electron from the next atom so as to keep in balance. The ability of atoms to do this is the secret of electric power. See Figure 6.

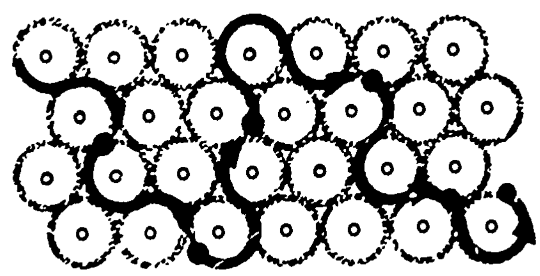


Figure 6

The speed of electricity is said to be 186,000 miles per second. From this we may get the idea that each electron travels from one end of the circuit to the other at this rate of speed. This is NOT the case, as the forward movement of electrons is no more than a drift. Free electrons, available due to overlapping electron orbits in conducting materials, are pulled from one atom to another and temporarily rotate about each new center.

The rate at which free electrons drift from atom to atom determines the amount of current flow. In order to create a drift of electrons through a circuit, it is necessary to have an electrical pressure called voltage.

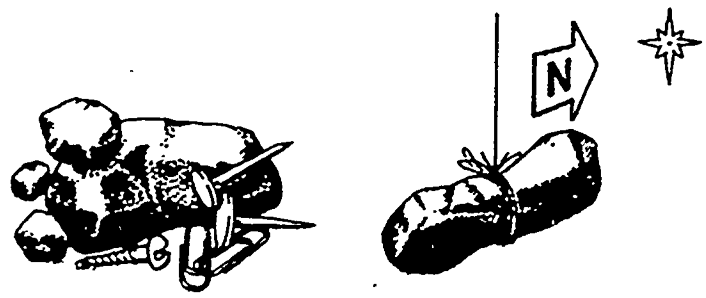
MAGNETISM -- Magnetism, like electricity, is still a mystery which cannot be thoroughly explained by present knowledge. It is always the things which we cannot see that are most difficult to understand. Pictures, however, help us to visualize activities when they are based upon sound known facts.

There are many known facts relating to magnetic forces and many known applications of magnetic principles which are responsible for the progress made in the electrical industry. Without the effects of magnetism there could be no generators or motors for charging batteries, cranking engines, and all the other uses to which generators and motors can be applied.

The effects of magnetism were first discovered when fragments of iron ore from certain parts of the world were found to attract each other and also to attract pieces of iron. It was further discovered that these fragments of ore pointed in the direction of the North Star when suspended in air. This principle became the basis for the first compass. The end of the piece of ore which pointed north was called the "north pole" and the other end the "south pole".

The space affected by a magnet is called a field of force. The extent of this field is determined by the strength of the magnet and can be explored by the use of a compass. It is common practice in illustration to show a field of force by lines which are called "lines of force".

Actually, there are no lines, but this is a convenient method of indicating the presence of invisible magnetic force. The number of lines of force which make up a field of force may be enormous.



In using the compass as a pointer in exploring a field of force, we may assume that lines of force have direction, leaving the north pole and traveling in a loop, returning and entering the south pole of the magnet. See Figure 7. This behavior is characteristic of all types of magnets. Because of this property of continuity, we speak of the paths through which lines of force flow as being magnetic circuits.

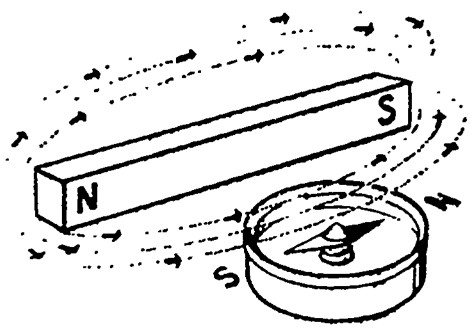


Figure 7

By stroking a piece of hardened steel with a natural magnet, it was found that the magnetic properties of the natural magnet were induced into the steel, which was then called an artificial or permanent magnet.

Most modern permanent magnets are made of special hardened steel alloys which retain their magnetic properties for a long time. These magnets obtain their original magnetism by being subjected to a strong electromagnetic field. Permanent magnets can be made to produce more concentrated fields by shortening the air gap between the north and the south poles of a magnet as in a "U" shaped or horseshoe magnet. See Figure 8. The smaller the air gap between the poles, the greater the concentration of the lines of force.

When two permanent magnets are so placed that the north pole on one and the south pole of the other are close together, they are found to attract each other. On the other hand, if the magnets are placed with their like poles

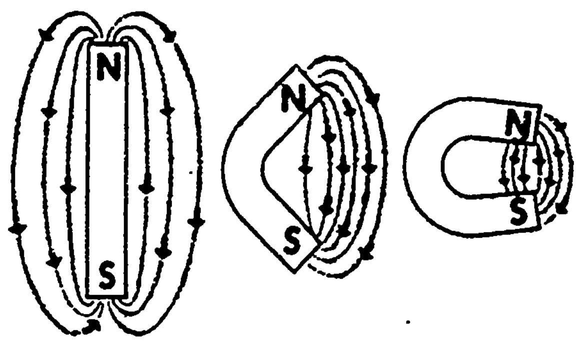


Figure 8

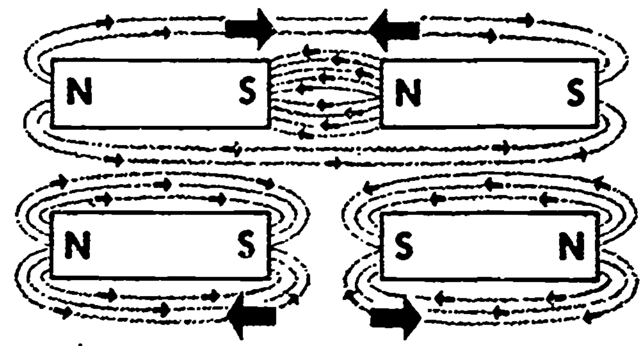


Figure 9

adjacent, they are found to repel each other. From these facts, we may state a fundamental law of magnetism: UNLIKE POLES ATTRACT EACH OTHER; LIKE POLES REPEL EACH OTHER. See Figure 9.

This fundamental law of magnetism makes it possible to use some rules for the concept of lines of force. We assume that lines leaving the north pole of one magnet will enter the south pole of an adjacent magnet, creating an attractive force, since all lines are in the same direction. On the same basis, we assume that lines leaving adjacent north poles, for instance, are repelled since they have opposite direction. "Lines of force never cross each other."

The Earth itself is now known to be a great magnet, with magnetic poles close to the geographical north and south poles. Since we call the pole of a compass, or the magnetic tip, which points to the geographical north, a "north pole", then the Earth's geographical north pole actually is a south magnetic pole. See Figure 10.

Magnetic lines of force seem to penetrate all substances and are deflected only by magnetic materials or by another magnetic field. From this we learn that there is no insulator for magnetism or for lines of force.

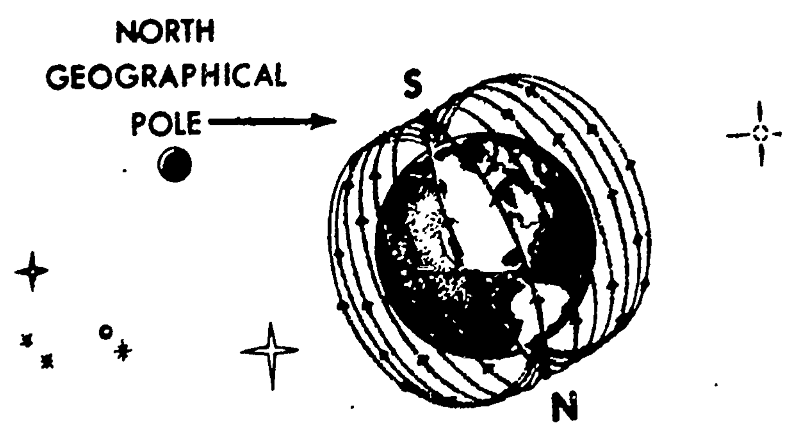


Figure 10

SECTION B -- ELECTROMAGNETIC FIELDS

The discovery that a magnetic field of force always exists around a conductor carrying electric current was responsible for most of the development of modern electrical equipment. Such a field of force always is at right angles to the conductor, as may be demonstrated by the attraction of a compass needle. See Figure 11. Since a magnetic force is the only force known to attract a compass needle, early investigators deduced that a flow of electric current produced a magnetic field similar to the field of a permanent magnet.

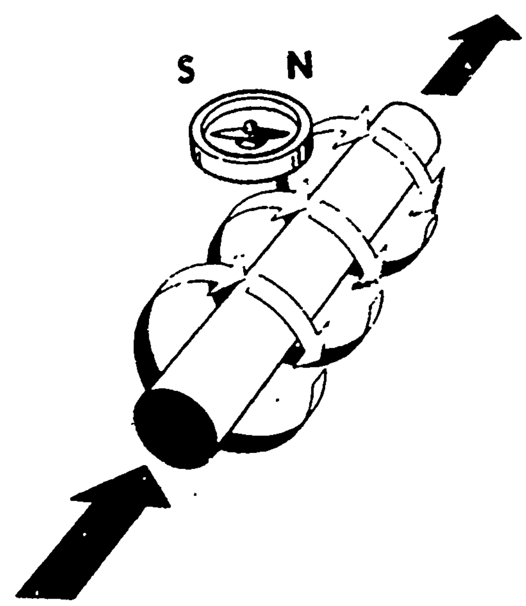


Figure 11

Further study, however, showed that these lines of force are concentric circles around the length of a straight conductor and that, in this respect, the field differs from that of a regular magnet. There are no magnetic poles in the conductor at which the lines of force can enter or leave. The greater the current flow, the stronger the magnetic field produced. The increase in the number of lines of force is in direct proportion to the increase in current, and the field is distributed along the full length of the conductor.

The direction of the lines of force around a conductor may be determined by a simple rule, when the direction of current flow is known. This convenient information is known as the "Right Hand Rule for determining the direction of lines of force around a straight conductor." This rule is based on the Conventional Current Flow theory which assumes that current flows from positive to negative. To apply this rule, grasp the insulated conductor with the right hand so that the thumb extends in the direction of current flow; then the fingers will point in the direction in which the lines of force surround the conductor. See Figure 12. By use of the compass, first determine the direction of the lines of force; the direction of current flow then may also be found by the same right hand rule.

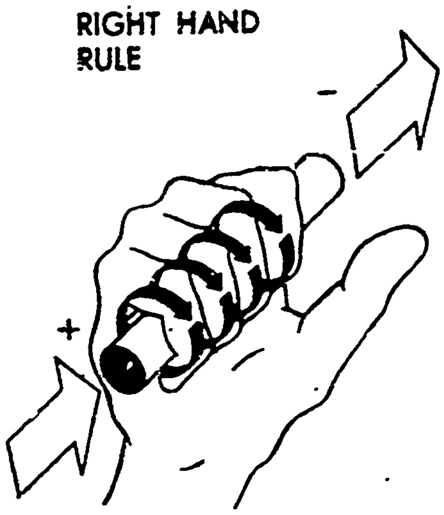


Figure 12

Figure 13

THE ELECTRON THEORY is based on the movement of electrons, as previously explained. To review briefly, the electron has a known negative charge and is light in weight compared to the proton, which has an equal positive charge. It is normal for the electrons to revolve at high speed in orbits about the proton. Under conditions of stress or voltage, free electrons in conductive materials drift through the material. The attractive force of the positive protons for the negative electrons tends to keep the atoms neutral. The drifting electrons represent current flow through the circuit. From these facts it is now generally accepted that electrons actually move from NEGATIVE TO POSITIVE. See Figure 13.

When the electron theory for the direction of current is used, however, the Left Hand Rule replaces the Right Hand Rule. With the left hand, grasp the conductor, so that the thumb extends in the direction of electron movement; then the fingers will point in the direction in which the lines of force surround the conductor. In either case, the direction of the lines of force remains the same and can always be determined by the use of a compass. See Figure 14.

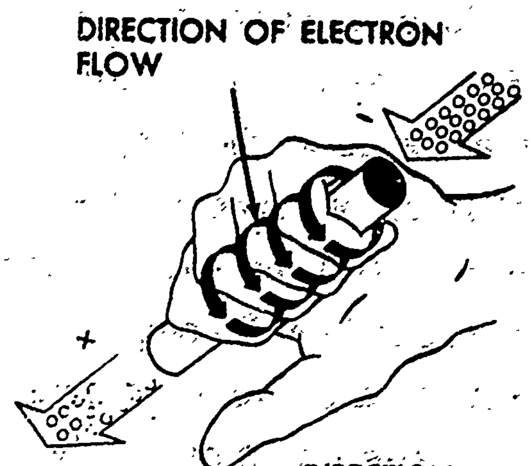


Figure 14

The lines of force, as expanding circles spread out into space, are not concentrated. The number of lines of force per unit area is called density. This density, therefore, is greatest at the surface of the conductor and decreases with the distance from the conductor. The number of lines of force created by a straight current-carrying conductor is directly proportional to the amount of current flowing in the conductor. When more current is allowed to flow, more lines of force are created, in direct proportion to the current.

The decrease in the number of lines of force per unit area is in inverse proportion to the distance from the conductor. At a distance of one inch from the conductor, for instance, there is one-half the density of force as there is at a distance of one-half inch. See Figure 15.

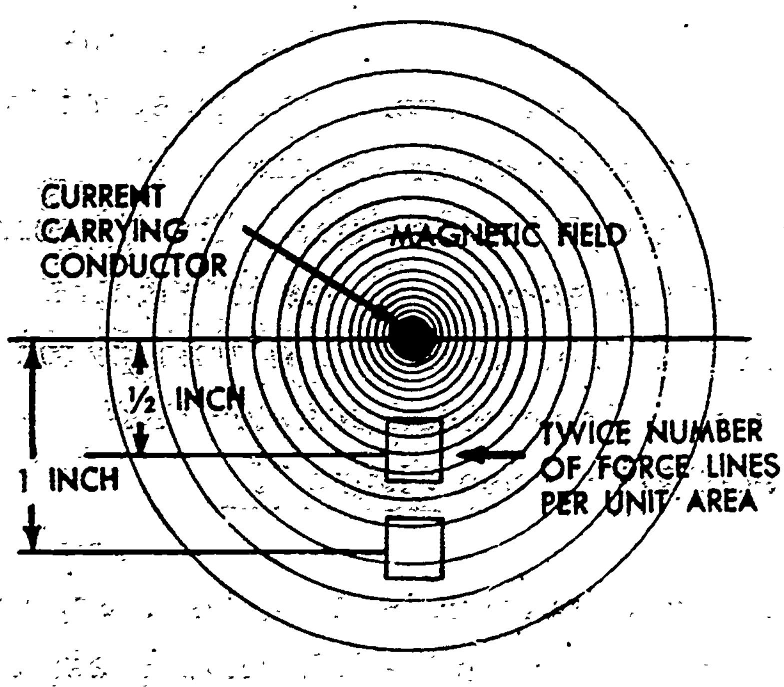


Figure 15

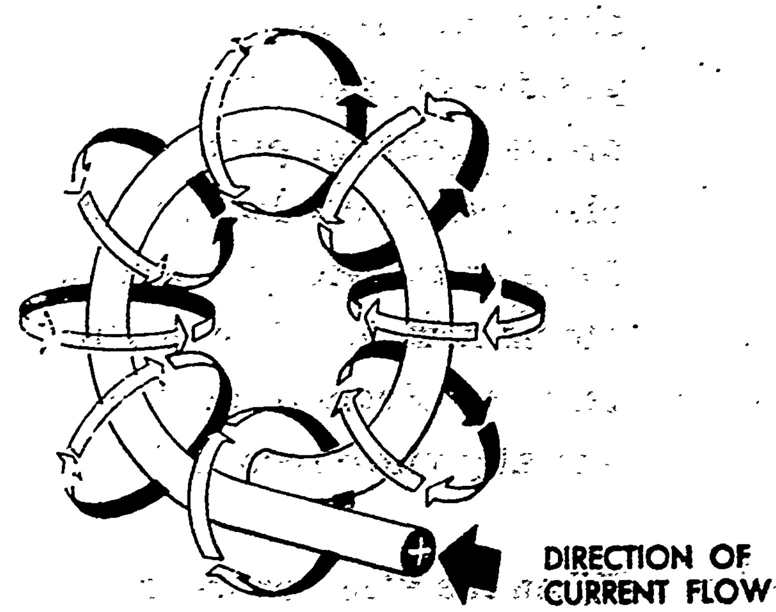


Figure 16

If a current-carrying conductor is formed into a single loop, all of the lines of force around the conductor must pass through the inside of the loop. The lines on the outside spread out into space as before, but the lines on the inside of the loop are confined, and increase the density of the number of lines of force in that area. See Figure 16. This creates a much greater effect with the same amount of current flow. In fact, it can be shown that current flow through the loop creates a magnetic field much the same as that of a permanent magnet. Exploration with a compass will indicate opposite poles on the two sides of the loop.

SECTION C -- MAGNETIC FORCE ON A CONDUCTOR

When a current-carrying conductor is located in a field of force created by either a permanent or electromagnet, there is a distortion of the normal lines of force between the poles. The reaction of the lines of force in the same direction join and make a stronger field. Lines of force in the opposite directions tend to cancel out and to create a weaker field. Under such conditions a movement of the conductor toward the weaker field is to be expected. See Figure 17.

Figure 17

Since the direction of current flow through a conductor determines the direction of the lines of force around the conductor, a movement in the opposite direction is obtained when the direction of current is reversed. With a conductor formed as illustrated in Figure 18, and current flowing into the left-hand side, the current will flow out of the right-hand side. In a permanent field with lines of force from right to left there will be a tendency for the conductor, if free to act, to turn in a clockwise direction, as indicated in Figure 19.

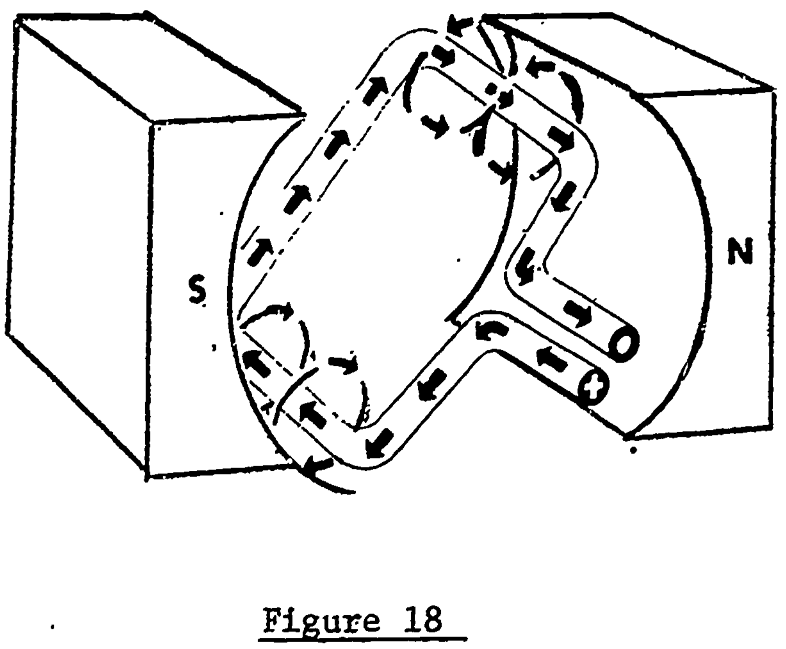


Figure 18

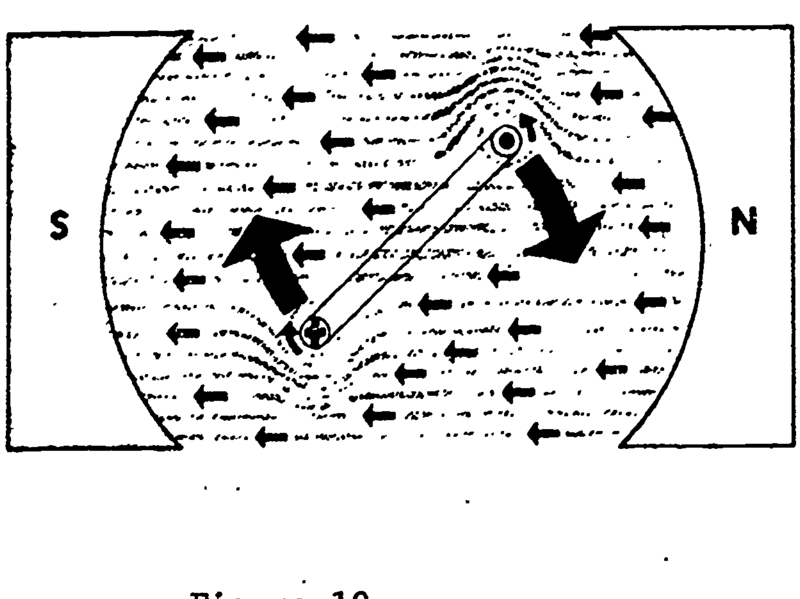


Figure 19

Current flow through the left-hand conductor creates a clockwise field around the conductor. The lines of force from the permanent magnet join with the lines of force below the conductor, and a strong field is produced. The lines of force from the permanent magnet oppose the lines of force above the conductor, and a weak field is produced. The result is an upward movement of the left-hand conductor. Since the current flow through the right-hand conductor is in the reverse direction, (toward the viewer) a counterclockwise field is created around the conductor. The lines of force from the permanent magnet join with the lines of force above the conductor, and the lines of force from the permanent magnet oppose the lines of force below the conductor. The field above the conductor is strengthened, the field below is weakened, and the conductor is pushed downward. By mounting this conductor on a shaft supported by bearings, we get a turning motion of the conductor. See Figure 19.

The design of many electrical units is nothing more than a practical application of these fundamental principles. The turning action principle is used in the construction of meter movements. A moveable coil, consisting of a number of turns of very fine wire wound around an aluminum frame, is mounted on jeweled bearings. Hairsprings keep the coil in a zero current position and react in direct proportion against the turning force when current flows in the coil. A pointer fixed to the coil gives a reading on a calibrated scale.

The same principle of turning force is used in cranking motors except that electromagnetic fields are used and the current value changes are greater. With very high current values, the forces produced by the conductors, while trying to move out of a strong field are enormous. Cranking motors, developing from one to forty horsepower produce this turning power by the action of a number of conductors pushing against pieces of insulation in the slots of the armature. The armature core, being made of a special grade of iron, reduces the air gap between the pole shoes, and a much greater magnetic field is created. The greater the magnetic field produced, the greater is the reaction.

With conductors wound around an iron core as in an armature, a magnet is created which would produce a north and a south pole in the core. The polarity would be in a direction to assist the turning effort; but the true turning force involves the conductor being forced out of a strong field into a weak field, as illustrated in Figure 19.

With an armature having 15 turns or hairpin coils assembled in a motor, there would be a turning force produced by 30 conductors. If each conductor produced one foot-pound push against the armature core, the cranking motor torque would be 30 foot-pounds.

With no provision for changing the direction of current flow when the left-hand conductor reaches the top, or when the conductor coil is located half-way between the pole shoes, there would be no movement of the conductor. See Figure 20.

A commutator is therefore required, to change the direction of current flow when the conductor reaches neutral, or the half-way point between the pole shoes, in order to maintain continuous motion. See Figure 21.

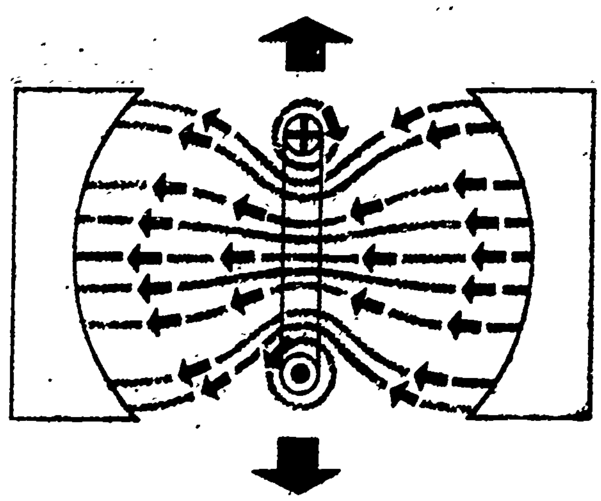


Figure 20

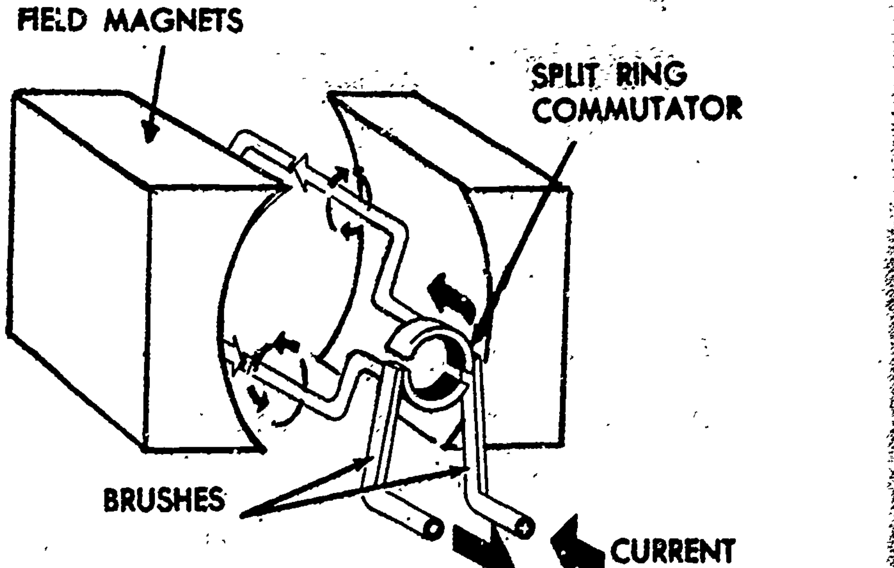


Figure 21 Current flow (constant)

SECTION D -- ELECTROMAGNETIC INDUCTION

The principle of electromagnetic induction is very important in automotive electricity; it is employed in three ways to produce voltage. For instance, voltage is developed by moving a conductor so that it cuts across magnetic lines of force as in a DC generator. The conductors are mounted in an armature, and the armature rotates through a magnetic field directed by stationary pole shoes. Voltage is created in the conductors as they pass through this magnetic field, and current will flow when an external circuit is completed.

When a conductor is forced to the RIGHT through a magnetic field, lines of force are cut or wrapped around the conductor on the leading side as illustrated in Figure 22. This induces a voltage in the conductor which would cause current to flow AWAY from the observer. Should the movement of the conductor be reversed (to the left), the lines of force building up on the leading side would induce voltage in the opposite direction, which would cause current to flow TOWARD the observer. See Figure 22.

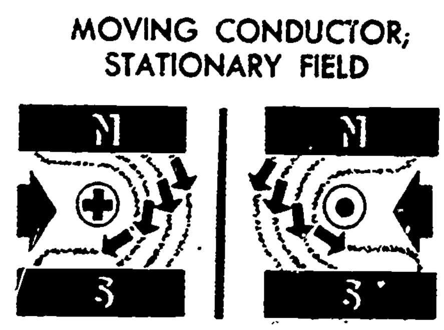


Figure 22

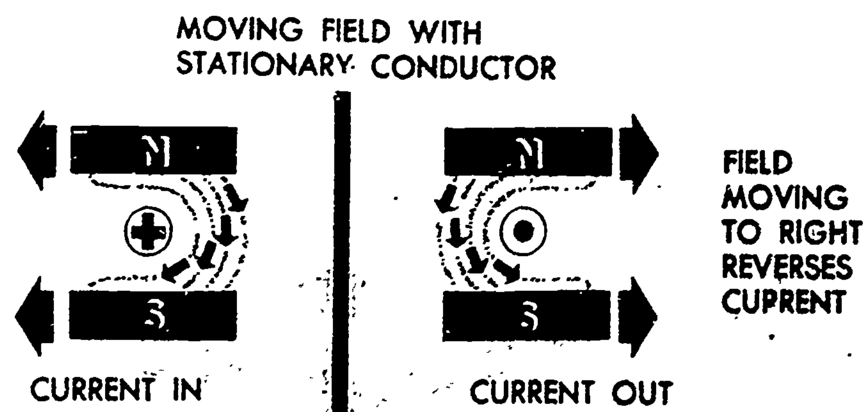


Figure 23

Alternating current generators, used in some applications, produce voltage in stationary conductors by rotating a magnetic field across them. Movement of a magnetic FIELD to the left, causes the lines of force to build up in such a direction that the induced voltage would cause current to flow away from the observer. Changing the field polarity or changing the direction of field motion will change the direction of current flow.

Mechanical motion of coils of wire through a magnetic field or mechanical motion of a magnetic field across stationary conductors produces voltage. It may be said that this voltage is "generated". There must be continuous rotation of these parts to enable a power plant to supply uninterrupted electrical power.

The third method of producing voltage may be considered pure electro-magnetic induction, since the voltage is not produced by moving parts, but by the change in the magnetic field. All parts remain stationary. The most common application of this principle is the transformer. Here, two stationary windings are placed over a common laminated steel core. One winding is excited by an alternating current source. Since both windings are linked together magnetically, a change in the magnetism produced by one winding will induce a voltage in the other. AC voltage generated in power plants may be stepped up by this transformer method for efficient long distance transmission of electrical power. Ignition coils operate on the same principle.

SECTION E -- OHM'S LAW

When a voltage exists across a conducting circuit there is a difference in electrical pressure. That voltage will result in a current flow or a drift of free electrons when a conductive path (complete circuit) is provided. This difference in electrical pressure is called "potential", "volts" or "electromotive force" (EMF). In the electron theory this might be called the "electron moving force".

Electric CURRENT flow is a direct result of an EMF and will continue as long as the EMF exists between the ends of a conductive circuit. The rate at which electrons pass a given point in a circuit is measured in amperes. An AMPERE can be defined as six billion two hundred eighty million billion electron charges passing a given point in one second.

When current flows through a conductor, the electron drift is slowed somewhat -- due to the fact that the free electrons which constitute current are constantly colliding with atoms. This opposition to the current flow is called RESISTANCE. The collisions of the moving electrons create heat. The unit of resistance is called the OHM, which is defined as the amount of resistance which will limit the current flow to one ampere when one volt of pressure is applied.

A very definite rule, known as OHM'S LAW, states that the electrical current through a conductor equals the pressure divided by the resistance, or:

$$\text{CURRENT} = \frac{\text{PRESSURE}}{\text{RESISTANCE}}$$

In electrical units this may be stated as $\text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$ or in symbols $I = \frac{E}{R}$. See Figure 24.

Another way of stating this law is to say that the current in a circuit is directly proportional to the voltage and is inversely proportional to the resistance. The three forms of Ohm's law allow the calculation of any unknown value where the two other values are known.

Ohm's law can be applied to an electrical circuit as a whole, or it can be applied to any part of the circuit. The amperes in the entire circuit equal the voltage across the entire circuit divided by the resistance of the entire circuit. The amperes in a certain section of a circuit equal the voltage across that part divided by the resistance of that part.

$I = \frac{E}{R}$	AMPERES	=	$\frac{\text{VOLTS}}{\text{OHMS}}$
$E = IR$	VOLTS	=	AMPERES X OHMS
$R = \frac{E}{I}$	OHMS	=	$\frac{\text{VOLTS}}{\text{AMPERES}}$

Figure 24 Ohm's law

VOLTAGE DROP -- With current flowing, the voltage difference across a resistor, or a piece of electrical equipment, or even a section of live wire, is called the voltage drop and is found by a direct application of Ohm's law, E = IR. The total voltage drop in a circuit is always equal to the potential of the source. Voltage drop, in other words, is voltage.

Ohm's law is one of the few rules which the automotive, truck and off-highway electrician must understand in order to acquire a working knowledge of how electric current will flow through the various branches of a circuit. Additional study and solving of Ohm's law problems will help you to gain this knowledge.

CIRCUITS -- A circuit is a closed path for the flow of electricity, with a difference in electrical pressure or voltage being the starting point or motivating force. No circuit is completely defined until the conducting path has been traced back to the starting point where the voltage originates.

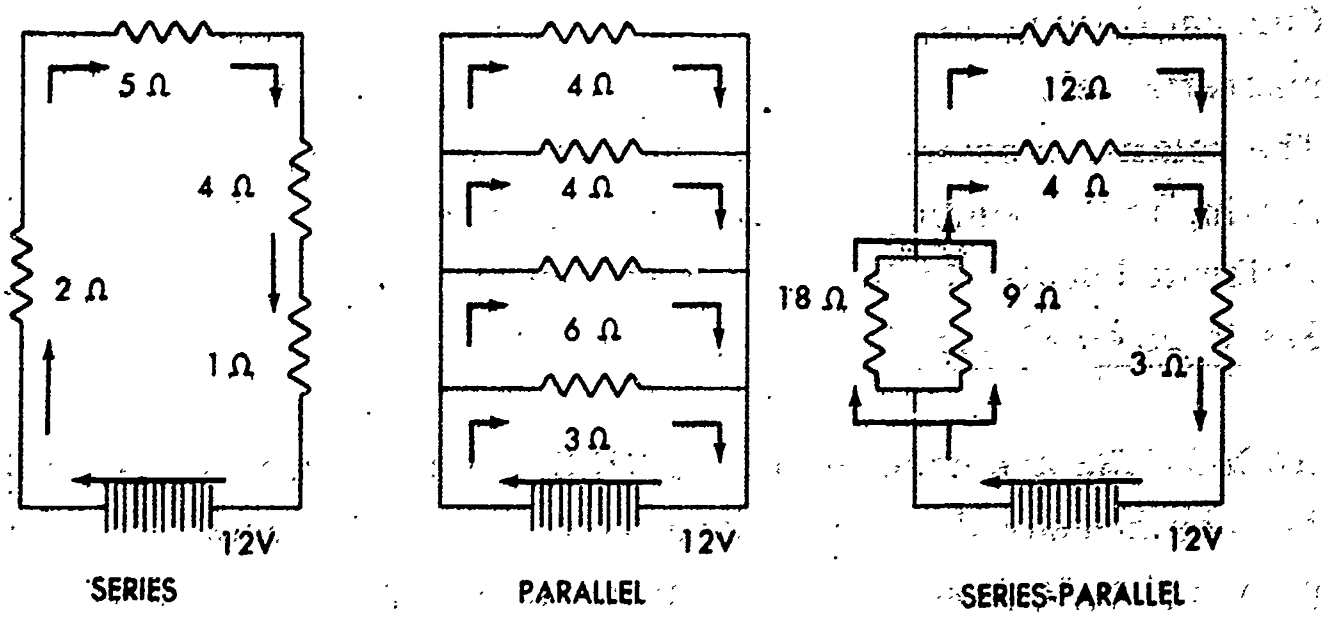


Figure 25 Circuits

Series circuits are those which have only one path in which the current can flow. A break or opening stops the flow of current in the entire circuit. Parallel circuits are those which have more than one path in which the current can flow. In such circuits one terminal of each device is connected to one common conductor and the remaining terminals to another common conductor. Series-parallel circuits are those which have some devices connected in series, while other devices are connected in parallel.

SECTION F -- METER MOVEMENTS

Diagnosing troubles in the electrical system is one of the more important duties of the automotive electrician. With proper instruments connected in the circuit he must be able to determine whether changes in adjustments are required, whether the system is performing satisfactorily, or whether a specific unit or part needs repairs or replacement. Of course, the accuracy of the readings will depend upon the accuracy of the meters used. If a choice is available, greater accuracy is desired in the voltmeter than in the ammeter.

Most modern meter movements are of the moving-coil type which consists of a permanent horseshoe or hoop-shaped magnet and a moveable coil. Current flowing through the moveable coil reacts with the permanent magnetic field, causing the coil to rotate against the light spring tension. The relative movement of the coil is in proportion to the amount of current flowing in the windings. A pointer attached to the coil moves across a calibrated scale, indicating the amount of current flowing in the coil. See Figures 27 and 28.

AMMETERS are connected in SERIES with the circuit in which the current is to be measured. Where necessary, external shunts (resistances) are provided so that only a small, proportional, part of the total current passes through the instrument. Ammeters are low resistance meters. See Figure 26.

VOLTMETERS are connected ACROSS the circuit (in parallel). They must have a very high resistance so that the small amount of current they take will not disturb the circuit. The voltage of a circuit should be essentially the same after a voltmeter is connected across the circuit as it was before.

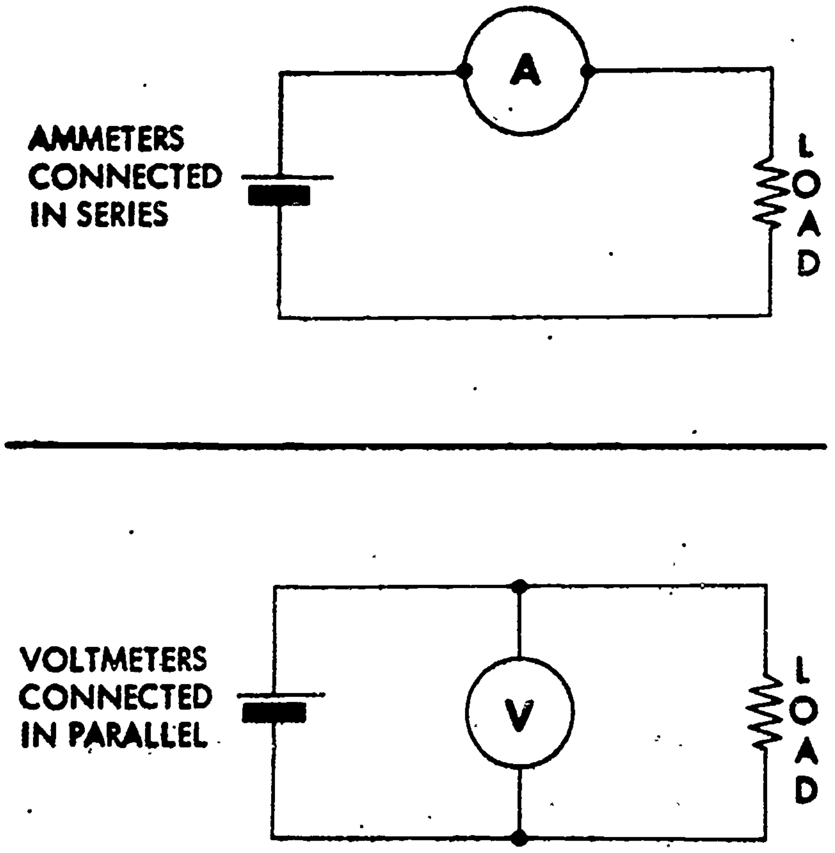


Figure 26 Meter circuits

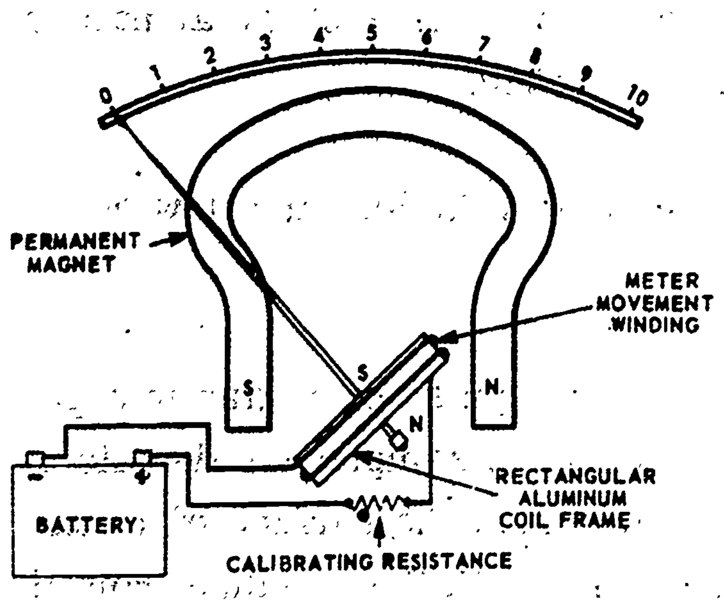


Figure 27 Meter movements

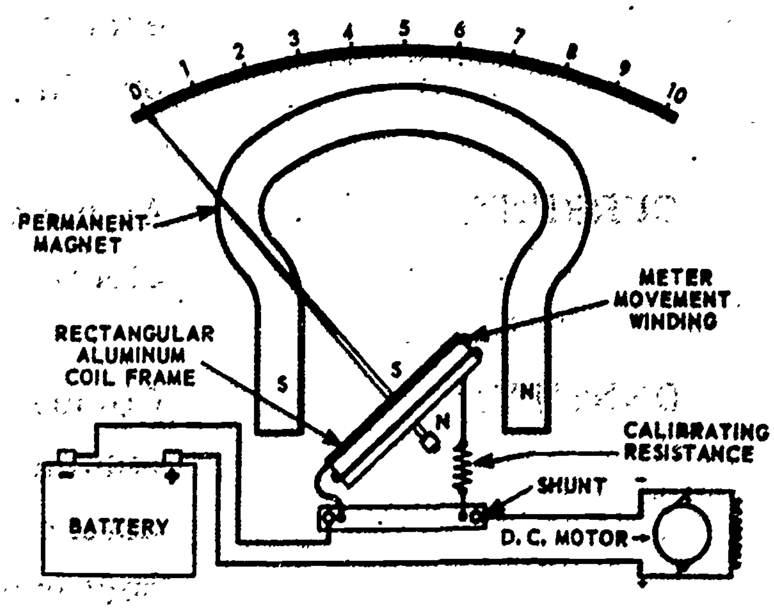


Figure 28 Meter movements

SECTION G -- GLOSSARY OF TERMS

ATOM:	The smallest particle of an element, now believed to be further divided into even smaller particles known as protons, neutrons and electrons.
AMMETER:	An instrument used for measuring the flow of an electric current.
AMPERE:	The unit of measurement for the flow of electric current.
AIR GAP:	The space between motor and generator fields, pole shoes, and the North and South poles of a magnet.
CIRCUIT:	The path of electrical current, a wire or other conductor such as vehicle frame or engine block.
COMMUTATOR:	A ring of adjacent copper bars insulated from each other, to which the wires of the armature or windings are attached.
CURRENT:	As used in automotive vehicles, the flow of electricity.
DENSITY:	Compactness; relative mass of matter in a given volume, or unit area. Example: the density of magnetism is greatest at the surface of a conductor and decreases with the distance from the conductor.

EMF: ElectroMotive Force or voltage. The difference in electrical pressure between two sides of a circuit or a circuit element.

FIELD OF FORCE: The space affected by a magnet is called a field of force. In illustration, it is shown by lines which are called lines of force.

ELECTRON THEORY: With some disturbing force (voltage) in any part of a circuit, there is a drift of electrons from one atom to another. This drift we call a flow of current, from negative to positive. This is the basis of the present theory of electricity.

CURRENT THEORY: This rule is based on the theory which assumes that current flows from positive to negative.

OHM: A unit of measurement of the resistance to the flow of electricity through a conductor.

POLARITY: Refers to the positive or negative terminal of a battery or an electric circuit; also the north and south poles of a magnet.

SERIES WINDING: Or series circuit, an electrical winding or coil of wire in series with other electrical equipment.

PARALLEL CIRCUIT: A circuit which has more than one path in which current can flow.

SERIES-PARALLEL: Circuits which have some devices connected in series, while others are connected in parallel.

TERMINAL: A junction point where connections are made, such as the terminal fitting on the end of a wire.

TRANSFORMER: An electrical device, such as a high tension coil, which transforms or changes the characteristics of an electrical current.

VOLT: A unit of electrical force which will cause a current of one ampere to flow through a resistance of one ohm.

VOLT-METER: An instrument for measuring the voltage in an electrical circuit.

DIDACTOR PLATES FOR AM 2-11D

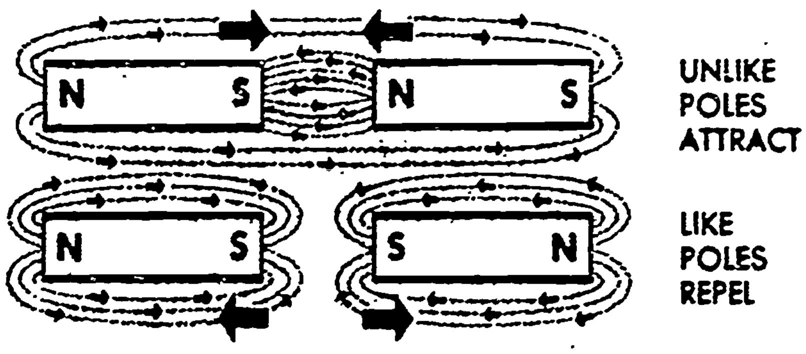


Plate I

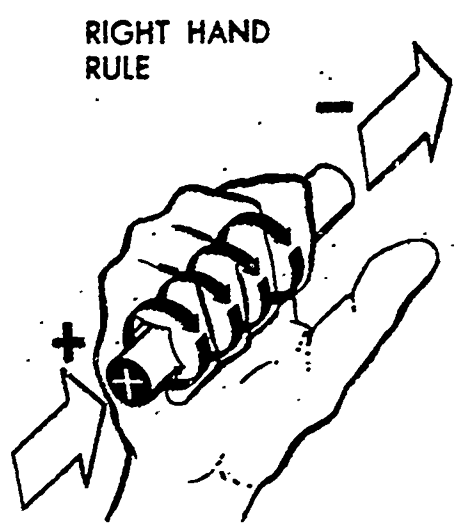


Plate II

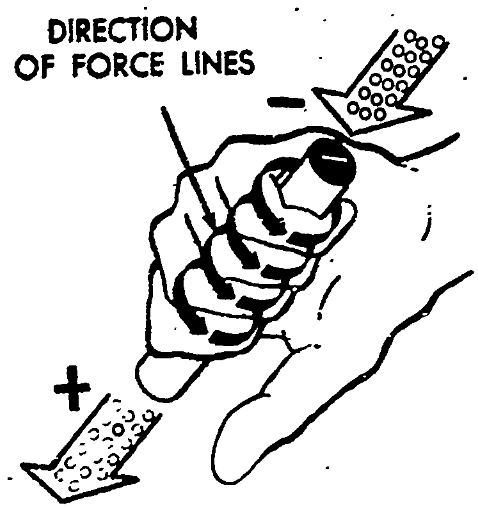


Plate III

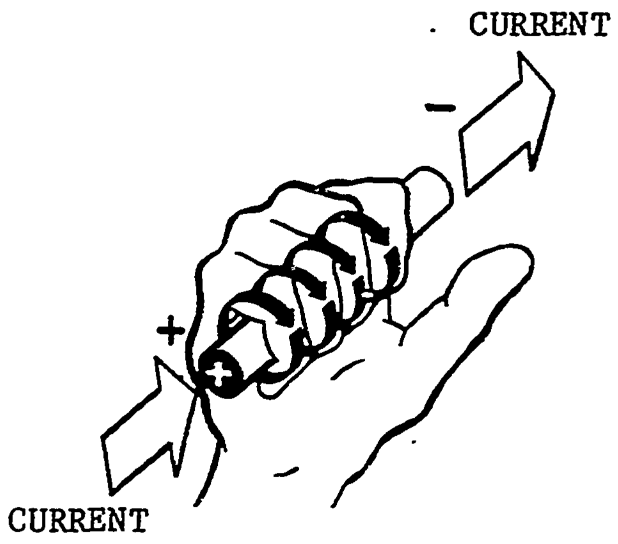


Plate IV Right hand rule (conventional current flow)

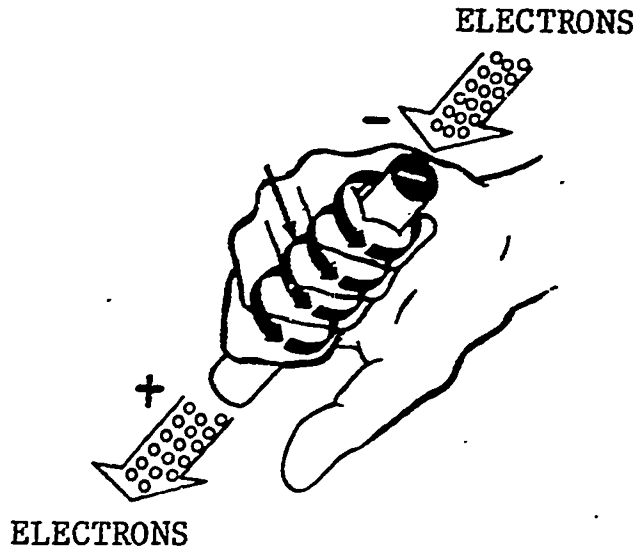


Plate V Left hand rule (electron flow)

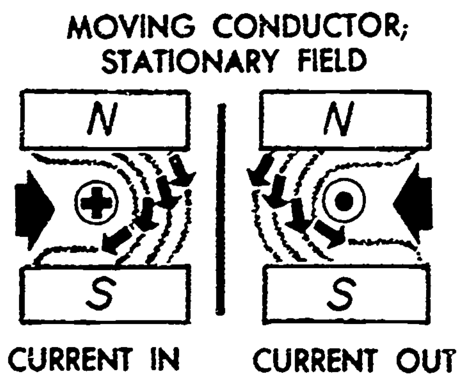


Plate VI Principle of D.C. generator

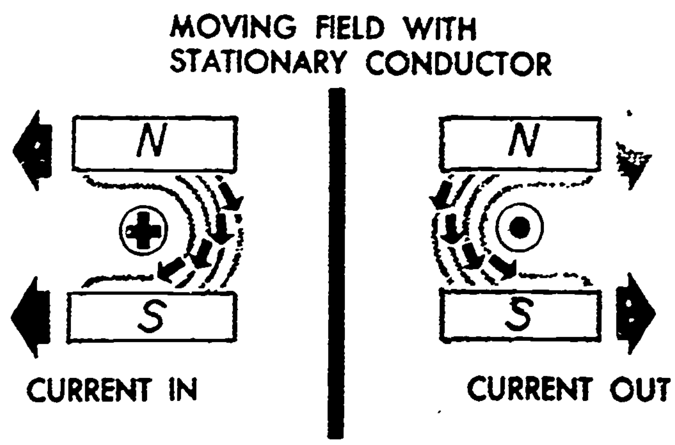
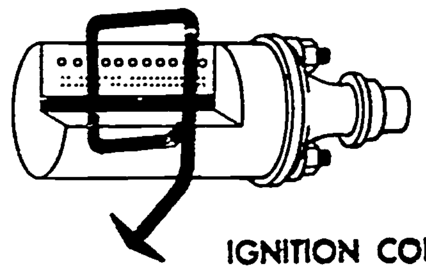


Plate VII Principle of A.C. generator (Alternator)



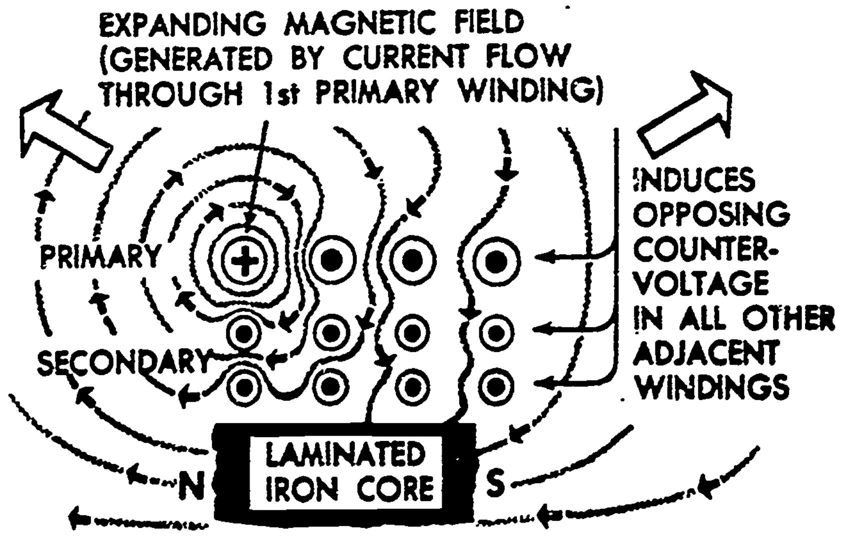


Fig. 1

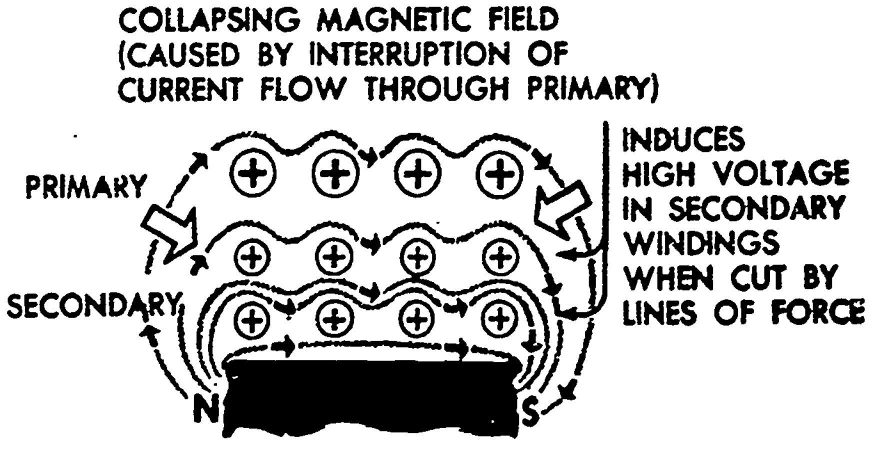


Fig. 2

Plate VIII Principle of ignition coil

0

AM 2-11D
9/6/67

UNDERSTANDING THE FUNDAMENTALS OF
ELECTRICITY AND MAGNETISM

Human Engineering Institute

Minn. State Dept. of Ed. Vocational Education

Press A 1 Check to see that timer is OFF.

1

This film is the first in a series in which we will cover information useful in the maintenance of the ELECTRICAL SYSTEMS of off-highway equipment.

In this film we will begin with a study of the composition of matter, then we will learn about some of the basic principles of electricity and magnetism.

Press A 2 1-1

2

In order to understand the fundamental principles of electricity and magnetism, it will help first to understand some basic ideas about the composition of matter.

All of the thousands of kinds of materials in the world are made up of various combinations of simple substances called ELEMENTS.

Press A 3 1-2

3

Some of the elements we are familiar with are hydrogen, oxygen, nitrogen, carbon, iron, copper, lead and sulfur. There are over one hundred elements known today.

The smallest particle of an element that still can be identified as that element is the ATOM. Atoms are extremely small particles -- an ordinary penny is about six million atoms thick!

Press A 4 1-3

4

Atoms of various materials combine to form MOLECULES.

A molecule is the smallest particle of a chemical compound. For example:

The smallest particle of iron (an element) that can exist is the iron ____(1)____. The smallest particle of salt (a compound) that can exist is the salt ____(2)____.

A. (1) molecule (2) atom 5
B. (1) atom (2) molecule 6

1-4

5

You are incorrect.

Since iron is one of the elements, the smallest particle of iron that can exist is the iron ATOM.

Common salt, on the other hand, is a compound made up of two different elements -- sodium and chlorine. The smallest particle of salt that can exist is the salt MOLECULE, sodium chloride.

Press A 6 1-5

6

OK.

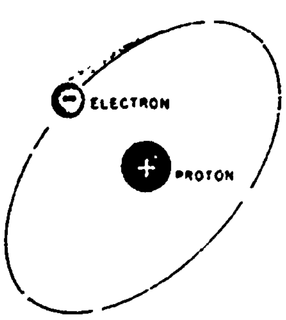
Compounds are substances that are made up of two or more elements, chemically combined.

It is now generally believed that the atoms which make up the elements consist of combinations of three still smaller particles. These particles are so different from anything we normally think of that it is difficult to picture them in our minds.

Press A 7 1-6

7

Of all known atoms, the HYDROGEN atom is the simplest.



It consists of a single positively charged particle in the center, with one negatively charged particle whizzing around it in orbit at fantastic speed.

Press A 8 1-7

8

Other atoms are, of course, more complex than the hydrogen atom. But they are all made up of various combinations of particles.

A positively charged atomic particle is known as a PROTON.

A negatively charged atomic particle is called an ELECTRON.

Press A 7

1-8

9

Atoms other than the hydrogen atom also contain varying numbers of a third particle called a NEUTRON.

As you might guess from the name, a neutron has no electrical charge -- it is electrically neutral.

Which particle has a positive charge?

A. neutron 10
B. electron 10
C. proton 11

1-9

10

You are incorrect.

We are looking for the name of the atomic particle which has a POSITIVE charge.

Take another look at the two frames preceding the question; then try it again.

Press A 7

1-10

11

Good.

In an atom the ___(1)___ carries a negative charge, while the ___(2)___ has no electrical charge.

A. (1) electron (2) neutron 14
B. (1) proton (2) neutron 12
C. (1) neutron (2) electron 13

1-11

12

Not quite.

You are right about the second part -- the neutron has no electrical charge.

But you said that the proton carries a negative charge. That is not true.

The particle which carries a negative charge is the ELECTRON.

Press A 14

1-12

13

You have the answers reversed.

The correct statements are:

The ELECTRON carries a negative charge, while the NEUTRON has no electrical charge.

Press A 14

1-13

14

OK.

The particle we are primarily interested in here is the electron. The ability of the electron to move about is what seems to offer the most practical explanation as to how electric current flows.

Press A 16

X(c)- 15

2-14

15

OK.

Before we go on, let's have a quick review of what we've covered so far, since you had trouble with a question or two.

Answer all the questions correctly and then we'll learn more about electrons.

Press A 2

1-15

16

Although the smallness of the atom is almost impossible to conceive, we must get an idea of the relative distance between the nucleus (center) and the orbiting electrons.

One explanation often given is this: Think of the center of the atom as being located in Kansas City.

Press A 17

2-16

17

Now, keeping everything in proper proportion, the electrons whirling around the nucleus would rotate in a large orbital path which would carry them over San Francisco in the West and New York City in the East.

Another way to think of it is to imagine the vast spaces between our Sun and its orbiting planets.

Press A 18

2-17

18

Relatively speaking, electrons have ______________ in which to move about.

A. very little room 19

B. quite a lot of room 20

2-18

19

Incorrect.

Even though an atom is an extremely small thing, the electrons have (relatively speaking) vast amounts of room in which to move about.

Press A 20

2-19

20

OK.

From the standpoint of the Automotive Diesel electrician, these points are extremely important:

Electrons are charges of electricity.
They are constantly in motion.
They are very tiny particles.
They have a lot of room in which to move.

Press A 21

2-20

21

If we could examine the electron arrangements in all the different kinds of atoms, we would find that the electrons are arranged in "shells" or layers surrounding the nucleus.

The force of attraction between the positively charged protons in the nucleus and the negatively charged orbiting electrons is what keeps the electrons in these "shells."

Press A 22

2-21

22

The nucleus of an atom is surrounded by some closely held electrons which never leave the atom. These are called "bound" electrons.

When this type of electron predominates in an element or a compound, that substance is known as a good insulator or NON-CONDUCTOR. These are classed as non-metallic substances.

Press A 23

2-22

23

In other atoms, the electrons in the outermost shell are "shielded" from the nucleus by one or more inner shells of electrons.

Under electrical stress (voltage) these electrons can be made to move from atom to atom. These are called "free" electrons.

Substances with an excess of free electrons are known as CONDUCTORS and are classed as metals.

Press A 24

2-23

24

Glass and hard rubber are two compounds made up of molecules in which "bound" electrons predominate.

Materials of this type are typically ________ conductors of electricity.

A. good 25
B. poor 26
C. only fair 25

2-24

25

You are incorrect.

Materials that consist of atoms and molecules with predominately "bound" electrons are typically POOR conductors of electricity. Their outermost electron shells are relatively stable. Their electrons are not easily lost.

Press A 26

2-25

26

OK.
Materials such as silver, copper and aluminum are excellent conductors of electricity. Their outermost electron shells contain predominantly ____(1)____ electrons, and these electrons are relatively ____(2)____ to displace.

A. (1) "free" (2) hard 27
B. (1) "free" (2) easy 29
C. (1) "bound" (2) hard 28
D. (1) "bound" (2) easy 27

2-26

27

Only part of your answer is correct.

Silver, copper and aluminum conduct electricity well. This means that they have outer electron shells which will give up electrons easily.

What do we call such electrons?

Try the question again.

Press A 26

2-27

28

No. Remember what we have said -- the atoms in poor conductors of electricity consist of predominantly "bound" electrons, which are relatively difficult to displace.

In the question, we asked about silver, copper and aluminum -- good conductors.

What do we know about their electrons? Try the question again. Press A 26

2-28

29

Good.

Electrical energy is transferred through conductors by the movement of free electrons which move from atom to atom inside the conductor. Each electron moves a short distance to a neighboring atom where it displaces one or more electrons, which move on and repeat this process throughout the length of the conductor.

Press A 30

2-29

30

Under the application of a given electrical force, the greater the number of electrons that can be made to move through a material, the ________ a conductor it is said to be.

A. better 32
B. poorer 31

2-30

31

Incorrect.

Under a given force (of electrical pressure), the more electrons which can be made to move through a material, the BETTER are its properties as a conductor.

Press A 32

2-31

32

OK.

Even today we do not fully understand the fundamental nature of electricity. The explanation we have offered here as to what makes a current flow is merely an application of the ELECTRON THEORY.

If you would like to review this section on ELECTRONS, press A. 16
Otherwise, press B. 34

X(c)-33

3-32

33

OK.

Since you made an error or two on the questions in this section, let's have a quick review.

When you answer all the questions correctly, we will examine more fundamentals of electricity.

Press A 16

2-33

34

In dealing with any useful commodity, there must be some way of measuring and keeping track of it. The same is true of the flow of electrons.

Electron flow is electric current.

There are three basic measurements of electron flow that every Automotive Diesel electrician needs to understand.

Press A 35

3-34

35

The three basic measures of electric current (electron) flow are these:

1. The rate of flow of electrons.
2. The force or pressure which makes them flow.
3. The opposition to their flow.

Let's look at these one at a time.

Press A 36

3-35

36

THE RATE OF FLOW OF ELECTRONS

We are primarily concerned here with the quantity rate of flow of electrons, rather than their speed. A quantity rate is, for example, "gallons per minute" (of water or gasoline) or "cubic feet per minute" (of air or natural gas).

Press A 37

3-36

37

We need a measure of quantity to start with. If we were to use the number of electrons per second flowing past a given point, the numbers would be so huge that few of us could handle them.

So we lump the huge number of electrons together, like potatoes into bushels, and find that we measure the rate of electron flow in COULOMBS per second.

Press A 38

3-37

38

A COULOMB equals 6,280,000,000,000,000,000 electrons passing a given point in one second.

We seldom hear "coulombs per second" because there is an even simpler way to express this quantity. The term is AMPERE.

One AMPERE is an electron flow rate of one coulomb per second.

Press A 39

3-38

39

How many amperes (amps) of current would be flowing in a circuit where the rate of electron flow was 15 coulombs per second?

A. 30 amperes 40
B. 7.5 amperes 40
C. 15 amperes 41

3-39

40

You are incorrect.

We defined one AMPERE as being equal to the flow of ONE coulomb per second.

In a circuit where the flow rate is 15 coulombs per second, the amperage would be 15 times 1, or 15 AMPERES.

Press A 41

3-40

41

OK.
One coulomb per second is the same as one ampere.

Now let's take a look at the force that moves the electrons. In order to make electrons behave in a useful way, they usually must be pushed through a conductor.

Press A 42

3-41

42

VOLTAGE -- THE FORCE OR PRESSURE THAT MOVES ELECTRONS

In order to be useful, electrons must be forced to flow in one direction through a conductive circuit. The force or push which is applied to them has been given various names. One is ELECTROMOTIVE FORCE (emf).

Press A 43

3-42

43

Emf (electromotive force) is sometimes called "electrical pressure" because it is similar to the pressure needed to make water flow through a pipe, or air through a duct.

Electrical pressure (emf) is measured in VOLTS.

Press A 44

3-43

44

VOLTAGE means the same as "electrical pressure" or emf.

Just as increased water pressure will cause more water to flow through a pipe, increased voltage will cause a greater electron flow in an electrical circuit.

Press A 45

3-44

45

Electrical "pressure" or emf is measured in ______________.

A. coulombs per second 46
B. volts 47
C. amperes 46

3-45

46

Incorrect.

Coulombs per second (amperes) is the measure of rate of electron flow.

Electrical pressure (emf) is measured in VOLTS.

Press A 47

3-46

47

OK.
Once they are set in motion, electrons do not continue to flow forever. Like a baseball moving through the air, or a boat through water, electrons meet opposition to their movement.

This friction-like opposition is called ELECTRICAL RESISTANCE.

Press A 48

3-47

48

Electrical resistance is thought to be due to the action of electrons moving through a conductor, colliding with the many atoms of the conducting material as they pass through.

Materials which offer the highest resistance to electron flow are the best insulators. Those with the lowest resistance are the best conductors.

Press A 49

3-48

49

The unit of measure of electrical resistance is the OHM.

One ohm is defined as the amount of resistance which permits a steady current of one ampere to flow when a steady emf of one volt is applied.

Press A 50

3-49

50

If the resistance in an electrical circuit is ONE ohm, it will require ________ volt(s) of electrical pressure to maintain one ampere of current flow.

A. ten 51
B. one hundred 51
C. one 52

3-50

51

You are incorrect.

Keep in mind that we already know that the resistance in this circuit is one ohm.

Take another look at the definition of an ohm and then try the question again. Think carefully.

Press A 49

3-51

52

Good.

This, of course, was a hypothetical problem. But in reality what you have just done is to solve one form of the most fundamental problem involving Ohm's law.

If you want to review the three basic measures of electron flow, press A. 34

Otherwise, press B. 54

4-52

53

Good.

Since you had some trouble with one or two of the questions in this section, let's have a review now.

The concepts of the ampere, the volt, and the ohm are vital to your understanding of vehicle electrical maintenance. Review this section carefully.

Press A 34

3-53

54

Of the various means of producing an electric current, currents produced by magnetism are among the most useful and important.

Magnetism remains largely a mystery today, much the same as electricity. But as with electricity, we can learn about some of the useful effects of this potent force and learn how they are applied.

Press A 55

4-54

55

Magnetic force is responsible for the operation of much of our modern industrial equipment. Without it there would be no motors, generators, measuring instruments, transformers, nor any of a great number of other electrical control devices in use today.

A MAGNET is a piece of material which attracts iron and steel and other materials such as nickel, cobalt and certain other minerals and alloys.

Press A 56

4-55

56

The force of a magnet is strongest at two spots known as the POLES of the magnet.

In a simple bar magnet, the poles are at either end. In a "horseshoe" magnet the poles are closer together, since the magnet is U-shaped.

The two poles of a magnet are known as the NORTH pole and the SOUTH pole.

Press A 57

4-56

57

When you place the NORTH pole (N pole) of one bar magnet close to the NORTH pole (N pole) of another bar magnet, the NORTH poles tend to _______________.

A. be drawn toward each other 58
B. be pushed away from each other 59

4-57

58

You are incorrect.

If you place the two NORTH poles close together, they will tend to be pushed away or repelled from each other.

Press A 59

4-58

59

OK.

Likewise, if the two SOUTH poles (S poles) are placed near each other, they will tend to repel each other also.

This is part of the basic law of magnetism -- LIKE POLES REPEL EACH OTHER.

What happens if you bring the N pole of one magnet close to the S pole of another?

A They will repel each other. 60
B. No force will exist between them. 60
C. They will attract each other. 61

4-59

60

That is not correct.

There will be a force between the two poles, but it will be the force of attraction.

When an N pole and an S pole are brought close together, they are strongly attracted to each other.

Press A 61

4-60

61

OK.

The remaining part of the basic law of magnetism is: UNLIKE POLES ATTRACT EACH OTHER.

The reason for the effects of attraction and repulsion seems to lie in the MAGNETIC FIELD that exists around every magnet.

Press A 62

4-61

62

Look at Plate I. This illustrates the effects of attraction and repulsion when the magnets are brought together in different ways

It is common to show the invisible "lines of force" or "flux lines" which make up a magnetic field in this way. There really are no lines, but it is a convenient way to illustrate the invisible magnetic field.

Press A 63

4-62

63

See Plate I. For the upper pair of magnets, the lines of force between the adjacent S and N poles cause a force of ___(1)___ because they are flowing in ___(2)___ direction(s).

A. (1) attraction (2) the same 66
B. (1) attraction (2) opposite 64
C. (1) repulsion (2) opposite 65

4-63

64

You are partly correct.

There is a force of attraction exerted between the adjacent N and S poles.

But it is NOT because the flux lines are flowing in opposite directions. If they were, there would be repulsion between the poles.

Press A 63

4-64

65

Incorrect.

See Plate I. You have described the conditions for the lower pair of magnets. In that pair, the two adjacent S poles are being repulsed because the flux lines are flowing in opposite directions.

Now, what is occurring in the upper pair of magnets?

Press A 63

4-65

66

Good.

The upper pair of magnets is under the force of attraction because the flux lines between the adjacent S and N poles are all flowing in the same direction.

In the lower pair, the magnets are under the force of repulsion, because the flux lines between the two S poles are flowing in opposite directions.

Press A 67

4-66

67

| S N | | N S |

In this setup, the two N poles will ___(1)___ each other because their flux lines flow in ___(2)___ direction(s).

A. (1) attract (2) the same 68

B. (1) repel (2) opposite 69

4-67

68

You are incorrect.

Just as in Plate I, where the two S poles were adjacent and repulsion took place, two adjacent N poles also will repel each other, because their flux lines will flow in opposite directions.

Press A 69

4-68

69

OK.

In this section we have introduced you to the Fundamental Law of Magnetism -- UNLIKE POLES ATTRACT EACH OTHER; LIKE POLES REPEL EACH OTHER.

If you would like a brief review of this section, press A. 54

Otherwise, press B. 71

X (c)-70

5-69

70

OK.

The Fundamental Law of Magnetism is: UNLIKE POLES ATTRACT EACH OTHER; LIKE POLES REPEL EACH OTHER.

Let's have a quick review of this law, since you missed a question or two.

Press A 54

4-70

71

The development of most of our modern electrical equipment was based on the discovery that a magnetic field of force always exists around a conductor carrying an electric current.

This field is always at right angles to the conductor and consists of concentric circles around a straight conductor.

Press A 72

5-71

72

The magnetic field produced around a current-carrying conductor differs from the field around a regular magnet in that there are no magnetic poles at which the flux lines enter or leave.

The direction of the lines of force around a conductor can be determined when the direction of current flow is known.

Press A 73

5-72

73

See Plate II. The "Right Hand Rule for Determining the Direction of Lines of Force around a Straight Conductor" is illustrated here. This rule is based on the CONVENTIONAL CURRENT THEORY which assumes that CURRENT flows from positive to negative.

To apply the rule, grasp the insulated conductor with your right hand so that the thumb points in the direction of current flow. The curl of your fingers will then indicate the direction of the lines of force, as shown in Plate II.

Press A 74

5-73

74

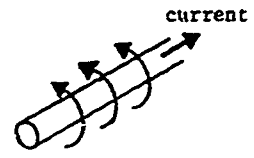


Fig. 1

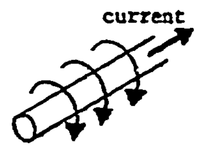


Fig. 2

According to the CURRENT THEORY, which of the above figures shows the correct direction of the magnetic lines of force, using the Right Hand Rule?

A. Figure 1 75
B. Figure 2 76
C. I don't know 72

5-74

75

No.
Remember that to apply the Right Hand Rule according to the CURRENT THEORY, you grasp the insulated conductor with your right hand, with the thumb pointing in the direction of current flow.

Then the curl of your fingers will show the direction of the magnetic lines of force.

Press A 74

5-75

76

Good.

According to the CURRENT THEORY, the accepted direction of current flow is from POSITIVE to NEGATIVE.

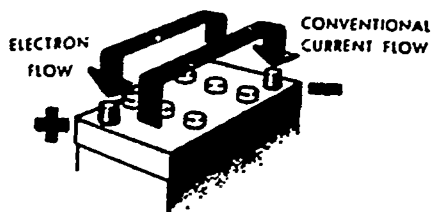
But it has been found that electrons flow from NEGATIVE to POSITIVE, according to the ELECTRON THEORY. How do we resolve this seeming contradiction?

Press A 77

5-76

77

There really is no contradiction. The explanation is that when electrons flow in one direction (from negative to positive), current is said to be flowing in the opposite direction.



Press A 78

5-77

78

When you want to determine the direction of the lines of force and you already know the direction of electron flow, the Left Hand Rule replaces the Right Hand Rule.

See Plate III. With your left hand grasp the insulated conductor, so that the thumb points in the direction of the electron flow. The curl of your fingers will then indicate the direction of the lines of force, as shown in Plate III.

Press A 79

5-78

79

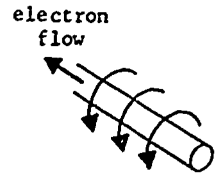


Fig. 1

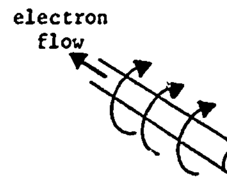


Fig. 2

According to the ELECTRON THEORY, which of the above figures shows the correct direction of the lines of force according to the Left Hand Rule?

A. Figure 1 81
B. Figure 2 80
C. I don't know 78

5-79

80

Incorrect.

Remember, that to apply the Left Hand Rule according to the ELECTRON THEORY, you grasp the insulated conductor with your left hand, with the thumb pointing in the direction of electron flow.

Then the curl of your fingers will show the direction of the magnetic lines of force.

Press A 79 5-80

81

OK.

Does the direction of the lines of force around the current-carrying conductor change, depending on whether you are talking about the conventional CURRENT THEORY or the ELECTRON THEORY?

No, it does not change.

Let's see why.

Press A 82 5-81

82

See Plates IV and V.

Plate IV shows the direction of the lines of force according to the Right Hand Rule of the conventional CURRENT THEORY. Note that the current is flowing from POSITIVE TO NEGATIVE.

Plate V shows the direction of the lines of force according to the Left Hand Rule of the ELECTRON THEORY. Note that ELECTRONS are flowing from NEGATIVE to POSITIVE.

Press A 83 5-82

83

Again see Plates IV and V.

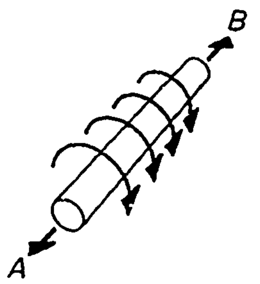
Note that in both cases the direction of the magnetic flux lines is the same.

When you see a diagram of flux lines around a straight conductor it is helpful to know whether the diagram was constructed on the basis of the conventional CURRENT THEORY or on the ELECTRON THEORY.

Press A 84 5-83

84

In this diagram, the direction of the lines of force is shown. Applying the Right Hand Rule, in which direction will the current be flowing?



A. In the direction of A 85
B. In the direction of B 87
C. I'm not sure 86

5-84

85

You are incorrect.

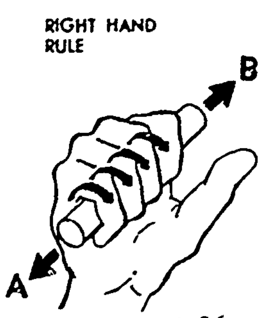
Remember that the Right Hand Rule tells us which way the lines of force will go when we know the direction of the current (meaning the direction of current according to the conventional CURRENT THEORY).

Press A for a brief discussion of the correct answer. 86 5-85

86

We were looking for the direction of current (according to the conventional CURRENT THEORY).

Applying the Right Hand Rule, curling the fingers in the same direction as the lines of force, we find that the thumb points toward "B". Therefore, the current is flowing in that direction.



Press A 84 5-86

87

OK. The current will be flowing in the direction of "B" according to the conventional CURRENT THEORY. If you would like a brief explanation of the last question, press A. 86

****

ELECTRONS are said to flow from ____(1)____ to ____(2)____.

B. (1) positive (2) negative 88
C. (1) negative (2) positive 89

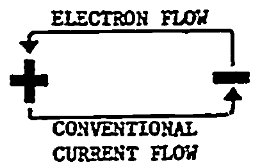
5-87

88

That is incorrect.

According to the ELECTRON THEORY, electrons are said to flow from NEGATIVE to POSITIVE.

The conventional CURRENT THEORY assumes that current flows from positive to negative.



Press A 89

5-88

89

OK.

Electrons are said to flow from negative to positive, while conventional current is said to flow from positive to negative.

We have been studying ELECTROMAGNETIC FIELDS in this section. If you would like to review what we have covered, press A. 71

Otherwise, press B. 91

X(c)-90

6-89

90

OK.

Electrons are said to flow from negative to positive.

Let's have a brief review of this section, since you made an error or two on the questions. When you answer all the questions correctly, we will talk about ELECTROMAGNETIC INDUCTION.

Press A 71

5-90

91

In the last section we learned that a magnetic field is always produced around a wire when current flows through it.

Conversely, if a MAGNETIC field is moved across a wire conductor, the lines of force will be "cut" by the wire and a current will be INDUCED in the conductor. This is the fundamental principle of ELECTROMAGNETIC INDUCTION.

Press A 92

6-91

92

Three different methods of producing voltage by electromagnetic induction are employed in automotive applications.

These methods vary, depending on whether the conductors and the magnetic field are moving or stationary during normal operation.

Press A 93

6-92

93

For example, in a DC GENERATOR the conductors are wound in an armature which rotates through a magnetic field created around stationary "pole shoes." When an external circuit is completed, current flows through the conductors in the armature.

Plate VI illustrates this principle. If the conductor is forced to the right, current flows "in," away from the observer. If it is forced to the left, current flows "out," toward the observer.

Press A 94

6-93

94

In an operating DC generator, the conductors ___(1)___ and the magnetic field ___(2)___.

A. (1) remain stationary (2) moves 95
B. (1) move (2) remains stationary 97
C. (1) remain stationary (2) collapses 96

6-94

95

No.

The answer you chose is the principle of operation for an AC generator or "Alternator," which we will discuss next.

In a DC GENERATOR, the conductors MOVE (rotate) and the magnetic field REMAINS STATIONARY.

Press A 97

6-95

96

No.
The answer you chose is the principle of operation for an ignition coil, which we will discuss shortly.

In a DC GENERATOR, the conductors MOVE (rotate) and the magnetic field REMAINS STATIONARY.

Press A 97

6-96

97

OK.
In a DC generator the conductors (armature windings) rotate through the magnetic field created between the pole shoes.

These conditions are reversed in an AC GENERATOR (Alternator). In this device the voltage is produced in stationary conductors by a rotating magnetic field. See Plate VII. If the field moves to the left, current flows "in." Reversing the direction of field movement (or reversing the polarity of the field) causes current to flow in the opposite direction. Press A 98 6-97

98

The AC generator (Alternator) develops voltage by means of ____(1)____ conductors and a ____(2)____ magnetic field.

A. (1) stationary (2) collapsing 99
B. (1) rotating (2) stationary 99
C. (1) stationary (2) rotating 100

6-98

99

Incorrect.

In an AC GENERATOR (Alternator) voltage is induced in STATIONARY conductors by the movement of a ROTATING magnetic field.

Press A 100

6-99

100

OK.
In an AC generator the field moves and the conductors are stationary.

A third form of producing voltage depends NOT on movement of parts, but on a change in the magnetic field. The IGNITION COIL operates on this principle. The coil consists of primary windings and secondary windings wrapped around a common core.
Press A 101

6-100

101

See Plate VIII. As current flow increases in the primary windings, an EXPANDING magnetic field (Figure1) cuts through the turns of primary winding and induces a voltage.

When the current to the primary is interrupted, the COLLAPSING magnetic field (Figure 2) cuts all the turns of both primary and secondary. Due to the relatively greater number of turns in the secondary, voltage there may reach as high as 25,000 volts.

Press A 102 6-101

102

In an operating ignition coil, the conductors (primary and secondary windings) ____(1)____, and the magnetic field ____(2)____.

A. (1) rotate (2) remains stationary 103
B. (1) remain stationary (2) expands and collapses 105
C. (1) remain stationary (2) rotates 103
D. (1) rotate (2) expands and collapses 104

6-102

103

You are incorrect.

The windings in an ignition coil DO NOT move. All parts remain stationary in an ignition coil.

But in electromagnetic induction SOMETHING must move in some way so that magnetic lines of force are "cut." How does this happen in an ignition coil?

Try the question again. Press A 102 6-103

104

You are right about the magnetic field, but not about the windings.

In an ignition coil the only thing that moves is the magnetic field of force.

Press A 102

6-104

105

Good. There are no "moving parts" as such in an ignition coil. What moves is the magnetic field, as it expands and then collapses.

Thus we have the three methods of electromagnetic induction employed in automotive applications.

If you would like to review this section, press A. 91
For a quick look at the three methods used, press B. 107

X (c)- 106

6-105

106

Good. The thing that moves in any ignition coil is the magnetic field as it expands and then collapses.

Since you had trouble with a question or two, let's have a quick review.

Press A 91

6-106

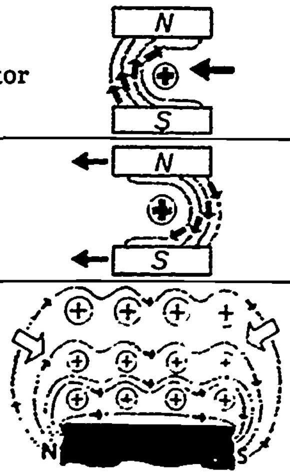
107

AUTOMOTIVE ELECTROMAGNETIC INDUCTION

moving conductor stationary field = DC generator

moving field stationary conductor = AC generator (alternator)

collapsing mag. field; stationary conductors = ignition coil



Press A 108

6-107

108

You have successfully completed this film, "UNDERSTANDING THE FUNDAMENTALS OF ELECTRICITY AND MAGNETISM." Congratulations!

You will find many applications of the principles you have studied here in your work as an automotive electrician.
Press REWIND.

6-108

INSTRUCTOR'S GUIDE

Title of Unit: INTRODUCTION TO ELECTRICAL MAINTENANCE FOR OFF-HIGHWAY VEHICLES

AM 2-11
8/8/67

OBJECTIVES:

1. To review the fundamentals of electricity and magnetism.
2. To familiarize the student with the basic terms and theories of electricity.
3. To familiarize the student with measuring and basic test instruments required in automotive service.

LEARNING AIDS suggested:

Visual Aids: Delco-Remy training charts.

Manual: No. 5133-A (Fundamentals of Electricity and Magnetism).

Models: Any small electrical components that could be brought into class and any demonstrations of magnetism that could be used in a classroom.

QUESTIONS FOR DISCUSSION AND GROUP PARTICIPATION:

1. Are electrons in a conductor held (bound) or are they free to move about?
2. Do similar charged bodies attract or repel each other?
3. What is the name of the area surrounding a magnet?
4. When using the right-hand rule as applied to a current carrying conductor, what does the direction of the thumb indicate? What does the direction of the fingers indicate?
5. The magnetic field of force surrounding an electrical conductor is in what direction? Parallel to the conductor or at right angles to the conductor.
6. State Ohm's law.
7. Are AMMETERS connected in series or parallel?
8. What happens when a coil of wire is moved through a magnetic field?

9. In what direction does a current-carrying conductor tend to move? From a strong magnetic field to a weak field, or from a weak magnetic field to a strong field?

10. VOLTMETERS are high resistance or low resistance meters?

11. Automotive circuits are classified as series, parallel, series-parallel or all three?

12. Will resistance in a circuit affect voltage drop?