FUNDAMENTALS OF MAGNETO IGNITION

FOREWORD

Ignition service within a relatively few years has become a field for specialists. The training, skill and general knowledge of the service technician are the outstanding characteristics of the progressive service business.

As a consequence frequent requests are received at the factory for fundamental information, prepared especially for study and reference in a particular service field. In providing a discussion of the principles of magneto ignition, considerable time has been devoted to the review of magnetism and electricity, after which an analysis of ignition requirements leads to the description of various ignition systems, their development, application and impulse coupling adaptations. The final section deals with magneto service in a general way, no attempt being made to describe specific service operations as applied to individual units, but rather to offer suggestions toward the establishment of efficient service practices.

It has been found impossible to cover the entire field of magneto ignition, or even to deal with individual topics on an exhaustive basis. The range of special applications and installations is so great that many are not even mentioned. Especially is this true of the older ignition systems, which due to changeovers are encountered infrequently in the field.

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SECTION ONE
INTRODUCTION

DEFINITION OF MAGNETO

A dynamo is any machine which transforms mechanical energy into electrical energy. Under this definition there are several distinct classifications, a magneto being the particular type of dynamo which uses permanent magnets to establish its magnetic field.

Strictly used, the term magneto applies only to the current-generating portion of the ignition unit and does not include the transformation of the low voltage primary current to the high voltage secondary ignition spark discharges, nor to the distribution of these spark discharges. As examples of this interpretation, the current-producing unit of the old style crank telephone or of the electric tachometer is also known as a magneto.

In the ignition field the technical definition is not commonly observed and it will be assumed throughout the following discussion that the magneto is the entire self-contained unit as it functions to supply the ignition spark discharges.

GENERAL PURPOSE OF MAGNETOS

Modern magnetos are compact, self-contained units designed and constructed specifically for the production of controlled electric spark discharges of adequate strength to meet the ignition requirements of internal combustion engines or of similar applications.

Entirely independent of any exterior source of electrical or chemical power, a magneto ignition unit depends solely upon mechanical energy, which can be supplied, for example, by hand cranking. This characteristic is of vital importance in remotely located or infrequently operated installations, and of considerable convenience in many others.

Another advantage based directly upon the fact that magnetos operate as a result of mechanical power is the adaptation of the impulse coupling. This simple mechanical device functions at slow speeds in order to produce an automatically retarded ignition spark of greatly increased intensity during the starting period of the engine.

THE MAGNETO ASSEMBLY

A magneto is a precision-built instrument combining painstaking mechanical construction with carefully engineered magnetic and electric circuits. As noted in preceding paragraphs three separate functions occur within the unit (Figure 1):

(a) Current generation, which occurs in the primary circuit when there is relative movement of the primary winding and the interlocking magnetic field.

(b) Voltage transformation, which takes place in the interlocking primary and secondary windings of the coil, the high voltage surge being caused by breaking the primary circuit at the point the primary current reaches its maximum value.

(c) Spark distribution, which consists in conducting the high voltage secondary surge to the desired ignition circuit at the correct intervals. In standard units for single cylinder engine applications, this function is unnecessary.

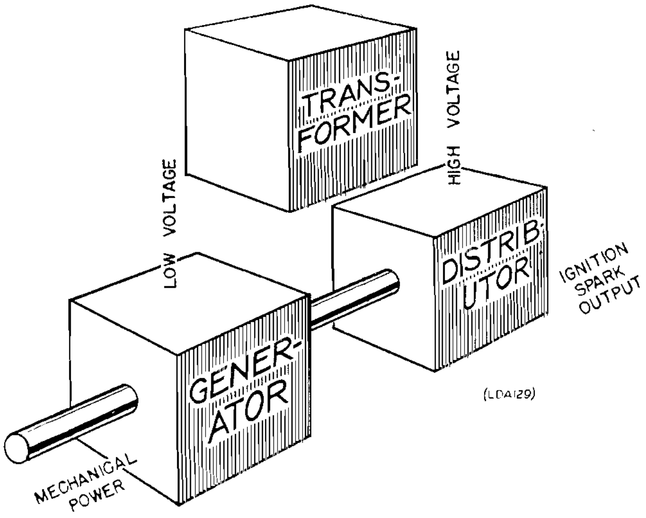


Figure 1—Functions of a Magneto

MAGNETO ENGINEERING

The design of magnetos is influenced by a number of important factors, among which are the requirements of the application, the performance of the magneto, the cost of manufacture and the ease with which the unit may be serviced. The constant research and development work maintained by individual manufacturers has resulted in greatly improved field performance, while both the size and the cost of units have been sharply reduced.

Magneto design over a period of years has been closely linked with the development of magnet steels. The progression from tungsten steels to chromium steels to cobalt steels to Alnico steels has provided the basis for major changes in magneto construction.

MANUFACTURE OF MAGNETOS

In the manufacturing industry a magneto is considered an accessory in relation to an engine, although it is entirely essential to the operation of the unit. Such a classification results from the common practice engine manufacturers have of buying the magneto unit complete from a different manufacturer. Many times the price of an engine is quoted less the magneto as well as other accessories, but it is rarely the case that the individual engine purchaser specifies the make or model of the magneto to be furnished.

Under such circumstances several magneto manufacturers supply the units for original application on many hundreds of kinds of engines. Usually the magneto selected by any one engine builder undergoes a series of exhaustive tests while installed on the actual engine model before it is accepted and designated as standard equipment. The magneto manufacturer then assumes the responsibility for the condition and service of the magneto over a definite period of time, usually 90 days, except under extraordinary conditions.

MAGNETO SERVICE

Service work of all kinds is often divided into the two general classes of maintenance and repair.

Maintenance work is usually considered to include inspection and adjustments made by the operator as well as field service work performed by service technicians. Repair work consists of the replacement of major parts, usually undertaken only in the specially equipped shop, and of the complete overhaul of the unit.

The distinction between the two classes of work is indefinite and varies widely with the field of application. In aircraft engine service practically no work is ever performed on magnetos installed on engines, maintenance consisting of a comprehensive test and inspection routine. After a definite number of hours of service, the aircraft magneto is removed from the engine and completely overhauled. In the tractor and power engine field the opposite is often true, that is, extensive repairs are frequently made on magnetos without removing them from the engine, and magnetos are seldom removed for overhaul until they become inoperative.

THE SKILLED TECHNICIAN

A competent serviceman is expected to be able to diagnose difficulties, make adjustments, install replacement parts and undertake the complete overhaul of many makes and models of magnetos. A thorough understanding of the fundamental design principles, combined with a general knowledge of magneto construction, is the only sound basis on which the skilled technician can apply the special information and equipment at his disposal.

Expert electrical and mechanical service are both required in the maintenance and overhaul of magneto ignition units. The serviceman must be capable of performing precision mechanical work as well as operating electrical test equipment to provide conclusive results.

FUTURE DEVELOPMENTS

The sweeping changes made during the past ten years in magneto design and construction has resulted in the universal acceptance of the rotating magnet principle and the use of Alnico magnets. The trend today is toward further simplification, compactness and reduction in cost. Introduction of new materials and improvement in old materials will be the most important factors in future magneto development. Continued research in steel alloys promises more powerful Alnico magnets as well as lamination steels of greater efficiency. Metals such as aluminum and magnesium will be developed to a point where they will be used to an advantage for many purposes. Better insulating materials have been developed, making possible the production of an entirely encapsulated molded high tension coil of epoxy compound; another example of improved performance standards. Plastics, ceramics and glass are now developed to a point where they will have far reaching effects on the designs of future ignition units.

The trend of the past toward the use of ignition systems completely shielded, so as not to cause radio interference, has been fully accepted and further developed. Today this type magneto is in use on far too many installations to mention here.

The great strides made in the development of the electronic tube may result in the replacement of the mechanically operated breaker mechanism by an electronic controlled switch.

Servicemen everywhere should make every effort to keep up to date on the many new developments in magneto ignition systems. One of the more important phases of the service industry is the complete replacement of obsolete equipment with the new and better units.

SECTION TWO
MAGNETISM & ELECTRICITY

APPLICATION OF FUNDAMENTAL THEORY

A clear and thorough working knowledge of the fundamental principles of magnetism and electricity is essential to service technicians engaged in the analysis, maintenance and repair of magneto ignition units and systems.

A magneto functions as the result of a synchronized combination of magnetic and electric circuits, these circuits being interlocked both mechanically and electrically. In the discussion which follows the theoretical basis for each of the circuits is developed and explained separately, their inter-relation being described in a later section when the operation of the complete magneto is analyzed (See Page 24).

MAGNETISM

A complete, sound explanation of magnetism has not yet been established, although some of the characteristics and effects have been known for centuries. To the average person the invisible forces surrounding magnetic poles are usually somewhat mysterious, possibly because their origin is seldom understood.

Magnetism, however, furnishes the absolute basis for the design of magnetos, as well as for most other electrical machinery. The importance of reviewing and analyzing the known facts and theories cannot be overemphasized.

MOLECULAR THEORY OF MAGNETISM

It has been well established by scientific research and reasoning that all matter is composed of atoms. Atoms are the ultimate division of matter in which the characteristics of the known elements are retained. Most substances, however, are composed of several elements, the atoms of the elements combining to form molecules, the smallest possible division of the substance to retain the physical characteristics of the substance. Conversely, the physical characteristics of a substance are determined by the kinds of atoms in its molecules as well as by their arrangement.

Magnetism is believed to result from the arrangement of the molecules in a particular material. It is assumed that the molecules of any substance are in constant motion, the pattern of such motion being entirely haphazard. When a material is placed in a magnetic field this pattern of molecular motion is subject to change, the extent depending greatly upon the nature of the material. In cases where the change is so great that the molecules line up to form a definite current, magnetic poles appear at the points of greatest concentration of positive or negative charges, and a field of force lines surround the space adjacent to the molecular path.

In certain steels the pattern of molecular motion continues even after the magnetizing force is removed, the steel thereby retaining the properties of a magnet and being classified as a permanent magnet. In other steels and nearly all other materials the pattern of molecular motion breaks up almost immediately when the magnetizing force is removed, the magnetic properties disappearing simultaneously.

TYPES OF MAGNETS

The basic classification of magnets group known types as either permanent or temporary magnets.

Permanent magnets occur in nature in the lodestone (magnetite ore) which was discovered hundreds of years ago, together with its remarkable properties of attracting bits of iron and of assuming a north and south direction when suspended in air. Subsequently it was learned that this magnetism could be transferred, as for example when a steel needle was brushed by a lodestone it acquired to some degree the magnetic properties of the lodestone. The fact that these magnetic properties were retained for an indefinite period by certain materials was the original basis for the definition of a permanent magnet.

Temporary magnets retain their magnetic properties only as long as the original magnetizing force is present.

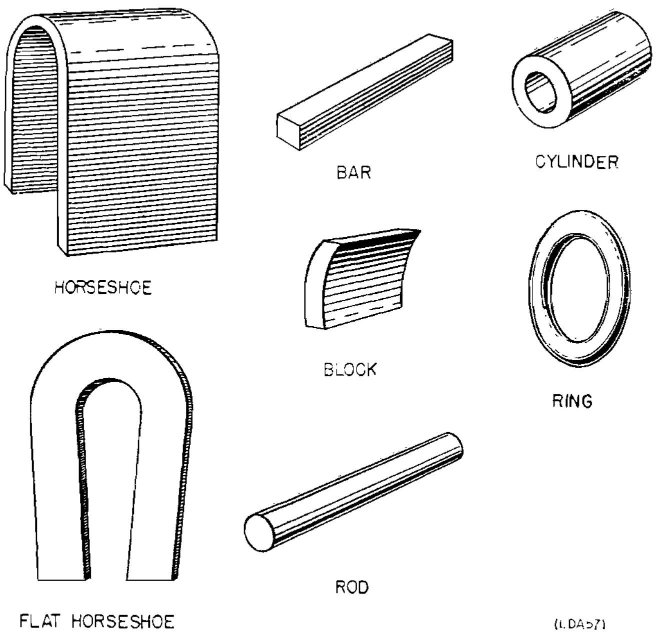


Figure 2—Physical Shapes of Permanent Magnets

Thus a piece of soft iron when placed adjacent to a permanent magnet will exhibit all the properties of the permanent magnet, except that when the permanent magnet is removed, the soft iron immediately loses its magnetic properties. Such a magnet is sometimes called an induced magnet. Another type of temporary magnet is the electromagnet, which is produced by passing an electric current through a coil wound around a soft iron core.

PHYSICAL SHAPES OF PERMANENT MAGNETS

Permanent magnets are available in a great many physical shapes (Figure 2), among the most common being the familiar horseshoe type and the plain bar or rod. The recent development of stronger permanent magnet steels has permitted the use of smaller and more compact magnets in magneto construction, with far-reaching design changes as a result.

Magnet steels such as tungsten, chromium and cobalt can be cast, forged or rolled into the physical shapes desired and can be machined for the final fit. The new Alnico steel can be either cast or "sintered", a process by which the powdered metals of the alloy are formed into the desired shapes by the application of heat and tremendous pressure. Alnico is an extremely hard, crystalline metal and cannot be machined by ordinary methods; it can, however, be cut with a grinder or rubber wheel.

DEMAGNETIZATION

Permanent magnets are permanent only in a relative sense. It is perfectly possible to completely demagnetize the best known permanent magnet steel. This can be accomplished by one or more of three general methods.

(a) Application of a sufficiently strong field of opposite polarity.

(b) Heating to a high temperature.

(c) Subjecting the piece to mechanical vibration.

Deliberate demagnetization is often necessary in machine shops in order to eliminate undesirable magnetism in crankshafts or other metal pieces.

Causes of demagnetization are equally important in the case where it is desired that a piece of steel retain its magnetism. The same three general methods listed above tend toward the demagnetization of steel (stray fields of opposite polarity, high temperatures, mechanical vibration). The ability a steel has to hold its magnetism in spite of these demagnetizing forces is known as its retentivity, and is a highly important factor in the selection of permanent magnet steel to be used in magneto construction.

PERMANENT MAGNET MATERIALS

Pure, soft iron does not retain magnetism, but many steel alloys have been found which do possess this property. Among these alloys are the chromium, tungsten and cobalt steels. Their magnetic retentivity varies, the cobalt steel being somewhat superior, but at the same time several times as expensive. The percentage composition of all of the magnetic alloys is a critical factor in their final characteristics.

The development of an aluminum-nickel-cobalt alloy of steel known as Alnico has during recent years practically obsoleted all other steels as permanent magnet material, at least in the magneto field. Alnico has more available energy for a given volume than any other permanent magnetic material; this greater stored energy being available at a lower cost. Because of its higher coercive force shorter and more compact magnets may be used, permitting considerable improvement in the design and construction of instruments requiring permanent magnetic fields. Alnico also possesses much greater stability than other permanent magnets as explained in the following paragraph.

STABILITY OF ALNICO MAGNETS

Possibly the greatest advantage in using Alnico magnets in place of other steels in the construction of magnetos is its extreme stability as a permanent magnet. Tests have shown that stray fields have only a very slight demagnetizing effect until they become very powerful (Figure 3), that temperatures up to 500°C. produce no discernible effect and that resistance to vibration is much greater than that of any other permanent magnet material (Figure 4).

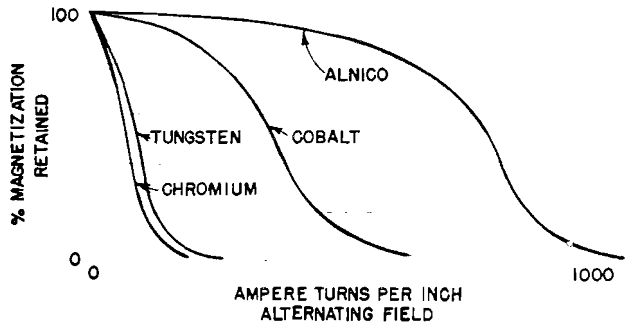


Figure 3—Effect of Stray Fields on Magnet Steels

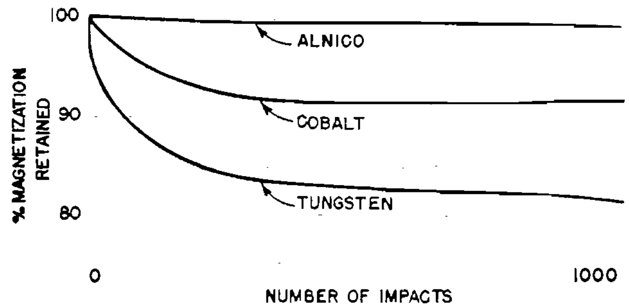


Figure 4—Effect of Vibration on Magnet Steels

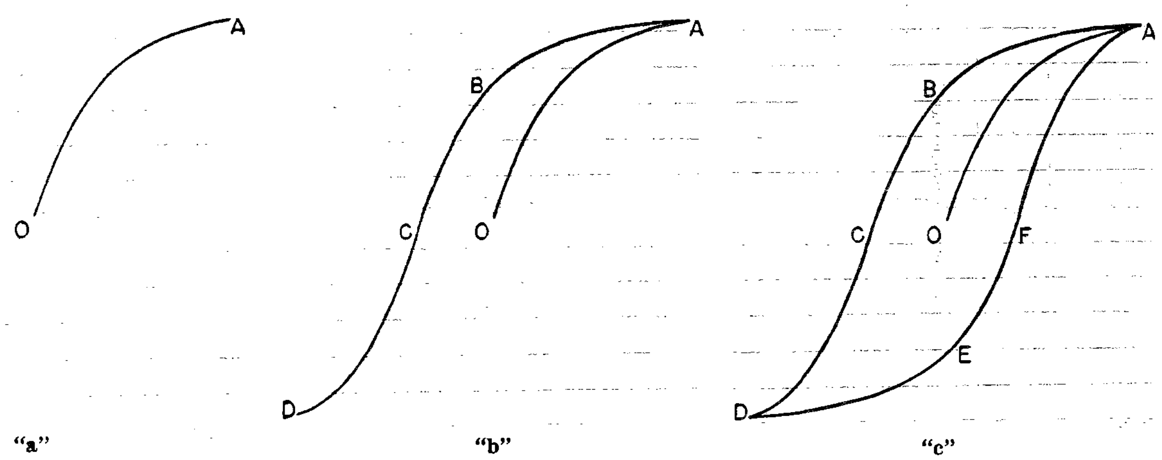


Figure 5—Development of a Hysteresis Loop

MAGNETIC CHARACTERISTICS OF STEELS

The magnetic characteristics of thousands of steels have been determined in extensive laboratory research programs devoted to tests of the retentivity, reluctance and magnetic saturation values of the steels.

Retentivity as explained in a preceding paragraph is the ability of a steel to retain magnetism.

Reluctance of a steel is defined as the resistance offered to the establishment of a magnetic flux path. Permeance is the reciprocal of reluctance and therefore indicates the ease with which a magnetic flux path can be established.

The magnetic saturation point of a steel is reached when further increases in the magnetizing force fail to produce any corresponding increases in the magnetic strength of the steel.

DEVELOPMENT OF THE HYSTERESIS LOOP

The study of the magnetic qualities of various steels is part of a research program concerned with magnetic hysteresis, which is defined as the lag of the magnetic flux in a material behind the magnetizing force. Hysteresis tests indicate graphically the important magnetic properties of a steel in a curve known as the hysteresis loop.

The hysteresis loop is the complete record of results obtained when a piece of steel is subjected to a variable magnetic field of known strength. As the strength of the field is increased from zero the magnetism of the steel increases as shown by the curve (Figure 5 "a") until a point (A) is reached, beyond which any further increase in the strength of the field does not produce any appreciable change in the magnetism of the steel. This point is known as the saturation point and is important because it indicates the maximum limit of magnetic strength which can be absorbed by the particular steel.

After reaching the saturation point, the magnetizing force is decreased until it reaches zero, the decreasing strength of the magnetism in the piece of steel being indicated by curve AB (Figure 5 "b"). It should be noted here that diminishing the magnetizing force to zero does not, however, return the steel to a neutral state, the amount of magnetism which remains in the steel being indicated by OB and known as the residual induction or magnetism.

Proceeding with the next step the polarity of the magnetizing force is reversed and then increased until the piece of steel reaches a neutral state as shown by the portion of the curve BC (Figure 5 "b"). The amount of magnetizing force necessary to bring the steel back to a neutral state is then indicated by OC, which is known as the coercive force for the particular steel.

As soon as the piece of steel has passed through its neutral state, and if subjected to an increasing magnetizing force, it will become magnetized in the opposite direction until it reaches the saturation point D (equal and opposite to A) as indicated by the portion of the curve CD (Figure 5 "b").

After the saturation point D has been attained, the magnetizing force is again diminished to zero (Figure 5 "c"), leaving a residual magnetism of OE (equal and opposite to OB). The magnetizing force is then reversed and increased until the steel again reaches a neutral state, and the coercive force OF (equal and opposite to OC) is indicated. Increasing the magnetizing force will then bring the steel back to its original saturation point.

It should be noted that only during the original magnetization of the piece of steel will the curve OA be secured, all subsequent changes occurring on the hysteresis loop ABCDEFA.

SIGNIFICANCE OF THE HYSTERESIS LOOP

The analysis of the hysteresis loop for a particular steel reveals most of the steel's important characteristics in relation to magnetism. In general there are two basic viewpoints: (a) use of the steel as a permanent magnet and (b) use of the steel as part of a magnetic circuit.

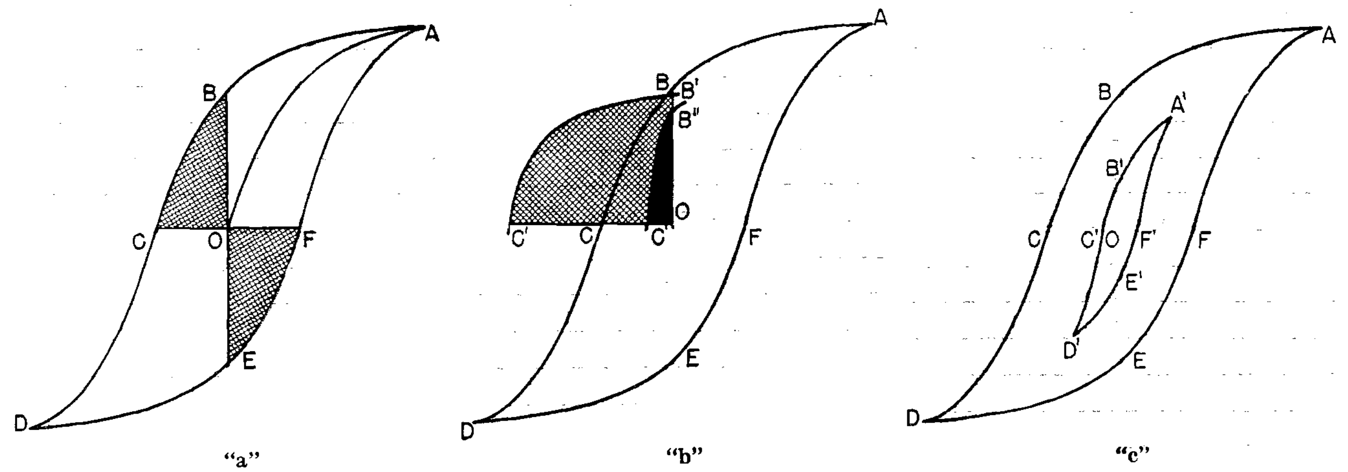


Figure 6—Significance of the Hysteresis Loop

The desired magnetic qualities of the steel are opposite for the two cases.

The area ABCDEFA within the hysteresis loop (Figure 5 "c") is directly proportional to the energy required to pass the steel through a complete magnetic cycle (that is, from the positively magnetized state through neutral to the negatively magnetized state, and back through neutral to the positively magnetized state). In choosing a steel for a permanent magnet this area should be as large as possible, while a steel for laminations should have a loop with as small an area as possible. The area of a hysteresis loop can be measured and by introducing the proper conversion factors the energy used can be given in watts. In the case of transformers this energy is known as the "transformer loss", and is important in computing the temperature rise.

The quality of a permanent magnet is usually judged by its coercive force and by the maximum of the product of its coercive force and its flux density.

The areas OBC and OEF (Figure 6 "a") are the basis for laboratory comparison of permanent magnet steels. For a chrome or tungsten steel the area OB″C″ (Figure 6 "b") is very small in comparison with the areas OB′C′ indicated for an Alnico steel.

The importance of completely magnetizing a permanent magnet steel is also demonstrated by comparing the hysteresis loops for different amounts of magnetization (Figure 6 "c"). Loop ABCDEA was obtained when the steel tested was magnetized to its saturation point (A), while loop A'B'C'D'E'A' was obtained when the maximum magnetization of the steel amounted to somewhat less than saturation (A'). Note the great differences in residual magnetism (OB/OB'), in the coercive force (OC/OC') and in the area (OBC/OB'C').

MAGNETIC ATTRACTION & REPULSION

When one of the poles of a magnet is held in the vicinity of a compass the compass needle turns and the north-seeking point is either attracted or repelled. Similarly, if one pole of a magnet is held in the vicinity of a pole of another magnet, there is either attraction or repulsion. From such experiments it has been established that like poles (that is, two north poles) repel each other, while unlike poles (that is, a north and a south pole) attract each other. The force exerted between two magnetic poles, either of attraction or repulsion, varies inversely as the square of the distance between them.

Unmagnetized iron is attracted equally by either north or south poles.

The north-seeking pole is often designated as the positive pole of a magnet while the south-seeking pole then becomes the negative pole.

MAGNETIC FIELD

Since the influence of a magnetic pole is apparent when the pole is in the vicinity of some magnetic material, it is reasonable to assume that a field of force surrounds the pole. To demonstrate the presence of this field and for an idea of its shape and extent a simple experiment can be conducted as follows: Lay a magnet, preferably of the bar type, on a flat surface and cover it with a piece of paper. Then shake iron filings on the surface of the paper and observe the pattern which is formed (Figure 7). The concentration of filings at the poles indicates that the strength of the field is greatest at these points, while the fact that some of the filings come to rest between the poles indicates that the field extends from one pole to the other. The experiment can be continued to show that, if two magnets are placed beneath the paper, the magnetic field will, no matter what the position of magnets, extend between unlike poles (Figures 8 & 9).

MAGNETIC FIELD STRENGTH

A convenient conception of the condition existing when unlike magnetic poles are placed a short distance apart is to imagine the two poles connected by lines of force

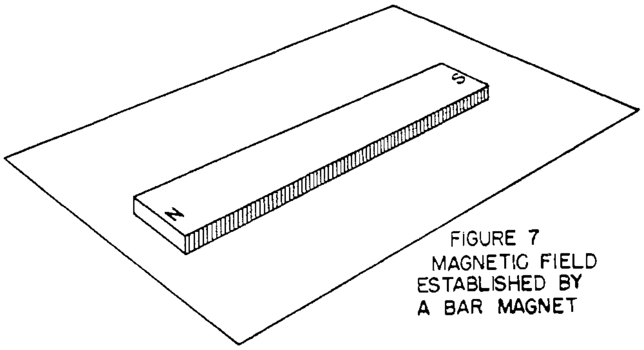


FIGURE 7
MAGNETIC FIELD ESTABLISHED BY A BAR MAGNET

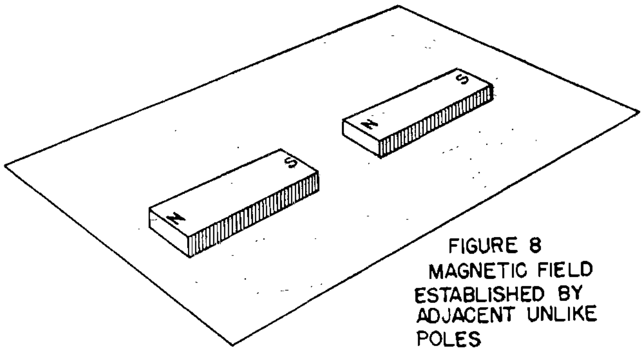


FIGURE 8
MAGNETIC FIELD ESTABLISHED BY ADJACENT UNLIKE POLES

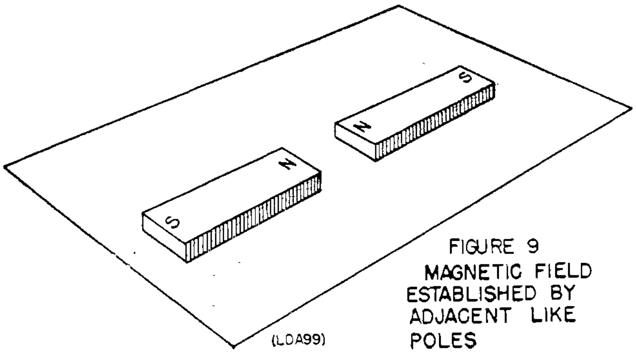


FIGURE 9
MAGNETIC FIELD ESTABLISHED BY ADJACENT LIKE POLES

(Figure 10). Furthermore, these lines of force can be thought of as being elastic, with a tendency to shorten themselves as much as possible. This characteristic accounts for the pull which unlike poles exert upon one another, or upon magnetic substances.

There must be noted in connection with the conception of a magnetic field that there is a dispersal effect as

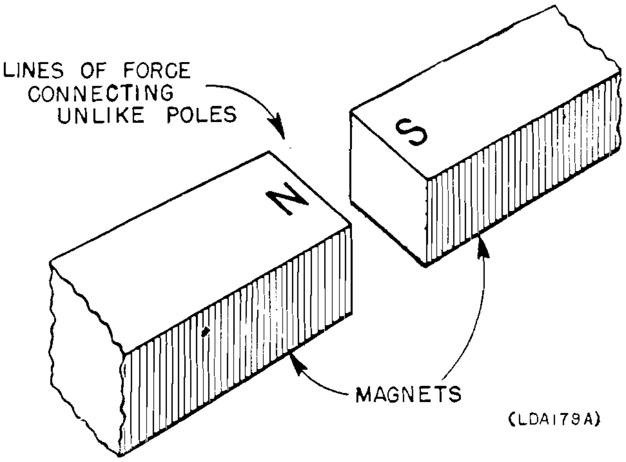


Figure 10—Magnetic Lines of Force

the distance from the pole increases; if the field is thought of as being made up of lines of force, it follows that these lines of force can be considered to repel one another (Figure 11).

By establishing as a standard the strength of a magnetic field assumed to have only one line of force per unit area, the strength of other magnetic fields can be determined by comparison.

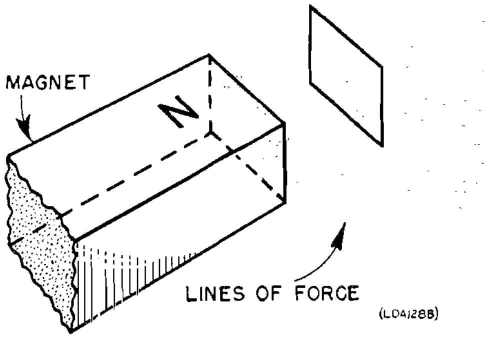


Figure 11—Dispersal Effect of a Magnetic Field

MAGNETIC CIRCUITS

There is no insulator for magnetism known; a magnetic field extends itself readily through glass, rubber or other materials. It is possible, however, to confine the magnetic field within predetermined limits by establishing a closed magnetic circuit.

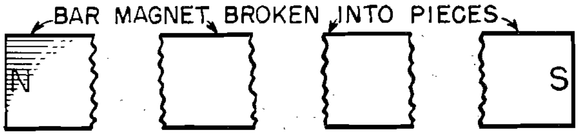


FIGURE 12 - PIECES OF A BAR MAGNET

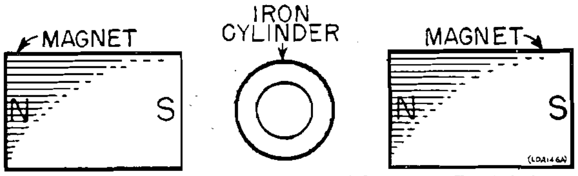
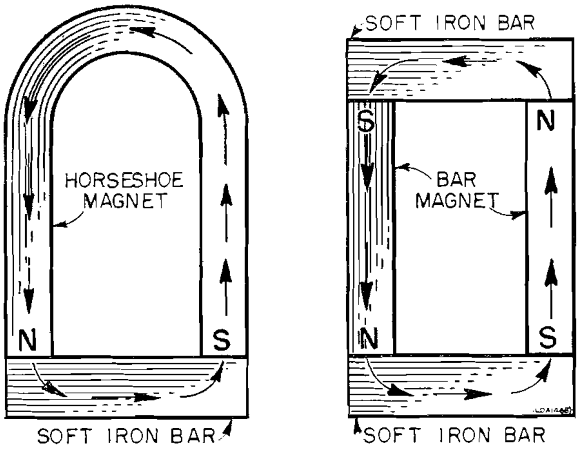


FIGURE 13 - SHIELDING EFFECT OF IRON

When a bar magnet is broken into pieces at right angles to its axis (Figure 12), each piece becomes a separate magnet, one edge of each break becoming a north pole while the opposite edge becomes a south pole. If the pieces are placed in line in the order in which the bar was broken, the original bar magnet is reconstituted, even though the individual pieces are slightly separated, the magnetic flux passing from the end of one piece across an air gap to the end of the adjacent piece. The magnetic circuit formed is not considered a closed circuit, however, since the two end poles have no adjacent, opposite poles. The field established must therefore be somewhat on the order of the original field established by an unbroken bar magnet (Figure 7).

In explaining the basis of magnetic circuits another important point must be noted. If two magnets are placed some distance apart with opposite poles adjacent and a piece of iron placed in the space between them, it will be found that practically all the magnetic flux linking the two poles passes through the iron rather than the air. If the piece of iron is in the form of a cylinder (Figure 13), no magnetic flux will be found inside the cylinder. This shielding effect of iron is of great importance in confining magnetic fields within desired limits.

A closed magnetic circuit is established when a piece of iron is placed across the poles of a horseshoe magnet (Figure 14 "a"). The magnetic flux in such a case will be found to be confined to the steel of the magnet and the iron bar. Identical results are obtained with two bar magnets and two pieces of iron (Figure 14 "b").



"a" "b"

Figure 14—Closed Magnetic Circuits

The principle of a closed magnetic circuit is the basis for the design of electric generators and motors. The closed magnetic circuit mentioned above is so arranged that a part of the circuit can be rotated (Figure 15 "a"); this part may be either the magnet or the iron connecting the poles. Assuming the rotating piece to be the magnet, a small amount of turning will still leave the magnetic circuit intact although the flux lines become quite crowded (Figure 15 "b"). A further turning, however, breaks the circuit (Figure 15 "c"), but a new and opposite circuit is established when the magnet approaches a position exactly opposite its original position (Figure 15 "d"). Rotation of the magnet therefore establishes an alternating flux (complete reversals) in the magnetic circuit; if the rotating member were a piece of iron forming part of the magnetic circuit, an intermittent flux (no reversals) would be established.

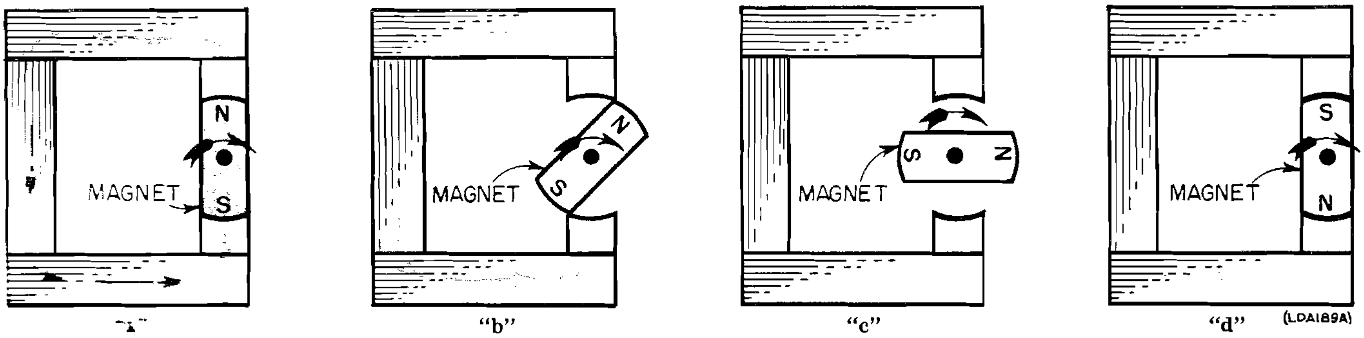
ELECTRICITY

Some consideration must be given to the basic theory of electricity before examining the interlocking effects of magnetism.

In developing an explanation of magnetism (Page 5) the statement was made that the smallest possible division of an element is the atom. The atom in turn is an assembly of an equal number of positive charges known as protons and negative charges known as electrons. the total number of protons and electrons being determined by the particular element. It is believed that such a division results in uniform factors for all matter; that is, that all protons, as well as electrons, are identical regardless of the elements which they constitute.

The accepted conception of the structure of the atom groups all of the protons and about half of the electrons in a compact nucleous which serves as the center for an orbitary system in which the remainder of the electrons are in constant, rapid motion. Some of these electrons can be detached by various methods, especially in the case of metals, and a transfer of electrons from one atom to another established. Substances in which the electrons can be moved on application of an electric force are known as conductors, while other bodies in which no movement of electrons is discernible are classed as insulators.

The electron is the smallest definite quantity of electricity known, the value of its charge being 4.774×10^{-10} electrostatic units. An electrostatic unit is that quantity of electricity which, when concentrated at a point unit distance from an equal and similar quantity, and surrounded by air, will be repelled by a force of one dyne.



"a" "b" "c" "d" (LDA189A)

Figure 15—Rotation of Magnet in Closed Magnetic Circuit

ELECTRIC CURRENT

The fact that electrons can be detached from the outer orbitary paths of one atom and transferred to the orbitary system of another atom provides the basis for the accepted definition of an electric current. Any inter-atomic movement of electrons can, by this reasoning, be considered an electric current, but more practically a current is defined as the orderly movement of electrons along a conductor. In many respects the passage of electrons along a conductor can be compared with the flow of water through a pipe.

A direct current is a current in which the electronic movement is unidirectional, although the value of the current may vary or pulsate. An alternating current is a current in which the direction of movement of the electrons reverses periodically, first being positive then negative—alternating between maximum positive and negative values.

The path of an electric current is known as a circuit, the electrons moving from a point of excess electrons (negative) to a point of electron deficiency (positive).

The unit of measurement of electric current is the ampere.

ELECTRIC POTENTIAL (VOLTAGE)

To make water flow through a pipe, there must be a difference of pressure between the inlet and the outlet. To make electric current flow along a conductor there must be a difference in potential between the two ends of the conductor. Electric potential (commonly known as voltage) is the excess of electrons which exist at one point in comparison with some other point.

The practical unit of electric potential is the volt.

Electric potential is established by electro-magnetic induction, chemical reactions and other less used methods.

RESISTANCE

When water flows through a pipe, the quantity which actually passes a certain point is limited by the friction of the walls of the pipe. A similar condition exists in the flow of an electric current in a conductor, where the opposition to the passage of electric current is termed the resistance. Both the water friction in the pipe and the electric resistance in the conductor result in a heat loss which can be computed.

Resistance to electric current varies widely with different materials. Silver has the lowest known resistance, but most other metals, especially copper, also have comparatively low resistance. Materials with a low resistance are known as conductors, while those with a very high resistance, such as mica, rubber, glass and air are known as insulators.

The practical unit of measurement of resistance is the ohm.

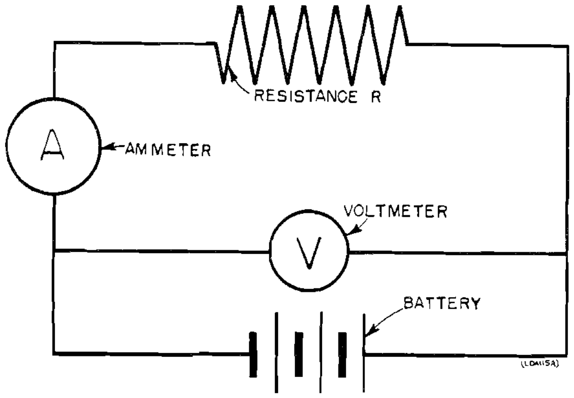


Figure 16—Simple Electric Circuit

OHM'S LAW

An electric circuit (Figure 16) always involves factors of potential (volts), current (amperes) and resistance (ohms). The relationship of these factors is expressed by Ohm's law: when a steady direct current flows in a circuit the current is directly proportional to the voltage and inversely proportional to the resistance. When the current is expressed in amperes, the voltage in volts and the resistance in ohms, the law takes the form of the following important equations:

$$I = \frac{E}{R} \ (1) \qquad E = IR \ (2) \qquad R = \frac{E}{I} \ (3)$$

The equation (2) should be especially noted since it is the basis of voltage drop calculations. The voltage drop E, across a known resistance R, through which a known current I, is flowing is by definition IR.

RESISTANCE IN SERIES

When two or more resistances are placed in a series circuit (Figure 17) the total resistance is the sum of the individual resistances.

$$R = R_1 + R_2, \text{ etc.}$$

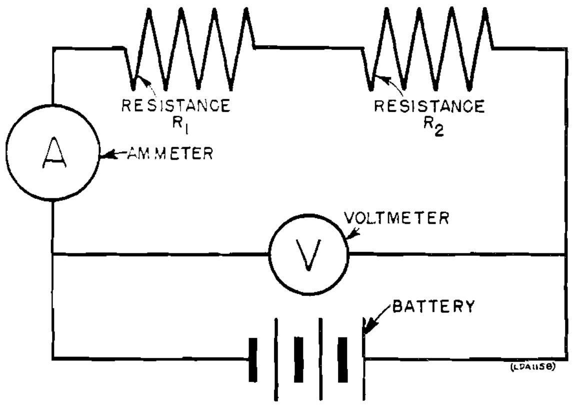


Figure 17—Resistances in Series

RESISTANCES IN PARALLEL

When two or more resistances are placed in a parallel circuit (Figure 18) the total resistance is the reciprocal

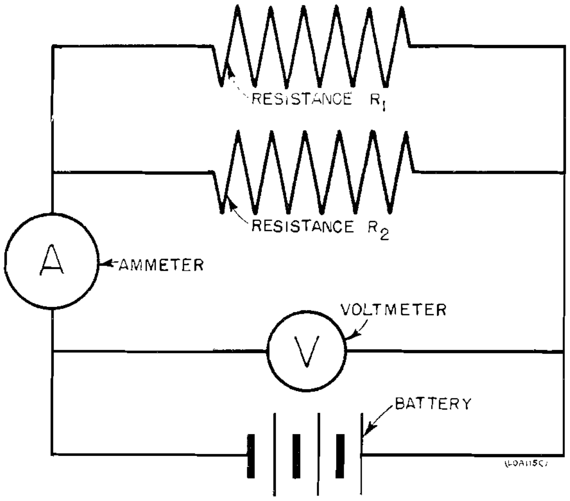


Figure 18—Resistances in Parallel

of the sum of the reciprocals of the individual resistances.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \text{ etc.}$$

The reciprocal of resistance is called the conductance and is often used as such in solving for values in parallel circuits.

$$\frac{1}{R} = C = C_1 + C_2 + C_3, \text{ etc.}$$

THE WHEATSTONE BRIDGE

The Wheatstone bridge is a simple electric circuit (Figure 19) set up primarily for the comparison of resistance values. In establishing a comparison circuit of this type at least one known resistance of suitable size is required, while the resistances in the other two legs of the bridge need give only a proportional value.

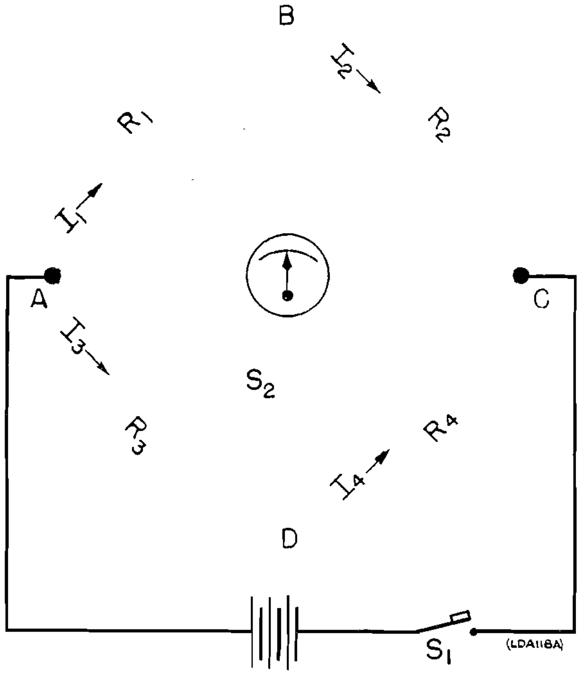


Figure 19—Circuit Diagram of the Wheatstone Bridge

In practice the Wheatstone bridge often consists of a board on which a long, straight resistance wire is mounted adjacent to an evenly divided rule (Figure 20). Connections are provided for the known and unknown resistances and for a battery and indicating instrument. By moving the sliding contact along the resistance wire the proportionate value of two of the legs of the circuit can be determined, and the value of the unknown resistance solved by a simple calculation.

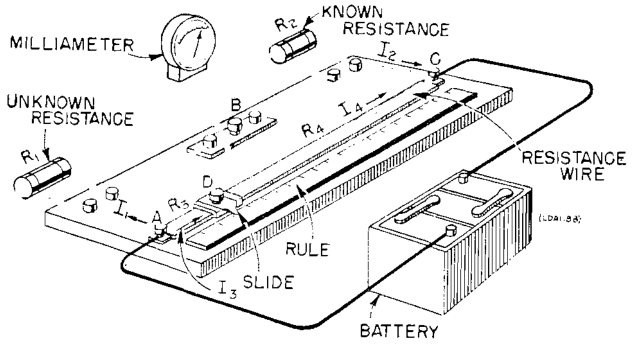


Figure 20—Simple Layout of the Wheatstone Bridge

To determine a resistance value with the bridge circuit a state of balance must first be obtained. With switch S_1 closed so that current flows through the circuit, the resistances R_3 and R_4 must be so adjusted that when switch S_2 is closed no current flows through the center connection BD. Consequently points B and D must be at the same potential and the voltage drop from A to B (R_1I_1) equal to that of A to D (R_3I_3). Similar reasoning establishes the voltage drop from B to C (R_2I_2) equal to that of D to C (R_4I_4). Since no current flows through the center connection, the current in branch AB (I_1) is equal to that of BC (I_2), while the current in branch AD (I_3) is equal to that of DC (I_4). Substituting these current values and dividing:

$$\frac{R_1I_1}{R_2I_2} = \frac{R_3I_3}{R_4I_4} \text{ and } \frac{R_1I_1}{R_2I_1} = \frac{R_3I_3}{R_4I_3}$$

which gives:

$$R_1 = \frac{R_2R_3}{R_4}$$

ELECTRIC CIRCUITS

Electric circuits consist of series circuits, parallel circuits or combinations of both (Figure 21). In a series circuit the entire current flows successively through each section of the circuit. In a parallel circuit the current divides and flows through the various sections.

Kirchhoff's laws of circuits are especially helpful in solving for the various values in a direct current circuit. The first law states that the algebraic sum of all the currents flowing through a point in an electric circuit equals zero. An equation which expresses this law is:

$$I_1 = I_2 + I_3 \quad \text{or} \quad I_1 - I_2 - I_3 = O$$

The second law of Kirchhoff can be stated as the algebraic sum of all the voltage drops in a series circuit equals zero. In equation form an example of this law is:

$$E = I_1R_1 + I_5R_5 \quad \text{or} \quad E - I_1R_1 - I_5R_5 = O$$

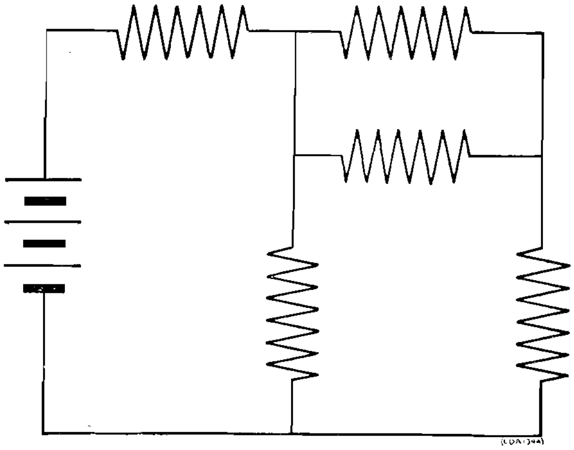


Figure 21—Electric Circuit

ELECTRO-MAGNETIC FIELD

When a compass is placed near a wire carrying an electric current, it will be noted immediately that the compass needle moves to establish a definite relation to the direction of the current in the wire. This action indicates the presence of a magnetic field around the wire and the compass can be used to determine the extent and direction of the flux lines composing the field. As shown in Figure 22 the flux lines surrounding a straight wire have been found to be concentric with the wire, their direction being indicated by the "right hand rule".

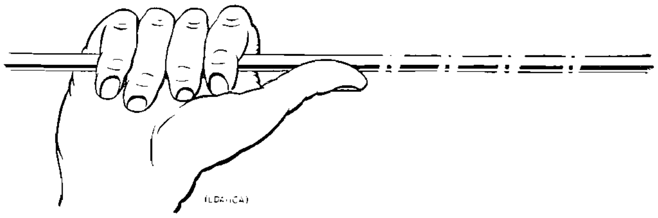


Figure 22—Field Surrounding a Straight Wire

According to this rule, if a wire carrying a current is grasped in the right hand with the thumb pointing in the direction the current is flowing, the curved fingers will point the direction the flux lines encircle the wire.

FIELD SURROUNDING A HELIX

When the straight wire of Figure 22 is bent into a loop as shown in Figure 23, the electro-magnetic field surrounding it is concentrated through the center of the loop. The direction of the flux lines around the wire will retain the same relation to the direction of the current.

If additional loops are added in the wire until a helix is formed, each loop will establish a field similar to that shown in Figure 23, but as the proximity of the loops increases it has been found that flux lines extending in the same direction form a continuous field through the center of the helix and around its ends (Figure 24). Some of the lines surrounding each of the individual loops still remain, the number of such lines decreasing as the loops are wound closer together.

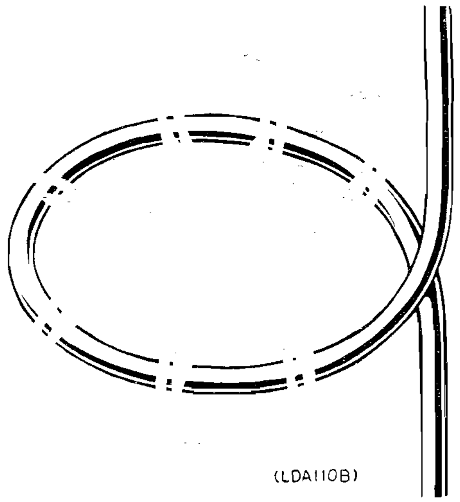


Figure 23—Field Surrounding a Wire Loop

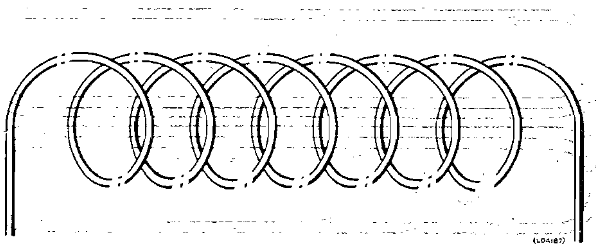


Figure 24—Field Surrounding a Helix

If the ends of a helix carrying a current are tested with a compass, it will be found that each end has the definite characteristics of a magnetic pole, and that the opposite ends of the helix have opposite poles.

INDUCTANCE

It has been shown (Figure 24) that when a current passes through a helix, a magnetic field surrounding the helix is established. When the current stops, this magnetic field collapses. Since the field established by each individual loop of the helix interlocks adjacent loops, any change in the field means that adjacent loops must cut lines of the field (Figure 25) with the result that a current is induced. The direction of this current is such as to oppose any change in the field surrounding the helix. The effect is termed self-inductance and has often been used in connection with low tension ignition circuits (See Page 23).

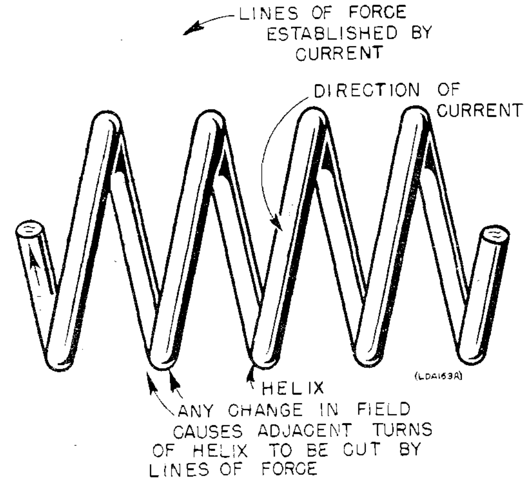


Figure 25—Self-Inductance

When a current flows in a straight conductor, a magnetic field is established surrounding the conductor (Figure 22) in what may be thought of as concentric circles. Any increase or decrease in the current produces corresponding changes in the field so that, if a second conductor is placed parallel to the first, the field will be cut by the conductor each time it rises and falls (Figure 26). If the conductor is part of a complete circuit, an induced current will flow in proportion to the current in the original circuit. The direction of the induced current is such as to oppose any change in the magnetic field of the original current. The effect is called mutual inductance and is the basis of all transformer design.

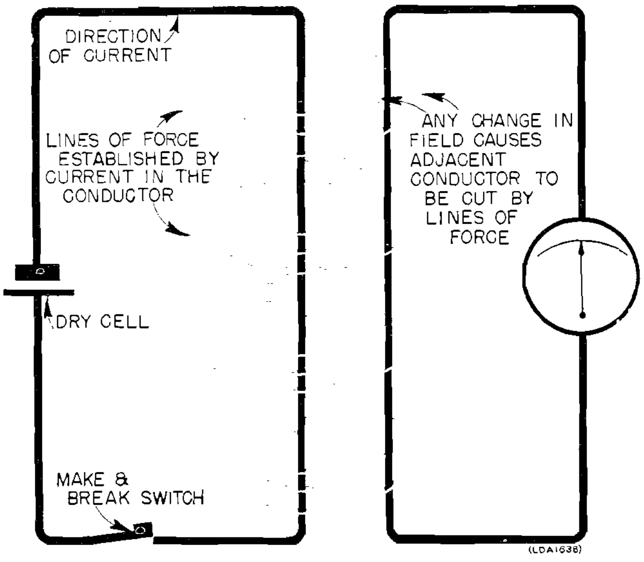


Figure 26—Mutual Inductance

TRANSFORMERS

The transformer is a practical application of the principle of mutual inductance. The assembly consists essentially in a primary winding, a secondary winding and a laminated iron core. When current flows in the primary winding, a magnetic field is established, the iron core concentrating this field so that it interlocks the secondary winding with minimum loss.

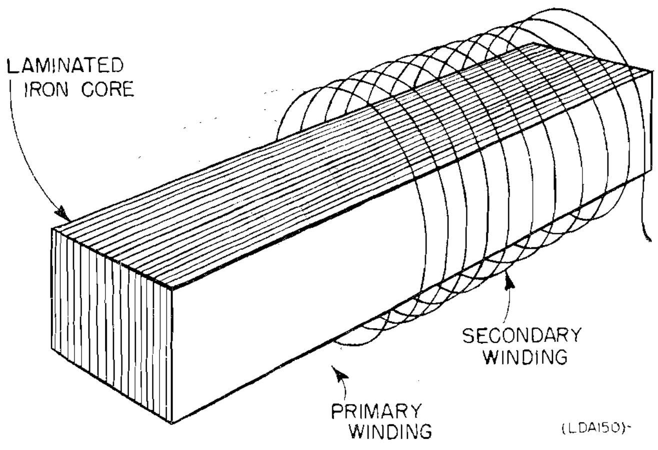


Figure 27—Simple Transformer

There are many forms of transformers, the different types usually being based on the design of the lamination assembly. In Figure 27 the simplest type is shown, where both primary and secondary windings are mounted on a straight core, while in Figure 28 a closed type core is used in order to increase the efficiency.

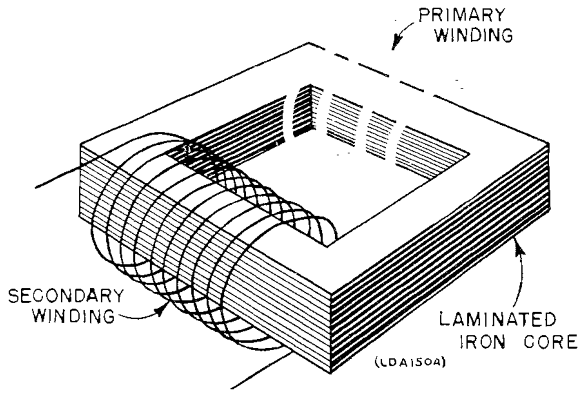


Figure 28—Closed-Core Transformer

The principal purpose of the transformer is to step voltage up or down. The ratio of the turns of the primary winding to those of the secondary winding determines the ratio of the primary voltage to the secondary voltage.

SPARK OR INDUCTION COIL

Transformer action to secure high voltage current from a low voltage supply is well illustrated in the spark or induction coil (Figure 29). Tracing the circuit shown in Figure 30, low voltage current is supplied by the battery to the contact post, across the breaker points to the primary terminal of the coil, through the primary winding

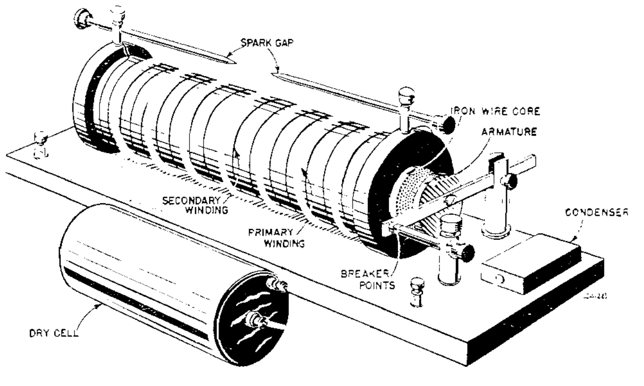


Figure 29—Spark Coil

and back to the battery. When the circuit is closed current flows through the primary winding and establishes a magnetic field, one of the results being that the iron core becomes magnetized and attracts the armature, which in turn opens the contact points and breaks the primary circuit. With the current cut, the magnetic field collapses and the armature is released, closing the contact points and repeating the cycle.

The high voltage circuit consists of a secondary winding on the coil, usually having a very high ratio of turns to that of the primary. The ends of the secondary winding are connected to a spark gap. Each time a magnetic field is established by current in the primary winding, the lines of force of the field cut the turns of the secondary winding and an electromotive force is induced, great enough to break down the spark gap and permit current to flow in the circuit. A similar condition exists when the primary circuit is broken and the field collapses.

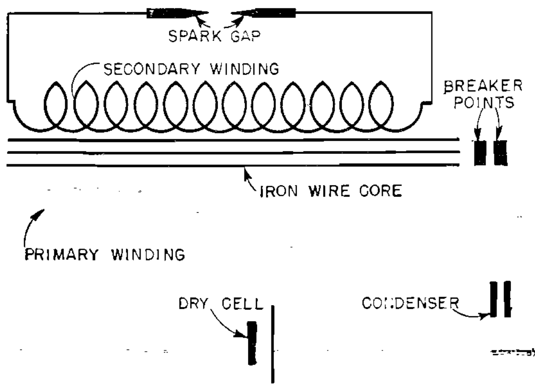


Figure 30—Circuit Diagram of Spark Coil

In a circuit such as this a condenser is usually connected across the contact points. When the armature separates the contact points the self-induction of the coil acts to prevent a break in the circuit by arcing across the points. The condenser acts to store this surge of energy and the break is much cleaner, which increases the secondary spark. After the circuit is broken, the condenser discharges back into the primary to demagnetize the core.

ELECTRO-MAGNETIC INDUCTION

When a magnet is so moved that the lines of its field are cut by a conductor, an electromotive force is induced in the conductor. Similarly, if a conductor is so moved that it cuts the lines of a magnetic field (Figure 31 "a"), an electromotive force is induced in the conductor. When the conductor is part of a closed circuit (Figure 31 "b"), an induced current will flow in the circuit.

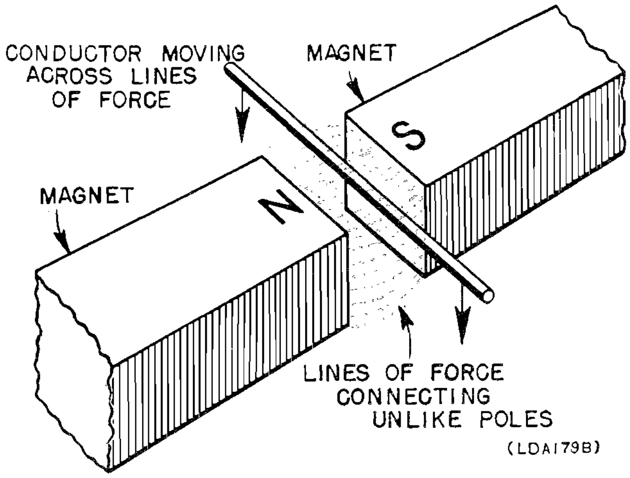


Figure 31 "a"—Electro-Magnetic Induction

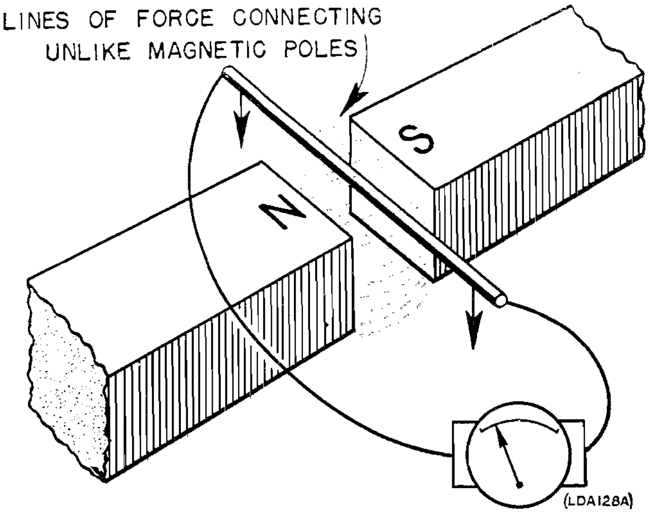


Figure 31 "b"—Induction of an Electric Current

The induced current is proportional to the strength of the magnetic field, to the rate at which the conductor cuts the lines of the field and to the number of conductors cutting the lines of the field.

The direction of the induced current is such as to establish a magnetic field which opposes the movement of the conductor. A variation of the right hand rule applies: Let the forefinger of the right hand point in the direction of the lines of the magnetic field, turn the hand so that the extended thumb points in the direction the conductor is moving; the middle finger bent at right angles to both the thumb and forefinger will then indicate the direction of the induced current.

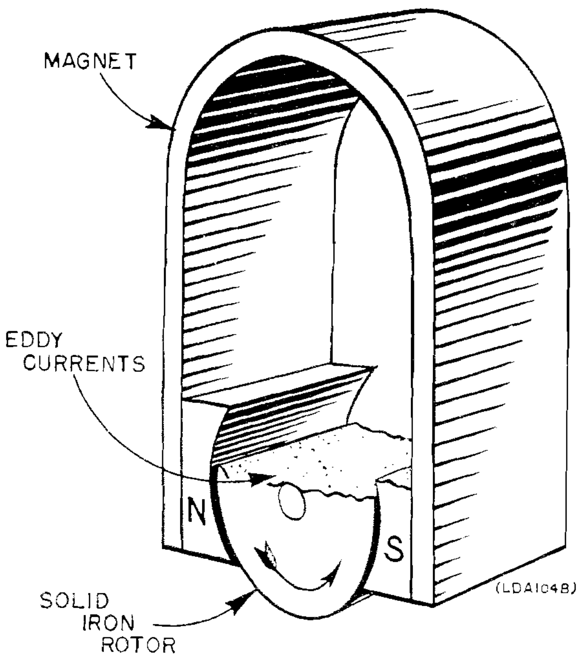


Figure 32—Eddy Currents

EDDY CURRENTS

Induced currents as a result of a changing magnetic flux appear not only in wires but also in conductors such as plates or blocks. If a solid iron rotor is turned rapidly within a magnetic field (and at right angles to the field), a definite heating effect will soon be noticed in the rotor. This heat is produced as the result of the flow of eddy currents in the rotor (Figure 32). Eddy currents flow in such a direction as to establish a field which opposes movement of the rotor. Except in the case of speedometers, watt-hour meters and similar instrument, eddy currents serve no useful purpose, but often are the cause of dangerous temperature increases due to the heat generated. Eddy currents are a direct loss in the efficiency of electrical machinery, but good design practices tend to reduce such loss to a minimum.

LAMINATED ASSEMBLIES

Since the path of induced eddy currents is at right angles to the magnetic field which causes them, it is possible to reduce such currents to a negligible factor by using what is known as a laminated assembly.

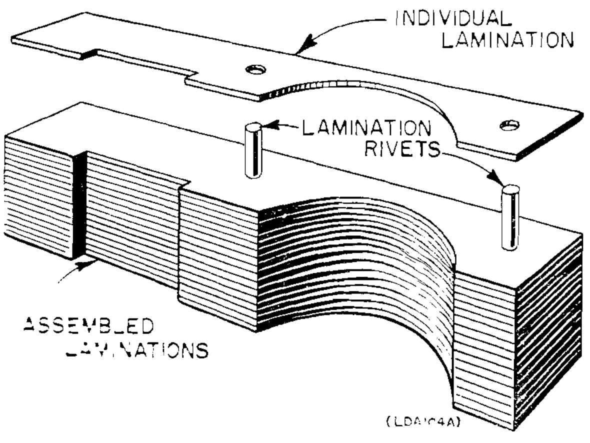


Figure 33—Laminated Field Assembly

A laminated assembly is made by stacking thin iron or steel punchings together (Figure 33) until the required pole piece, core or rotor is formed, then riveting the sheets together and machining the assembly if necessary. The plane of the laminations must be perpendicular to the direction of the induced eddy currents in order to prevent their flow; the oxide on the surfaces of the laminations usually provides sufficiently high resistance to the formation of eddy currents, although the surfaces are sometimes painted or varnished. Insulated rivets are often used in binding the assembly into one piece. The thinner the laminations and the better they are insulated from each other, the more effectively eddy currents are prevented.

Some types of ignition coils (Figure 29) are made with cores of varnished or painted iron wire, the purpose being identical with that of laminated sheet assemblies.

CAPACITANCE

In its simplest form (Figure 34) a capacitor (or condenser, as it is more commonly known) is a pair of flat metal plates, placed parallel to each other and separated by air. When the metal plates are connected to a source of electric potential, the air separating the plates undergoes a definite stress. When the electric potential is disconnected this condition of stress remains, but it may be relieved by short-circuiting the two plates, the electrical discharge which occurs indicating the amount of energy stored in the condenser.

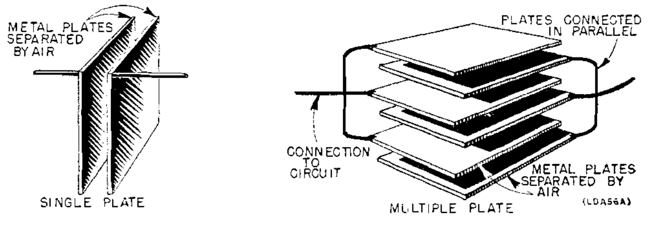


Figure 34—Simple Parallel Plate Condensers

The function of a condenser in an electric circuit corresponds with the use of a diaphragm in a water circuit.

The capacitance of a condenser depends upon the adjacent area of the plates, the distance they are separated and upon the substance separating the plates (known as the dielectric). Extensive research has been made concerning dielectrics. Probably the most familiar type of condenser (Figure 35) is of wound-construction with metal foil strips separated by wax-impregnated paper, but many other materials such as glass, mica and oil make excellent dielectrics.

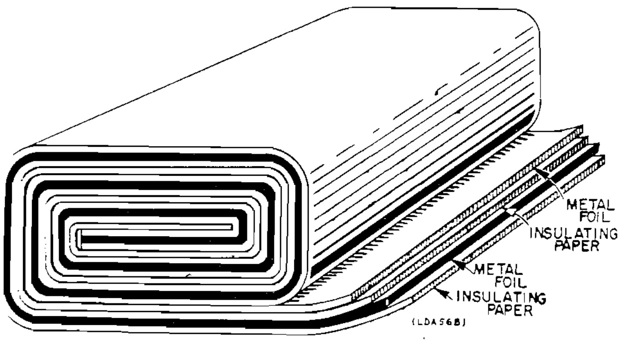


Figure 35—Paper-and Foil-Wound Condenser

INDUCTIVE & NON-INDUCTIVE CONDENSERS

Commercial condensers for ignition circuits are usually of the wound design and in order to secure the necessary capacitance often consist of comparatively long strips of foil separated by a dielectric such as paper.

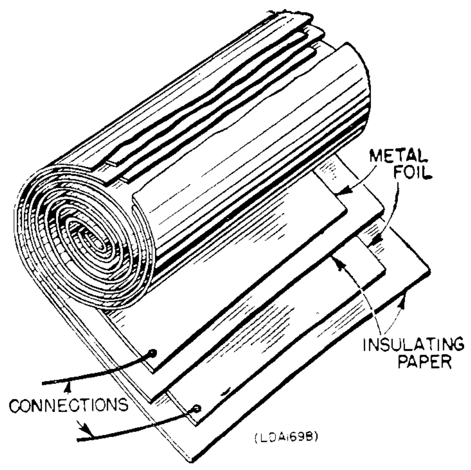


Figure 36—Inductive Type Wound Condenser

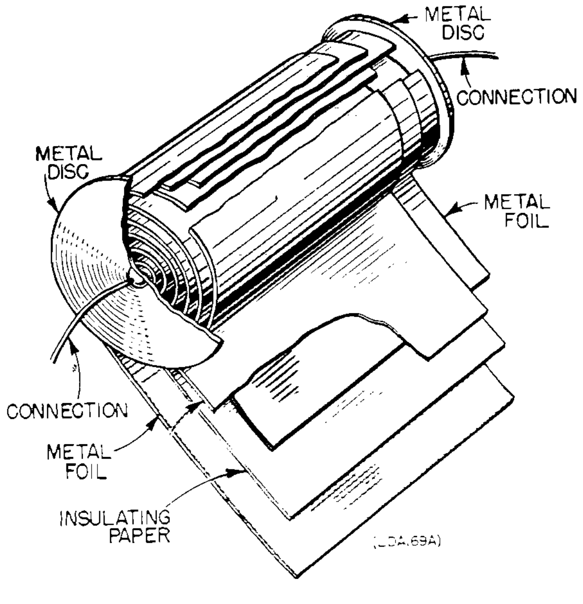


Figure 37—Non-Inductive Type Wound Condenser

Such a condenser provides the capacitance for the ignition circuit, but it has been found that when the connections are made at the extreme end of each strip of foil (Figure 36), an undesirable inductance effect also enters the electrical circuit. This type of condenser has therefore been termed an inductive condenser.

To avoid this inductance effect, a non-inductive condenser is obtained by making the connections at a number of points along the foil strips (Figure 37) instead of just at the ends. Actually this construction amounts to an arrangement of condensers in parallel, the total capacitance being the sum of the individual values.

LEAKAGE CURRENT

Insulators such as rubber or glass have enormous resistance to the flow of electric current, but it has been established that, regardless of the material, when a difference of potential exists some current actually flows. This current is called leakage current.

Leakage current results in heat, light or chemical reactions and, while the energy loss is usually negligible, the changes caused in the chemical composition of the insulator may in time destroy its insulating value.

Moisture, temperature and voltage gradient are important factors influencing the effects of leakage currents.

MEASUREMENT OF HIGH VOLTAGE

Ordinary voltmeters cannot be used to measure the high voltage of ignition spark discharges, which lie within a range of 10,000 to 30,000 volts, usually expressed as 10 to 30 kilovolts. For laboratory work a specially designed instrument known as the electrostatic voltmeter is used, but its cost and limited use hardly make such equipment worthwhile in service stations.

High voltages can be approximately measured by using

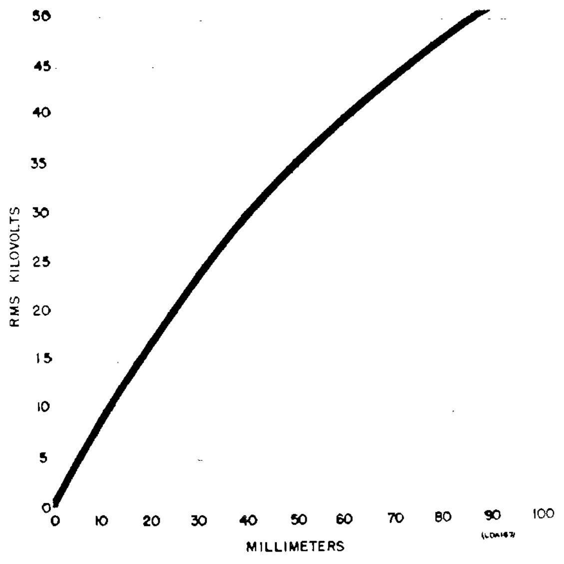


Figure 38—Spark Gap Values

an adjustable spark gap, but great care must be taken in the construction of the apparatus and in meeting certain test conditions. The values shown in the graph (Figure 38) are given for a temperature of 25°C. and 760 mm. barometric pressure.

The test apparatus consists of two No. 00 sewing needles supported axially at the ends of linear conductors which were at least twice the length of the gap and clear space surrounded the gap for a radius of at least twice the gap length. It should be noted that once the air gap between the points has been broken down by a spark discharge subsequent tests do not become dependable until all traces of ionization are removed.

For voltages over 50 kilovolts a gap between metal spheres must be used, an entirely new set of values being necessary in such a case.

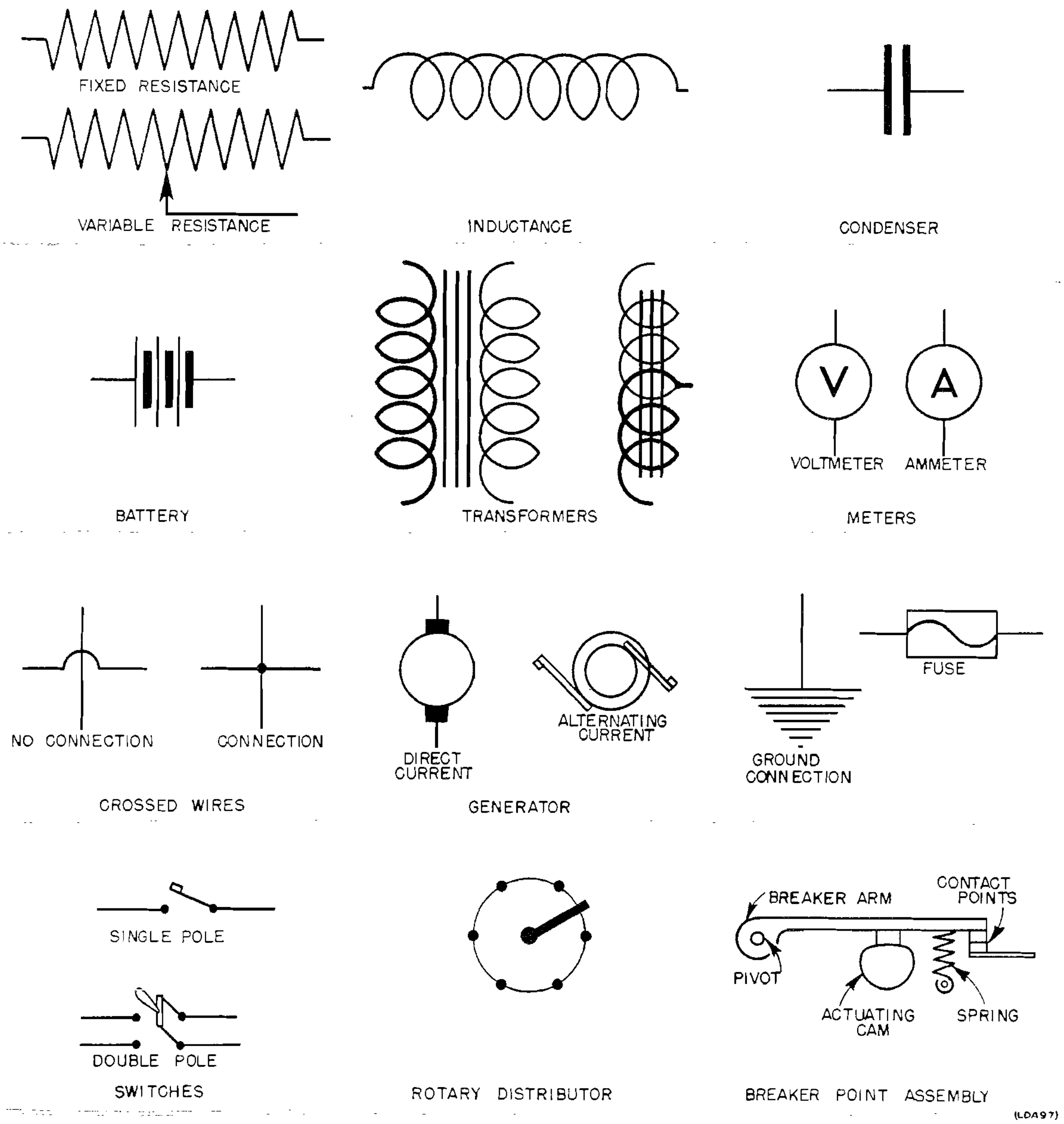


Figure 39—Conventional Drawing Symbols for Electrical Parts

SECTION THREE

IGNITION REQUIREMENTS

INTERNAL COMBUSTION ENGINES

Any discussion of ignition requirements necessitates a general knowledge of internal combustion engine design principles and operation. Internal combustion engines operate on the fundamental principle that when a combustible substance is ignited under pressure an explosion occurs, the force of the resultant expansion of the burning gases being transferred to the engine crankshaft by means of the reciprocating action of a piston.

Internal combustion engines are divided according to ignition into two main classes: (a) Compression-ignition (Diesel) engines and (b) spark-ignition engines. Engines may also be grouped according to the arrangement of their cylinders: (a) in-line, (b) v-bank, (c) radial, (d) rotary, (e) opposed piston and (f) opposed cylinders. An even broader classification divides all engines into either two or four cycle engines or into either horizontal or vertical engines.

COMPRESSION-IGNITION ENGINES

In a compression-ignition engine the air in the cylinder is compressed until it reaches a certain maximum point at which liquid fuel is injected into the cylinder, the heat of the compression at this point being sufficient to ignite the fuel. The compression ratio of the Diesel engine is several times greater than that of the average spark-ignition engine and consequently it is a decidedly more expensive engine to build. Furthermore, an intricate and costly fuel injection system is required.

Cheap, low grade fuel can, however, be burned in compression-ignition engines with a comparatively high efficiency, the result being that operating costs are often considerably lower than for other types of engines.

Some compression-ignition engines are so designed and built that they can be started and "warmed up" as spark-ignition engines, after which they are switched over to run as compression-ignition engines.

SPARK-IGNITION ENGINES

In the spark-ignition engine the fuel and air mixture is usually controlled and supplied to the cylinders by a carburetor. The combustible mixture is drawn into each cylinder by piston action, being compressed during the piston's upward stroke and ignited by an electrical discharge occurring across the points of a spark plug.

By far the greater number of internal combustion engines in use are of the spark-ignition design. This is true mainly because such engines can be built at a fraction of the cost of comparable compression-ignition engines, and because both operation and service are considerably simpler. Spark-ignition engines in general require a refined type of fuel such as gasoline, although special adaptations permit the use of natural or artificial gas, kerosene and light fuel oils.

The weight per horsepower of the spark-ignition engine is ordinarily much less than that of a corresponding compression-ignition engine, a definite advantage in the application to vehicles and aircraft.

TWO CYCLE ENGINES

A two cycle engine is one which requires two full

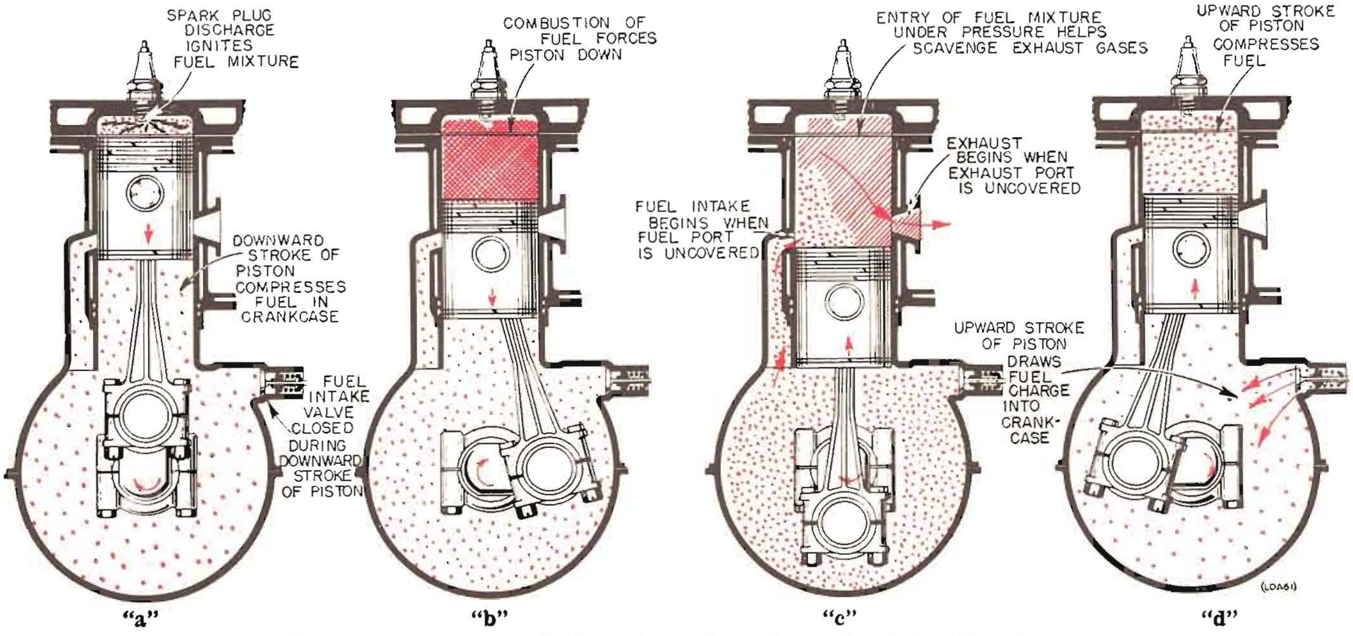


Figure 40—Sequence of Operations—Two Cycle Spark-Ignition Engine

strokes (one upward, one downward) of the piston assembly to complete the sequence of operations involved.

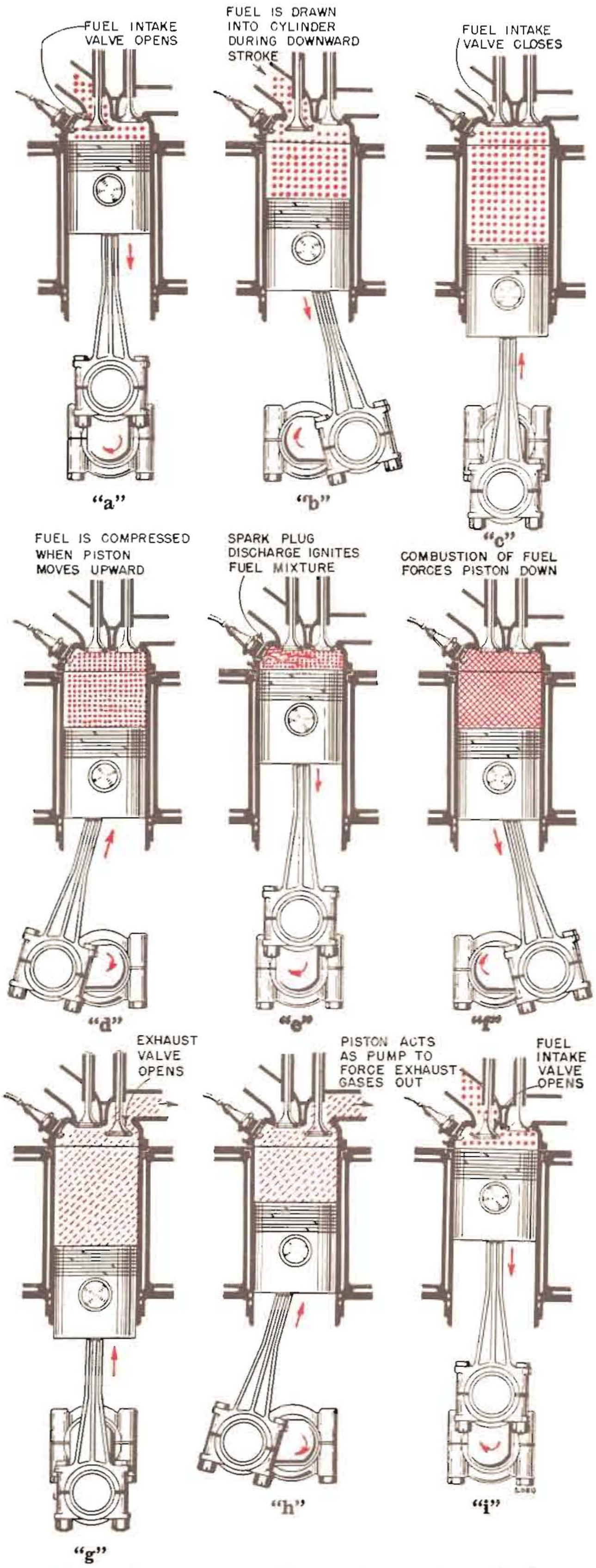


Figure 41—Sequence of Operations—Four Cycle Spark-Ignition Engine

Beginning with the ignition by the spark plug of the compressed combustible mixture of fuel and air (Figure 40 "a"), the expansion of the burning gases in the cylinder drives the piston down (Figure 40 "b") until the cylinder exhaust ports are uncovered (Figure 40 "c"). Meanwhile, this downward movement of the piston has compressed the fuel and air mixture which fills the crankcase, the intake valve being closed during this period. When the inlet ports of the cylinder open as the result of further downward movement of the piston the compressed fuel and air mixture rushes into the cylinder. The design of the inlet ports and top of the piston is such as to promote a swirling effect which aids in scavenging the exhaust gases from the cylinder. The piston then begins its upward stroke, first closing the inlet ports, then the exhaust ports and continuing upward (Figure 40 "d") to compress the fresh combustible mixture in the cylinder until the point is reached where ignition again occurs (Figure 40 "a"), and the sequence of operations is repeated. During the upward stroke of the piston (Figure 40 "d") the crankcase intake valve opens and a new charge of fuel and air mixture is drawn into the crankcase.

FOUR CYCLE ENGINES

A four cycle engine is one which requires four full strokes (two upward, two downward) of the piston assembly to complete the sequence of operations involved.

Beginning with the piston starting its first downward stroke (Figure 41 "a"), a combustible charge of fuel and air is drawn from the carburetor into the cylinder through the open intake valve (Figure 41 "b"). When the piston reaches the bottom of its first downward stroke the intake valve closes (Figure 41 "c") and the piston begins moving upward (Figure 41 "d"), compressing the fuel and air mixture in the cylinder. This compression reaches its maximum when the piston reaches top dead center (Figure 41 "e"), at which point an electric spark jumps across the spark plug point gap and ignition of the combustible fuel mixture occurs. The expansion of the burning gases then forces the piston downward (Figure 41 "f") until the bottom of the stroke is reached. At this point (Figure 41 "g") the exhaust outlet valve opens and the piston begins its upward stroke, the exhaust gases being forced out of the cylinder (Figure 41 "h"). When the piston reaches the top of its stroke the exhaust outlet valve closes and the fuel inlet valve opens (Figure 41 "i"), the sequence of operations then being repeated.

IMPORTANCE OF IGNITION

Because engine performance is so vitally affected, the problem of ignition is one of major importance to every designer of spark-ignition engines. The following list indicates some of the factors directly related to the ignition system which must be considered when the original engine layouts are made:

(a) Shape of combustion chamber

(b) Type of spark plug

(c) Possibility of pre-ignition

(d) Intensity of ignition spark

(e) Ignition during starting period

(f) Effects of compression and speed

(g) Ignition sparks during exhaust strokes.

(h) Timing of the ignition spark

Decisions on design work such as this are best made when a complete summary of modern ignition units and their application is available for reference.

IGNITION SPARK TIMING — ENGINE SPEED

During the starting period of an engine the speed of rotation is low and it is obvious that for safe operation the ignition spark should occur either at or just after top dead center is reached in the piston stroke (Figure 42 "a"). The abrupt reversal of engine rotation known as "back-firing" which often results at slow speeds when the fuel is ignited before top dead center is reached is likely to cause damage to the engine and injury to the operator.

Ignition of the fuel charge does not, however, take place instantaneously, a certain amount of time being required for the complete combustion. As the engine speed increases the time during which the fuel may burn decreases; a point soon being reached where incomplete combustion results in very poor engine operation. To gain more time for the fuel combustion period the ignition point must be advanced considerably ahead of top dead center of the piston stroke (Figure 42 "b"). Back-firing does not occur because the fuel combustion is relatively slow in comparison with the speed of the piston and top dead center is reached before the expansion force of the burning gases has reached its maximum.

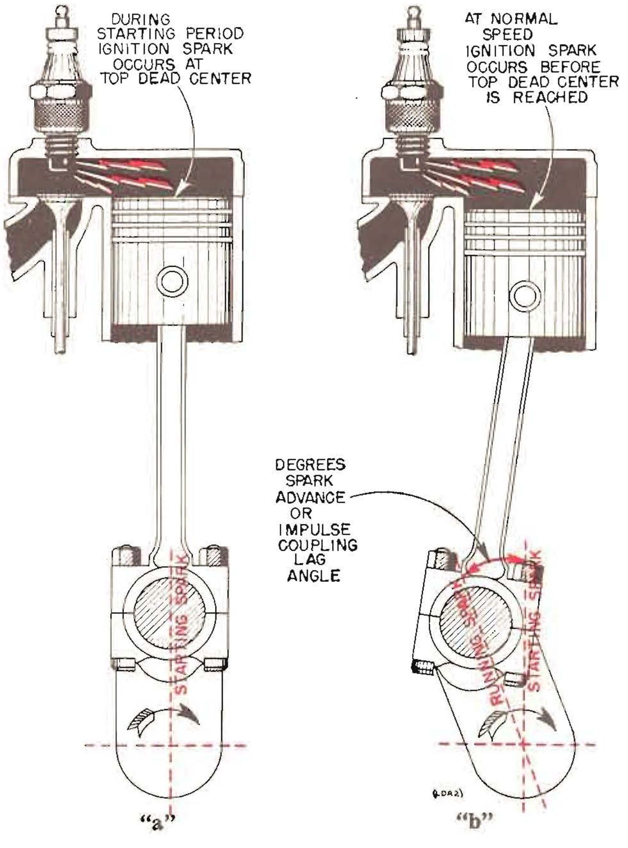


Figure 42—Starting and Running Spark

SPARK PLUGS

The actual occurrence of the ignition spark within the engine cylinder takes place across the points of a spark plug, the importance of which must not be overlooked, since the performance of the entire ignition system is completely dependent upon the proper functioning of this part. Spark plugs are specifically constructed for different types of service and should be selected carefully according to the manufacturer's recommendations.

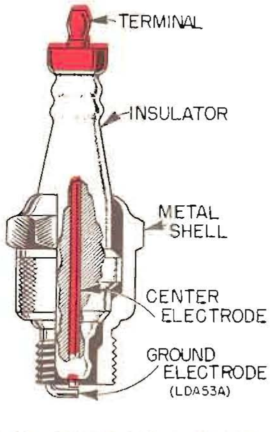


Figure 43—Spark Plug Construction

A spark plug (Figure 43) consists of a metal shell on which one of the electrodes is mounted, and an insulated centerpiece through which the second electrode is passed. Since the metal outer shell and its electrode are grounded to the engine head, only the one electrical connection to the center electrode is necessary. The spark plug must be set into the cylinder head gas-tight, usually accomplished by inserting a copper compression gasket between the plug and the head.

SPARK PLUG ELECTRODES

During engine operation the ignition sparks occur between the electrodes of the spark plug and as a result one or both of the electrodes is gradually eaten away. This action changes the width of the spark gap and eventually impairs engine operation to the point where readjustment of the gap must be made. By making the ends of the electrodes blunt instead of sharp the length of time the gap remains constant is increased, but a higher voltage spark is required to bridge the gap.

The center electrode is usually made of a nickel alloy wire while the insulator in which it is set is generally made of porcelain, although steatite (soapstone) and laminated mica have also been used. Requirements of the insulator are that it possess high electrical resistance, high heat resistance and high resistance to mechanical pressure.

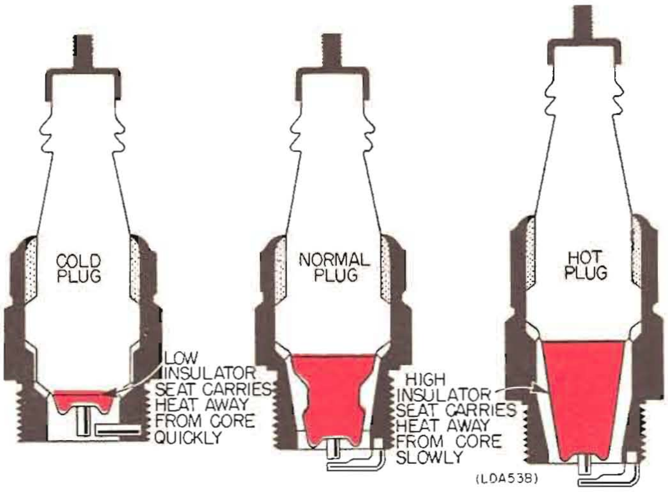


Figure 44—Cold-Normal-Hot Spark Plugs

HOT-NORMAL-COLD PLUGS

The inner end of the spark plug insulator should be so designed that under normal conditions the temperature it reaches is sufficient to burn off carbon deposits but not great enough to result in pre-ignition of the fuel charge. Since it is obvious that such a characteristic depends upon the operating conditions, spark plug manufacturers have offered (Figure 44) "hot" plugs in which there is considerable distance between the top of the insulator and the nearest point at which contact is made by the shell, and "cold" plugs in which there is only a short distance between the tip of the insulator and the shell contact, in addition to "normal" plugs which have a medium distance between the insulator and the shell. Cold plugs are ordinarily used for engines subjected to long continuous runs, while hot plugs are recommended for engines used for short intervals.

The recommendations made by the engine manufacturer should be carefully consulted before making any change in the type of spark plug used.

ENGINE SPEED & COMPRESSION

Spark-ignition engines are built to operate at rotative speeds ranging from 75 to 6000 rpm. It is obvious that the magneto specified must be able to function throughout the speed range of the engine. Furthermore, the impulse coupling used to provide the starting ignition must be of such design as to cut-out before idling speed is reached.

It is common practice to operate magnetos on slow speed engines at either crankshaft or twice crankshaft speed, and to operate magnetos on high speed engines at half crankshaft or camshaft speed. In all applications the required spark interval is the original determining factor.

Heavy duty magnetos with oversize coils and magnets are likely to be required on low speed engines in order to secure sufficiently strong ignition sparks.

As the compression within the cylinders of an engine increases the voltage required (Figure 45) to produce ignition sparks also increases. In effect this means that standard magnetos are unlikely to provide suitable ignition for very high compression engines, although the operation of high compression engines at a relatively higher rotative speed often acts as a counter-balance, in that the magneto produces higher voltage discharges.

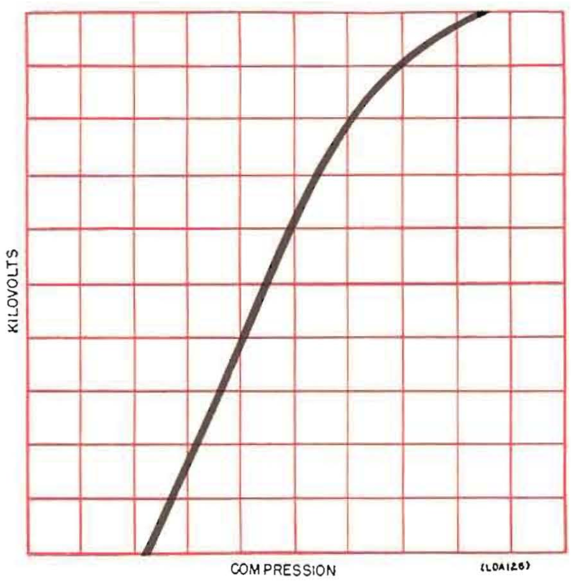


Figure 45—Compression/Kilovolt Spark Curve