3. All switches illustrated in schematics are __________.
   a. Shown in their normal position
   b. Always shown in their on position
   c. Always shown in their off position
   d. Shown in their on position except for lighting switches
4. When testing a relay using an ohmmeter, which two terminals should be touched to measure the coil resistance?
   a. 87 and 30
   b. 86 and 85
   c. 87a and 87
   d. 86 and 87
5. Technician A says that a good relay should measure between 60 and 100 ohms across the coil terminals. Technician B says that OL should be displayed on an ohmmeter when touching terminals 30 and 87. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Which relay terminal is the normally closed (N.C.) terminal?
   a. 30
   b. 85
   c. 87
   d. 87a
7. Technician A says that there is often more than one circuit being protected by each fuse. Technician B says that more than one circuit often shares a single ground connector. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Two technicians are discussing finding a short-to-ground using a test light. Technician A says that the test light, connected in place of the fuse, will light when the circuit that has the short is disconnected. Technician B says that the test light should be connected to the positive (+) and negative (−) terminals of the battery during this test. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A short circuit can be located using a __________.
   a. Test light
   b. Gauss gauge
   c. Tone generator
   d. All of the above
10. For an electrical device to operate, it must have __________.
   a. Power and a ground
   b. A switch and a fuse
   c. A ground and fusible link
   d. A relay to transfer the current to the device

chapter 46 CAPACITANCE AND CAPACITORS

OBJECTIVES: After studying Chapter 46, the reader should be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain capacitance. • Describe how a capacitor can be used to filter electrical noise. • Describe how a capacitor can store an electrical charge. • Explain how a capacitor circuit can be used as a timer circuit.

KEY TERMS: Capacitance 493 • Condenser 493 • Dielectric 494 • Farads 495 • Leyden jar 493

CAPACITANCE

DEFINITION **Capacitance** is the ability of an object or surface to store an electrical charge. Around 1745, Ewald Christian von Kliest and Pieter van Musschenbroek independently discovered capacitance in an electric circuit. While engaged in separate studies of electrostatics, they discovered that an electric charge could be stored for a period of time. They used a device, now called a **Leyden jar**, for their experimentation, which consisted of a glass jar filled with water, with a nail piercing the stopper and dipping into the water.

The two scientists connected the nail to an electrostatic charge. After disconnecting the nail from the source of the charge, they felt a shock by touching the nail, demonstrating that the device had stored the charge.

In 1747, John Bevis lined both the inside and outside of the jar with foil. This created a capacitor with two conductors (the inside and outside metal foil layers) equally separated by the insulating glass. ● **SEE FIGURE 46–1**. The Leyden jar was also used by Benjamin Franklin to store the charge from lightning as well as in other experiments. The natural phenomenon of lightning includes capacitance, because huge electrical fields develop between cloud layers or between clouds and the earth prior to a lightning strike.

NOTE: Capacitors are also called condensers. This term developed because electric charges collect, or condense, on the plates of a capacitor much like water vapor collects and condenses on a cold bottle or glass.

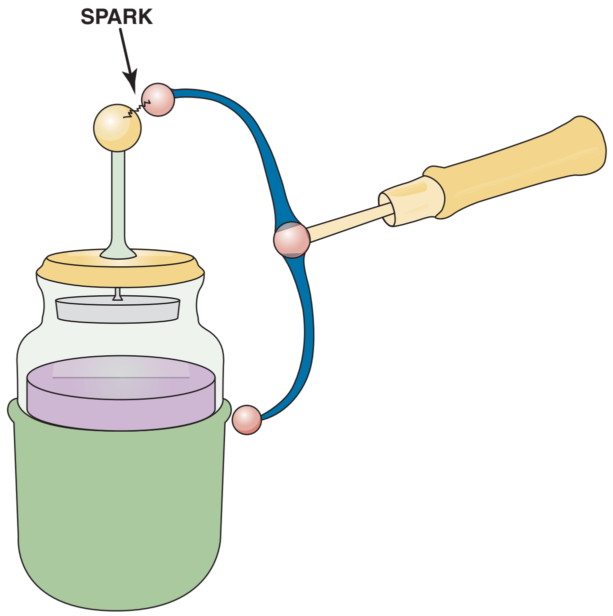


FIGURE 46–1 A Leyden jar can be used to store an electrical charge.

MATERIAL	DIELECTRIC CONSTANT
Vacuum	1
Air	1.00059
Polystyrene	2.5
Paper	3.5
Mica	5.4
Flint glass	9.9
Methyl alcohol	35
Glycerin	56.2
Pure water	81

CHART 46–1

The higher the dielectric constant is, the better the insulating properties between the plates of the capacitor.

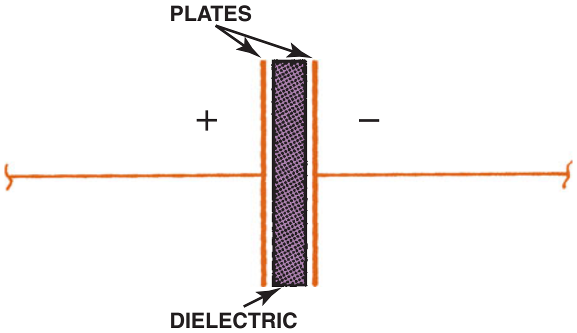


FIGURE 46–2 This simple capacitor, made of two plates separated by an insulating material, is called a dielectric.

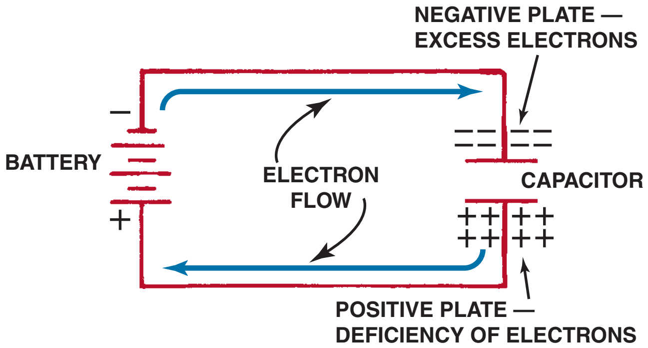


FIGURE 46–3 As the capacitor is charging, the battery forces electrons through the circuit.

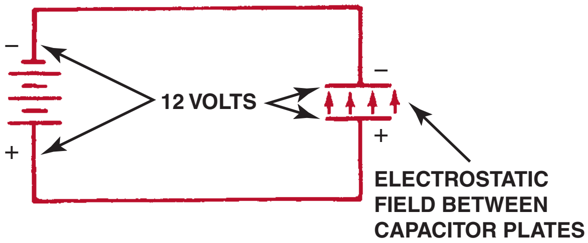


FIGURE 46–4 When the capacitor is charged, there is equal voltage across the capacitor and the battery. An electrostatic field exists between the capacitor plates. No current flows in the circuit.

CAPACITOR CONSTRUCTION AND OPERATION

CONSTRUCTION A capacitor (also called a condenser) consists of two conductive plates with an insulating material between them. The insulating material is commonly called a **dielectric**. This substance is a poor conductor of electricity and can include air, mica, ceramic, glass, paper, plastic, or any similar nonconductive material. The dielectric constant is the relative strength of a material against the flow of electrical current. The higher the number is, the better the insulating properties. ● **SEE CHART 46–1**.

OPERATION When a capacitor is placed in a closed circuit, the voltage source (battery) forces electrons around the circuit. Because electrons cannot flow through the dielectric of the capacitor, excess electrons collect on what becomes the negatively charged plate. At the same time, the other plate loses electrons and, therefore, becomes positively charged. ● **SEE FIGURE 46–2**.

Current continues until the voltage charge across the capacitor plates becomes the same as the source voltage. At that time, the negative plate of the capacitor and the negative terminal of the battery are at the same negative potential. ● **SEE FIGURE 46–3**.

The positive plate of the capacitor and the positive terminal of the battery are also at equal positive potentials. There is then a voltage charge across the battery terminals and an equal voltage charge across the capacitor plates. The circuit is in balance, and there is no current. An electrostatic field now exists between the capacitor plates because of their opposite charges. It is this field that stores energy. In other words, a charged capacitor is similar to a charged battery. ● **SEE FIGURE 46–4**.

If the circuit is opened, the capacitor will hold its charge until it is connected into an external circuit through which it can discharge. When the charged capacitor is connected to an external circuit, it discharges. After discharging, both plates of the capacitor are neutral because all the energy from a circuit stored in a capacitor is returned when it is discharged. ● **SEE FIGURE 46–5**.

Theoretically, a capacitor holds its charge indefinitely. Actually, the charge slowly leaks off the capacitor through the dielectric. The better the dielectric, the longer the capacitor holds its charge. To avoid an electrical shock, any capacitor should be treated as if it were charged until it is proven to be discharged. To safely discharge a capacitor, use a test light with the clip attached to a good ground, and touch the pigtail or terminal with the point of the test light. ● **SEE FIGURE 46–6** for the symbol for capacitors as used in electrical schematics.

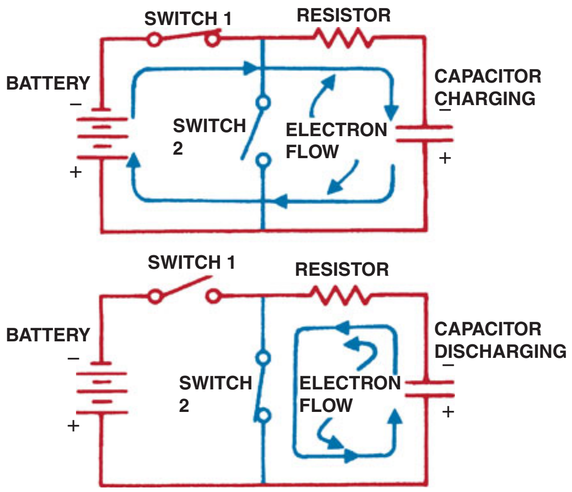


FIGURE 46–5 The capacitor is charged through one circuit (top) and discharged through another (bottom).

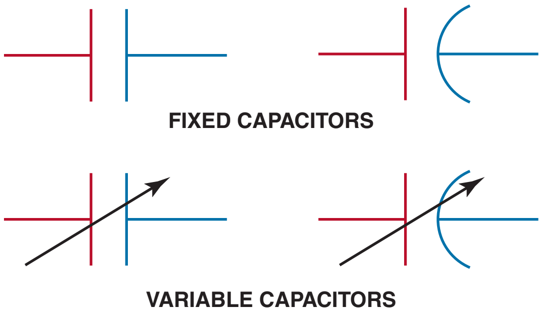


FIGURE 46–6 Capacitor symbols are shown in electrical diagrams. The negative plate is often shown curved.

FACTORS OF CAPACITANCE

Capacitance is governed by three factors.

- The surface area of the plates
- The distance between the plates
- The dielectric material

The larger the surface area of the plates is, the greater the capacitance, because more electrons collect on a larger plate area than on a small one. The closer the plates are to each other, the greater the capacitance, because a stronger electrostatic field exists between charged bodies that are close together. The insulating qualities of the dielectric material also affect capacitance. The capacitance of a capacitor is higher if the dielectric is a very good insulator.

MEASUREMENT OF CAPACITANCE Capacitance is measured in **farads,** which is named after Michael Faraday (1791–1867), an English physicist. The symbol for farads is the letter *F*. If a charge of 1 coulomb is placed on the plates of a capacitor and the potential difference between them is 1 volt, then the capacitance is defined to be 1 farad, or 1 F. One coulomb is equal to the charge of 6.25×10^{18} electrons. One farad is an extremely large quantity of capacitance. Microfarads (0.000001 farad), or μF, are more commonly used.

The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential.

? FREQUENTLY ASKED QUESTION

What Are "Points and Condenser"?

Points and condenser are used in point-type ignition systems.

Points. A set of points uses one stationary contact and a movable contact that is opened by a cam lobe inside the ignition distributor. When the points are closed, current flows through the primary windings of the ignition coil and creates a strong magnetic field. As the engine rotates, the distributor can open the contact points, which opens the circuit to the coil. The stored magnetic field in the coil collapses and generates a high-voltage arc from the secondary winding of the coil. It is this spark that is sent to the spark plugs that ignites the air-fuel mixture inside the engine.

Condenser. The condenser (capacitor) is attached to the points and the case of the condenser is grounded. When the points start to open, the charge built up in the primary winding of the coil would likely start to arc across the opening points. To prevent the points from arcing and to increase how rapidly the current is turned off, the condenser stores the current temporarily.

Points and condenser were used in vehicles and small gasoline engines until the mid-1970s. ● **SEE FIGURE 46–7**.

USES FOR CAPACITORS

SPIKE SUPPRESSION A capacitor can be used in parallel to a coil to reduce the resulting voltage spike that occurs when the circuit is opened. The energy stored to the magnet field of the coil is rapidly released at this time. The capacitor acts to absorb the high voltage produced and stop it from interfering with other electronic devices, such as automotive radio and video equipment.

NOISE FILTERING Interference in a sound system or radio is usually due to alternating current (AC) voltage created somewhere in the vehicle, such as in the alternator. A capacitor does the following:

- Blocks the flow of direct current (DC)
- Allows alternating current (AC) to pass

By connecting a capacitor (condenser) to the power lead of the radio or sound system amplifier, the AC voltage passes through the capacitor to the ground where the other end of the capacitor is connected. Therefore, the capacitor provides a path for the AC without affecting the DC power circuit. ● **SEE FIGURE 46–8**.

Because a capacitor stores a voltage charge, it opposes or slows any voltage change in a circuit. Therefore, capacitors are often used as voltage "shock absorbers." You sometimes find a capacitor attached to one terminal of an ignition coil. In this application, the capacitor absorbs and dampens changes in ignition voltage that interfere with radio reception.

SUPPLEMENTAL POWER SOURCE A capacitor can be used to supply electrical power for short bursts in an audio system to help drive the speakers. Woofers and subwoofers require a lot of electrical current that often cannot be delivered by the amplifier itself. ● **SEE FIGURE 46–9**.

TIMER CIRCUITS Capacitors are used in electronic circuits as part of a timer, to control window defoggers, interior lighting, pulse

FIGURE 46–7 A point-type distributor shown with the condenser from an old vehicle being tested on a distributor machine.

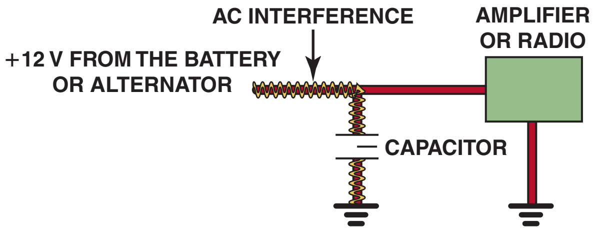


FIGURE 46–8 A capacitor blocks direct current (DC) but passes alternating current (AC). A capacitor makes a very good noise suppressor because most of the interference is AC and the capacitor will conduct this AC to ground before it can reach the radio or amplifier.

FIGURE 46–9 A 1 farad capacitor used to boost the power to large speakers.

wipers, and automatic headlights. The capacitors store energy and then are allowed to discharge through a resistance load. The greater the capacity of the capacitor and the higher the resistance load, the longer the time it takes for the capacitor to discharge.

COMPUTER MEMORY In most cases, the main memory of a computer is a high-speed random-access memory (RAM). One type of main memory, called dynamic random-access memory (DRAM), is the most commonly used type of RAM. A single memory chip is made up of several million memory cells. In a DRAM chip, each memory cell consists of a capacitor. When a capacitor is electrically charged, it is said to store the binary digit 1, and when discharged, it represents 0.

CONDENSER MICROPHONES A microphone converts sound waves into an electric signal. All microphones have a diaphragm that vibrates as sound waves strike. The vibrating diaphragm in turn causes an electrical component to create an output flow of current at a frequency proportional to the sound waves. A condenser microphone uses a capacitor for this purpose.

In a condenser microphone, the diaphragm is the negatively charged plate of a charged capacitor. When a sound wave compresses the diaphragm, the diaphragm is moved closer to the positive plate. Decreasing the distance between the plates increases the electrostatic attraction between them, which results in a flow of current to the negative plate. As the diaphragm moves out in response to sound waves, it also moves farther from the positive plate. Increasing the distance between the plates decreases the electrostatic attraction between them. This results in a flow of current back to the positive plate. These alternating flows of current provide weak electronic signals that travel to an amplifier and then to a loudspeaker.

CAPACITORS IN CIRCUITS

CAPACITORS IN PARALLEL CIRCUITS Capacitance can be increased in a circuit by connecting capacitors in parallel. For example, if a greater boost is needed for a sound system, then additional capacitors should be connected in parallel because their value adds together. ● **SEE FIGURE 46–10**.

We know that capacitance of a capacitor can be increased by increasing the size of its plates. Connecting two or more capacitors in parallel in effect increases plate size. Increasing plate area makes it possible to store more charge and therefore creates greater capacitance. To determine total capacitance of several parallel capacitors, simply add up their individual values. The following is the formula for calculating total capacitance in a circuit containing capacitors in parallel.

$$C_T = C_1 + C_2 + C_3 \ldots$$

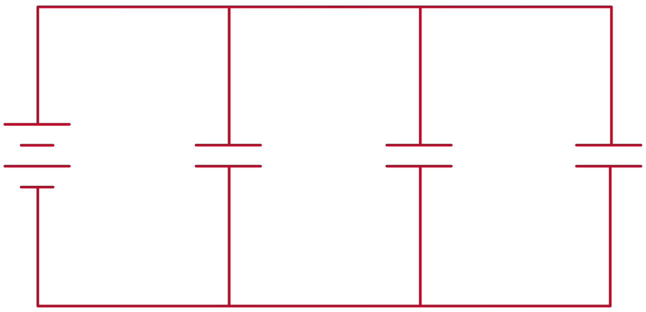


FIGURE 46–10 Capacitors in parallel effectively increase the capacitance.

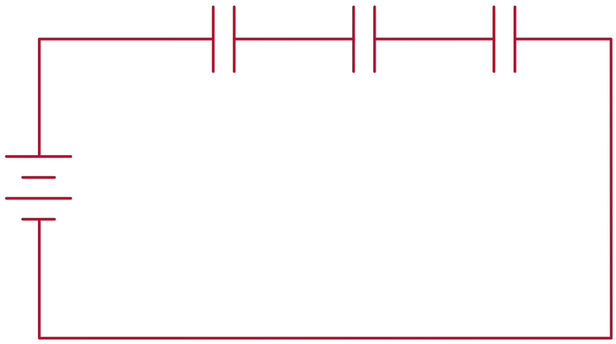


FIGURE 46–11 Capacitors in series decrease the capacitance.

For example, 220 µF + 220 µF = 440 µF when connected in parallel.

CAPACITORS IN SERIES CIRCUITS Capacitance can be decreased in a circuit by capacitors in series, as shown in ● **FIGURE 46–11**.

We know that capacitance of a capacitor can be decreased by placing the plates farther apart. Connecting two or more capacitors in series in effect increases the distance between the plates and thickness of the dielectric, thereby decreasing the amount of capacitance.

Following is the formula for calculating total capacitance in a circuit containing two capacitors in series.

$$C_T = \frac{C_1 \times C_2}{C_1 \times C_2}$$

For example, $\frac{220\,\mu F \times 220\,\mu F}{220\,\mu F \times 220\,\mu F} = \frac{48{,}400}{440} = 110\,\mu F$

NOTE: Capacitors are often used to reduce radio interference or to improve the performance of a high-power sound system. Additional capacitance can, therefore, be added by attaching another capacitor in parallel.

SUPPRESSION CAPACITORS Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used across the following:

- The primary circuit of some electronic ignition modules
- The output terminal of most alternators
- The armature circuit of some electric motors

Radio choke coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as electromagnetic interference (EMI) filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.

REVIEW QUESTIONS

1. How does a capacitor store an electrical charge?
2. How should two capacitors be electrically connected if greater capacitance is needed?
3. Where can a capacitor be used as a power source?
4. How can a capacitor be used as a noise filter?

CHAPTER QUIZ

1. A capacitor ______________.
   a. Stores electrons
   b. Passes AC
   c. Blocks DC
   d. All of the above
2. A capacitor can also be called a ______________.
   a. Condenser
   b. Dielectric
   c. Farad
   d. DRAM
3. Capacitors are commonly used as a ______________.
   a. Voltage supply
   b. Timer
   c. Noise filter
   d. All of the above
4. A charged capacitor acts like a ______________.
   a. Switch
   b. Battery
   c. Resistor
   d. Coil
5. The unit of measurement for capacitor rating is the ____________.
   a. Ohm
   b. Volt
   c. Farad
   d. Ampere
6. Two technicians are discussing the operation of a capacitor. Technician A says that a capacitor can create electricity. Technician B says that a capacitor can store electricity. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Capacitors block the flow of ______________ current but allow ______________ current to pass.
   a. Strong; weak
   b. AC; DC
   c. DC; AC
   d. Weak; strong
8. To increase the capacity, what could be done?
   a. Connect another capacitor in series.
   b. Connect another capacitor in parallel.
   c. Add a resistor between two capacitors.
   d. Both a and b
9. A capacitor can be used in what components?
   a. Microphone
   b. Radio
   c. Speaker
   d. All of the above
10. A capacitor used for spike protection will normally be placed in ______________ to the load or circuit.
    a. Series
    b. Parallel
    c. Either series or parallel
    d. Parallel with a resistor in series

chapter 47

MAGNETISM AND ELECTROMAGNETISM

OBJECTIVES: After studying Chapter 47, the reader should be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain magnetism. • Describe how magnetism and voltage are related. • Describe how an ignition coil works. • Explain how an electromagnet works.

KEY TERMS: Ampere-turns 502 • Counter electromotive force (CEMF) 504 • Electromagnet 502 • Electromagnetic induction 504 • Electromagnetic interference (EMI) 506 • Electromagnetism 500 • Flux density 499 • Flux lines 498 • Ignition control module (ICM) 505 • Left-hand rule 500 • Lenz's law 504 • Magnetic flux 498 • Magnetic induction 499 • Magnetism 498 • Mutual induction 504 • Permeability 499 • Pole 498 • Relay 502 • Reluctance 500 • Residual magnetism 499 • Right-hand rule 500 • Turns ratio 505

FUNDAMENTALS OF MAGNETISM

DEFINITION **Magnetism** is a form of energy that is caused by the motion of electrons in some materials. It is recognized by the attraction it exerts on other materials. Like electricity, magnetism cannot be seen. It can be explained in theory, however, because it is possible to see the results of magnetism and recognize the actions that it causes. Magnetite is the most naturally occurring magnet. Naturally magnetized pieces of magnetite, called *lodestone,* will attract and hold small pieces of iron. ● **SEE FIGURE 47–1.**

Many other materials can be artificially magnetized to some degree, depending on their atomic structure. Soft iron is very easy to magnetize, whereas some materials, such as aluminum, glass, wood, and plastic, cannot be magnetized at all.

LINES OF FORCE The lines that create a field of force around a magnet are believed to be caused by the way groups of atoms are aligned in the magnetic material. In a bar magnet, the lines are concentrated at both ends of the bar and form closed, parallel loops in three dimensions around the magnet. Force does not flow along these lines the way electrical current flows, but the lines *do* have direction. They come out of the north end, or **pole,** of the magnet and enter at the other end. ● **SEE FIGURE 47–3.**

The opposite ends of a magnet are called its north and south poles. In reality, they should be called the "north seeking" and "south seeking" poles, because they seek the earth's North Pole and South Pole, respectively.

The more lines of force that are present, the stronger the magnet becomes. The magnetic lines of force, also called **magnetic flux** or **flux lines,** form a magnetic field. The terms *magnetic field, lines of force, flux,* and *flux lines* are used interchangeably.

TECH TIP

A Cracked Magnet Becomes Two Magnets

Magnets are commonly used in vehicle crankshaft, camshaft, and wheel speed sensors. If a magnet is struck and cracks or breaks, the result is two smaller-strength magnets. Because the strength of the magnetic field is reduced, the sensor output voltage is also reduced. A typical problem occurs when a magnetic crankshaft sensor becomes cracked, resulting in a no-start condition. Sometimes the cracked sensor works well enough to start an engine that is cranking at normal speeds but will not work when the engine is cold. ● **SEE FIGURE 47–2.**

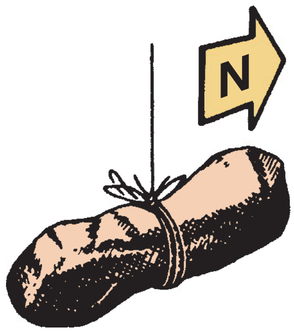


FIGURE 47–1 A freely suspended natural magnet (lodestone) will point toward the magnetic north pole.

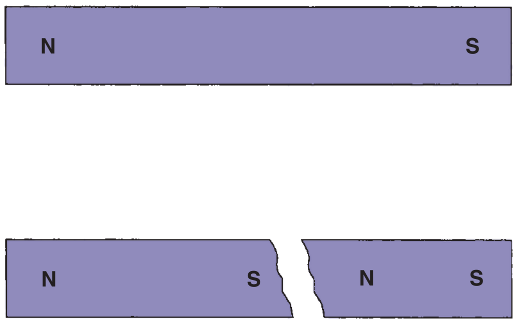


FIGURE 47–2 If a magnet breaks or is cracked, it becomes two weaker magnets.

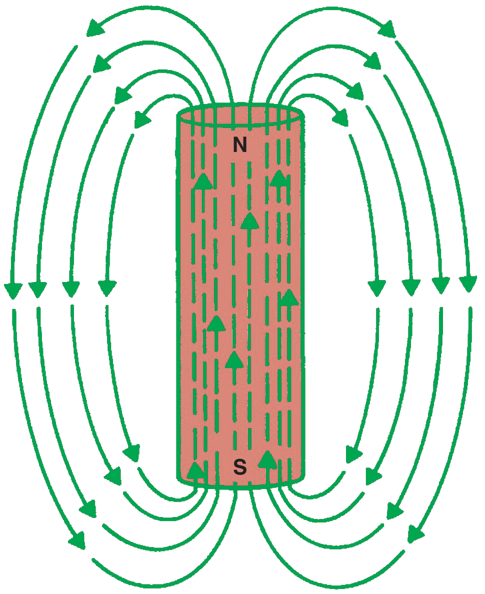


FIGURE 47–3 Magnetic lines of force leave the north pole and return to the south pole of a bar magnet.

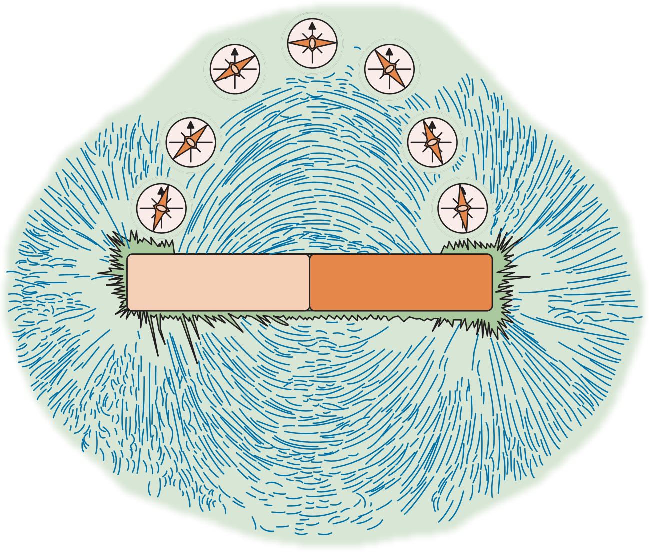


FIGURE 47–4 Iron filings and a compass can be used to observe the magnetic lines of force.

Flux density refers to the number of flux lines per unit of area. A magnetic field can be measured using a Gauss gauge, named for German scientist Johann Carl Friedrick Gauss (1777–1855).

Magnetic lines of force can be seen by spreading fine iron filings or dust on a piece of paper laid on top of a magnet. A magnetic field can also be observed by using a compass. A compass is simply a thin magnet or magnetized iron needle balanced on a pivot. The needle will rotate to point toward the opposite pole of a magnet. The needle can be very sensitive to small magnetic fields. Because it is a small magnet, a compass usually has one north end (marked N) and one south end (marked S). ● **SEE FIGURE 47–4.**

MAGNETIC INDUCTION If a piece of iron or steel is placed in a magnetic field, it will also become magnetized. This process of creating a magnet by using a magnetic field is called **magnetic induction.**

If the metal is then removed from the magnetic field, and it retains some magnetism, this is called **residual magnetism.**

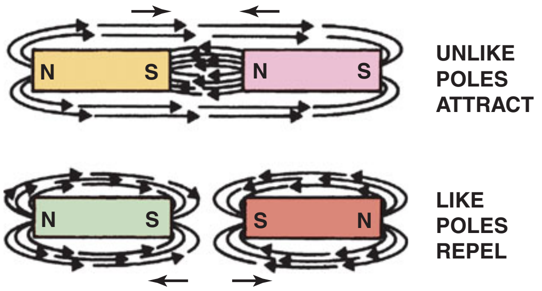


FIGURE 47–5 Magnetic poles behave like electrically charged particles—unlike poles attract and like poles repel.

> **TECH TIP**
>
> **Magnetize a Steel Needle**
>
> A piece of steel can be magnetized by rubbing a magnet in one direction along the steel. This causes the atoms to line up in the steel, so it acts like a magnet. The steel often will not remain magnetized, whereas the true magnet is permanently magnetized.
>
> When soft iron or steel is used, such as a paper clip, it will lose its magnetism quickly. The atoms in a magnetized needle can be disturbed by heating it or by dropping the needle on a hard object, which would cause the needle to lose its magnetism. Soft iron is used inside ignition coils because it will not keep its magnetism.

ATTRACTING OR REPELLING The poles of a magnet are called north (N) and south (S) because, when a magnet is suspended freely, the poles tend to point toward the earth's North Pole and South Pole. Magnetic flux lines exit from the north pole and bend around to enter the south pole. An equal number of lines exit and enter, so magnetic force is equal at both poles of a magnet. Flux lines are concentrated at the poles, and therefore magnetic force (flux density) is stronger at the ends.

Magnetic poles behave like positively and negatively charged particles. When unlike poles are placed close together, the lines exit from one magnet and enter the other. The two magnets are pulled together by flux lines. If like poles are placed close together, the curving flux lines meet head on, forcing the magnets apart. Therefore, like poles of a magnet repel and unlike poles attract. ● **SEE FIGURE 47–5.**

PERMEABILITY Magnetic flux lines cannot be insulated. There is no known material through which magnetic force does not pass, if the force is strong enough. However, some materials allow the force to pass through more easily than others. This degree of passage is called **permeability.** Iron allows magnetic flux lines to pass through much more easily than air, so iron is highly permeable.

An example of this characteristic is the use of a reluctor wheel in magnetic-type camshaft position (CMP) and crankshaft position (CKP) sensors. The teeth on a reluctor cause the magnetic field to increase as each tooth gets closer to the sensor and decrease as the tooth moves away, thus creating an AC voltage signal. ● **SEE FIGURE 47–6.**

RELUCTANCE Although there is no absolute insulation for magnetism, certain materials resist the passage of magnetic force. This can be compared to resistance without an electrical circuit. Air does

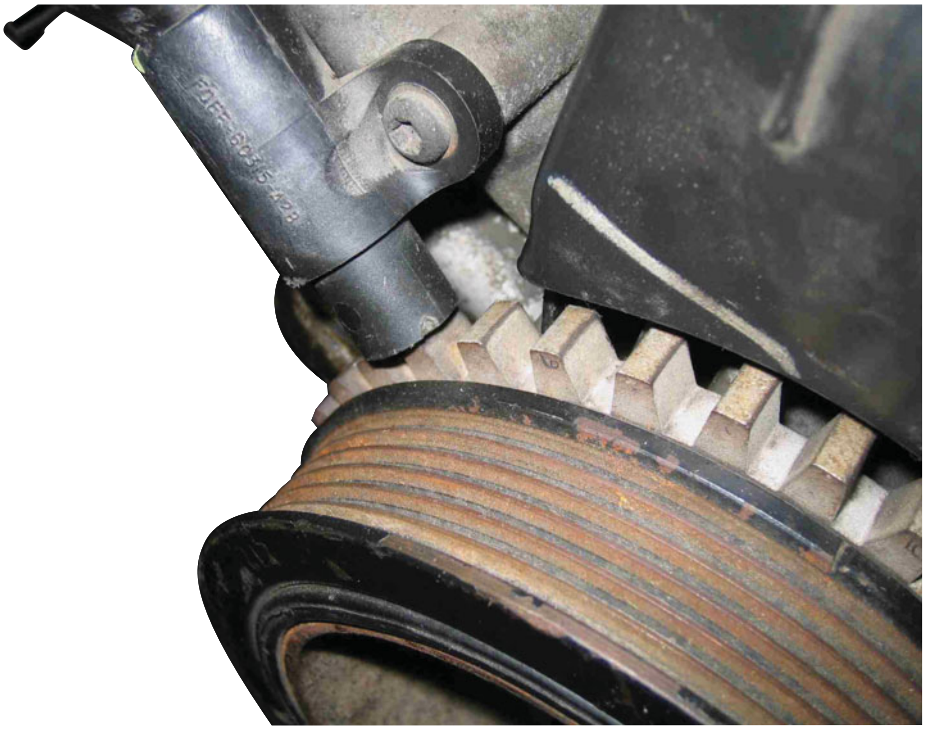


FIGURE 47–6 A crankshaft position sensor and reluctor (notched wheel).

not allow easy passage, so air has a high **reluctance.** Magnetic flux lines tend to concentrate in permeable materials and avoid materials with high reluctance. As with electricity, magnetic force follows the path of least resistance.

ELECTROMAGNETISM

DEFINITION Scientists did not discover that current-carrying conductors also are surrounded by a magnetic field until 1820. These fields may be made many times stronger than those surrounding conventional magnets. Also, the magnetic field strength around a conductor may be controlled by changing the current.

- As current increases, more flux lines are created and the magnetic field expands.
- As current decreases, the magnetic field contracts. The magnetic field collapses when the current is shut off.
- The interaction and relationship between magnetism and electricity is known as **electromagnetism.**

TECH TIP

Electricity and Magnetism

Electricity and magnetism are closely related because any electrical current flowing through a conductor creates a magnetic field. Any conductor moving through a magnetic field creates an electrical current. This relationship can be summarized as follows:

- Electricity creates magnetism.
- Magnetism creates electricity.

From a service technician's point of view, this relationship is important because wires carrying current should always be routed as the factory intended to avoid causing interference with another circuit or electronic component. This is especially important when installing or servicing spark plug wires, which carry high voltages and can cause high electromagnetic interference.

CREATING AN ELECTROMAGNET An easy way to create an electromagnet is to wrap a nail with 20 turns of insulated wire and connect the ends to the terminals of a 1.5 volt dry cell battery. When energized, the nail will become a magnet and will be able to pick up tacks or other small steel objects.

STRAIGHT CONDUCTOR The magnetic field surrounding a straight, current-carrying conductor consists of several concentric cylinders of flux that are the length of the wire. The amount of current flow (amperes) determines how many flux lines (cylinders) there will be and how far out they extend from the surface of the wire. ● **SEE FIGURE 47–7.**

LEFT-HAND AND RIGHT-HAND RULES Magnetic flux cylinders have direction, just as the flux lines surrounding a bar magnet have direction. The **left-hand rule** is a simple way to determine this direction. When you grasp a conductor with your left hand so that your thumb points in the direction of electron flow (− to +) through the conductor, your fingers curl around the wire in the direction of the magnetic flux lines. ● **SEE FIGURE 47–8.**

Most automotive circuits use the conventional theory of current (− to +) and, therefore, the **right-hand rule** is used to determine the direction of the magnetic flux lines. ● **SEE FIGURE 47–9.**

FIELD INTERACTION The cylinders of flux surrounding current-carrying conductors interact with other magnetic fields. In the following illustrations, the cross symbol (+) indicates current moving inward, or away from you. It represents the tail of an arrow. The dot symbol (•) represents an arrowhead and indicates current moving outward. If two conductors carry current in opposite directions, their magnetic fields also carry current in opposite directions

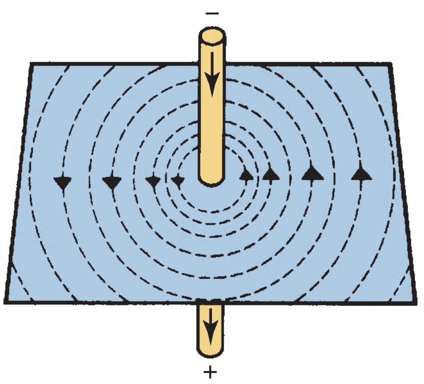


FIGURE 47–7 A magnetic field surrounds a straight, current-carrying conductor.

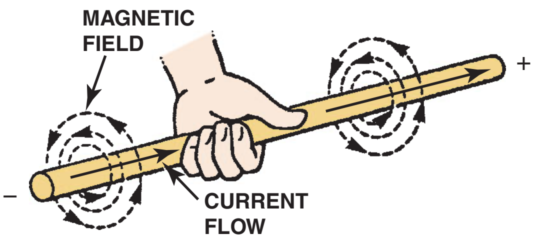


FIGURE 47–8 The left-hand rule for magnetic field direction is used with the electron flow theory.

FIGURE 47–9 The right-hand rule for magnetic field direction is used with the conventional theory of electron flow.

(according to the left-hand rule). If they are placed side by side, then the opposing flux lines between the conductors create a strong magnetic field. Current-carrying conductors tend to move out of a strong field into a weak field, so the conductors move away from each other. ● **SEE FIGURE 47–10.**

If the two conductors carry current in the same direction, then their fields are in the same direction. The flux lines between the two conductors cancel each other out, leaving a very weak field between them. The conductors are drawn into this weak field, and they tend to move toward each other.

MOTOR PRINCIPLE

Electric motors, such as vehicle starter motors, use this magnetic field interaction to convert electrical energy into mechanical energy. If two conductors carrying current in opposite directions are placed between strong north and south poles, the magnetic field of the conductor interacts with the magnetic fields of the poles. The counterclockwise field of the top conductor adds to the fields of the poles and creates a strong field beneath the conductor. The conductor then tries to move up to get out of this strong field. The clockwise field of the lower conductor adds to the field of the poles and creates a strong field above the conductor. The conductor then tries to move down to get out of this strong field. These forces cause the center of the motor, where the conductors are mounted, to turn clockwise. ● **SEE FIGURE 47–11.**

COIL CONDUCTOR

If several loops of wire are made into a coil, then the magnetic flux density is strengthened. Flux lines around a coil are the same as the flux lines around a bar magnet. ● **SEE FIGURE 47–12.**

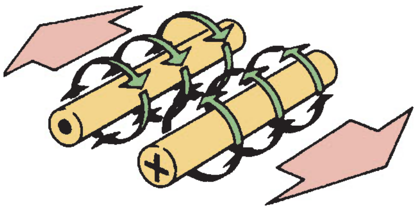


FIGURE 47–10 Conductors with opposing magnetic fields will move apart into weaker fields.

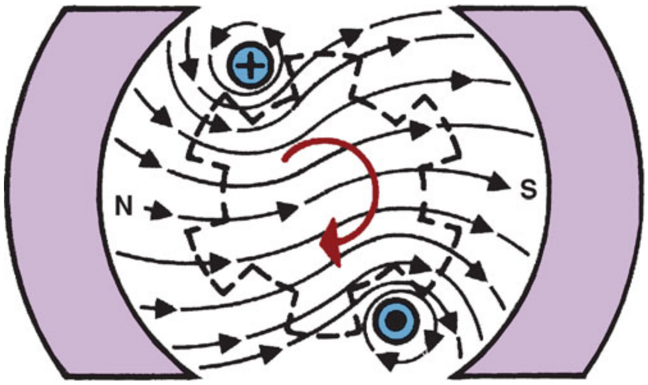


FIGURE 47–11 Electric motors use the interaction of magnetic fields to produce mechanical energy.

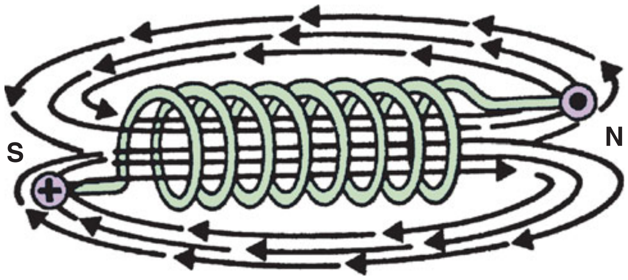


FIGURE 47–12 The magnetic lines of flux surrounding a coil look similar to those surrounding a bar magnet.

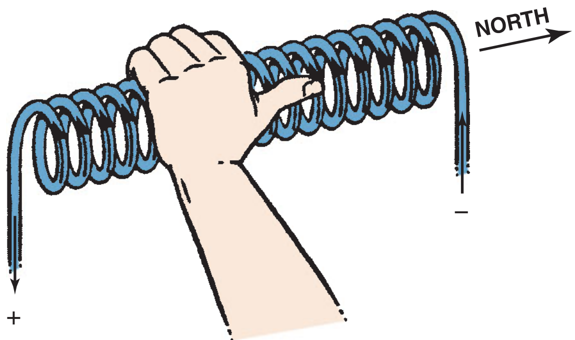


FIGURE 47–13 The left-hand rule for coils is shown.

They exit from the north pole and enter at the south pole. Use the left-hand rule to determine the north pole of a coil, as shown in ● **FIGURE 47–13.**

Grasp the coil with your left hand so that your fingers point in the direction of electron flow; your thumb will point toward the north pole of the coil.

ELECTROMAGNETIC STRENGTH

The magnetic field surrounding a current-carrying conductor can be strengthened (increased) three ways.

- Place a soft iron core in the center of the coil.
- Increase the number of turns of wire in the coil.
- Increase the current flow through the coil windings.

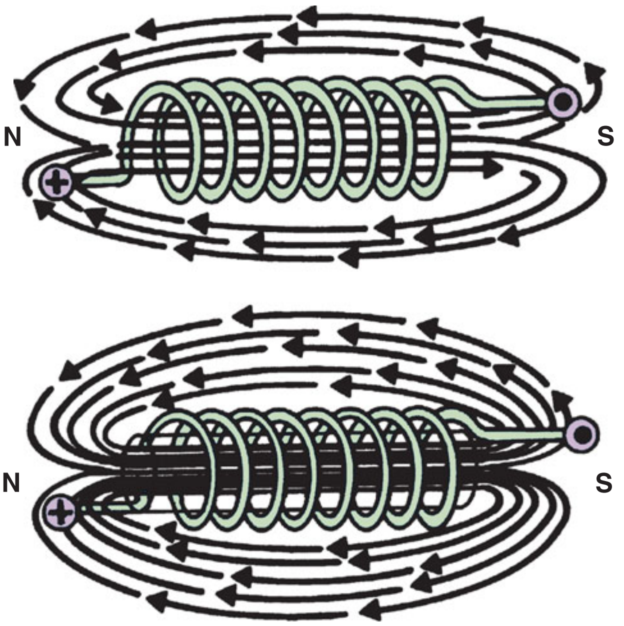


FIGURE 47–14 An iron core concentrates the magnetic lines of force surrounding a coil.

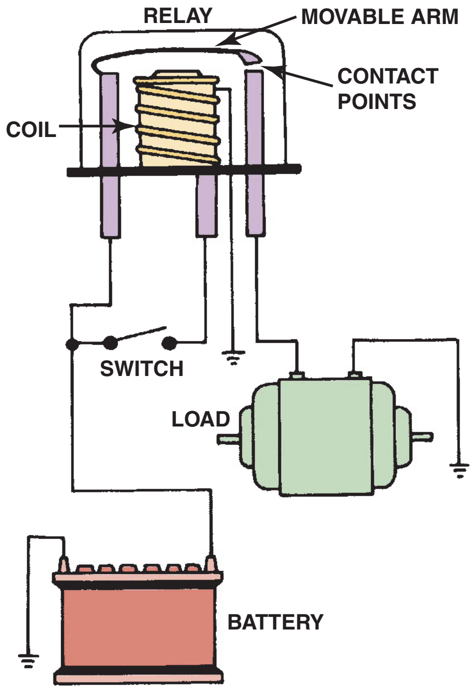


FIGURE 47–15 An electromagnetic switch that has a movable arm is referred to as a relay.

	CONSTRUCTION	AMPERAGE RATING	USES	CALLED IN SERVICE INFORMATION
Relay	Uses a movable arm Coil: 60 to 100 ohms requiring 0.12 to 0.20 A to energize	1 to 30 A	Lower current switching, lower cost, more commonly used	Electromagnetic switch or relay
Solenoid	Uses a movable core Coil(s): 0.2 to 0.6 ohm requiring 20 to 60 A to energize	30 to 400 A	Higher cost, used in starter motor circuits and other high-amperage applications	Solenoid, relay, or electromagnetic switch

CHART 47–1

Comparison between a relay and a solenoid.

Because soft iron is highly permeable, magnetic flux lines pass through it easily. If a piece of soft iron is placed inside a coiled conductor, the flux lines concentrate in the iron core, rather than pass through the air, which is less permeable. The concentration of force greatly increases the strength of the magnetic field inside the coil. Increasing the number of turns in a coil and/or increasing the current flow through the coil results in greater field strength and is proportional to the number of turns. The magnetic field strength is often expressed in the units called **ampere-turns.** Coils with an iron core are called **electromagnets.** ● **SEE FIGURE 47–14.**

USES OF ELECTROMAGNETISM

RELAYS As mentioned in the previous chapter, a **relay** is a control device that allows a small amount of current to control a large amount of current in another circuit. A simple relay contains an electromagnetic coil in series with a battery and a switch. Near the electromagnet is a movable flat arm, called an *armature*, of some material that is attracted by a magnetic field. ● **SEE FIGURE 47–15.**

The armature pivots at one end and is held a small distance away from the electromagnet by a spring (or by the spring steel of the movable arm itself). A contact point, made of a good conductor, is attached to the free end of the armature. Another contact point is fixed a small distance away. The two contact points are wired in series with an electrical load and the battery.

When the switch is closed, the following occurs.

1. Current travels from the battery through a coil, creating an electromagnet.
2. The magnetic field created by the current attracts the armature, pulling it down until the contact points close.
3. Closing the contacts allows current in the heavy current circuit from the battery to the load.

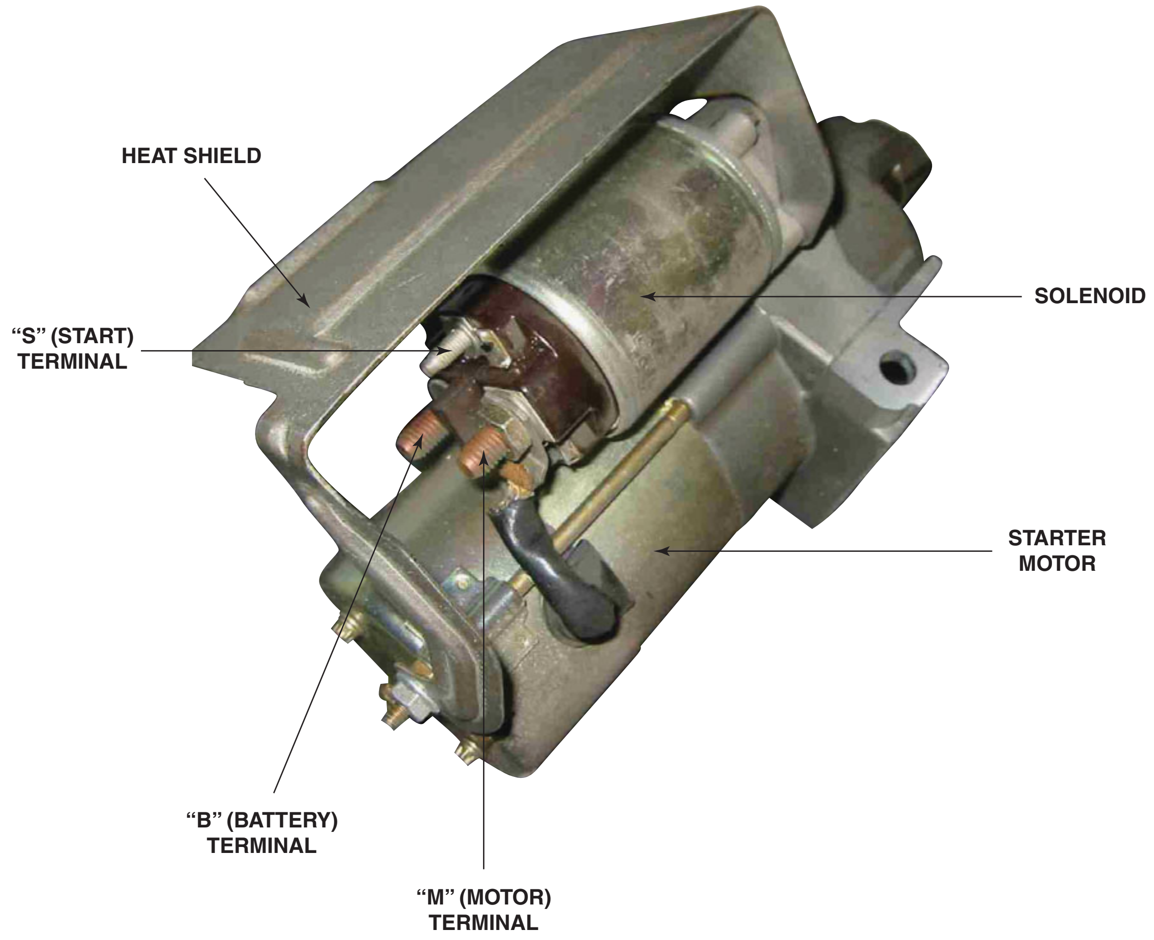
When the switch is open, the following occurs.

1. The electromagnet loses its magnetism when the current is shut off.

? FREQUENTLY ASKED QUESTION

Solenoid or Relay?

Often, either term is used to describe the same part in service information. ● **SEE CHART 47–1** for a summary of the differences.



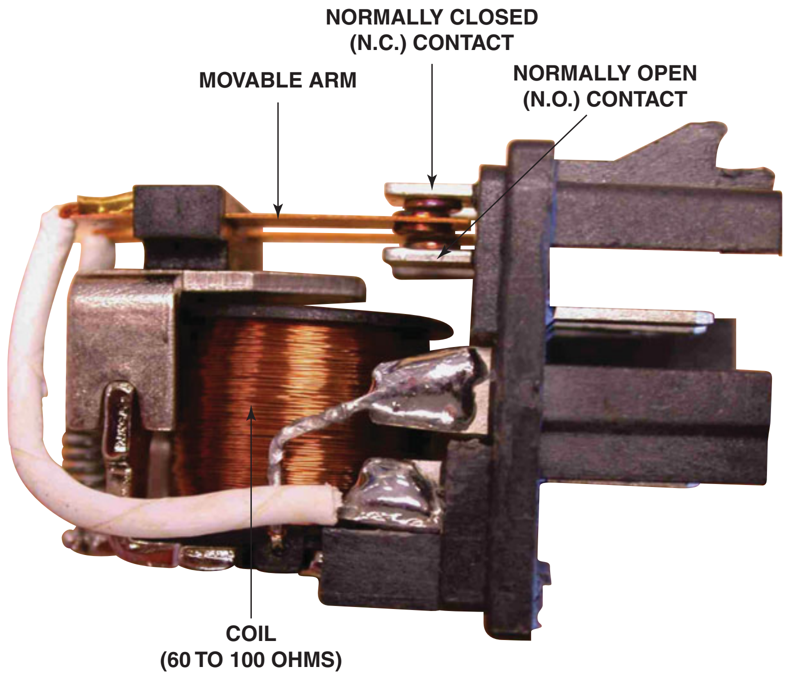


FIGURE 47–16 (a) A starter with attached solenoid. All of the current needed by the starter flows through the two large terminals of the solenoid and through the solenoid contacts inside. (b) A relay is designed to carry lower current compared to a solenoid and uses a movable arm.

2. Spring pressure lifts the arm back up.
3. The heavy current circuit is broken by the opening of the contact points.

Relays also may be designed with normally closed contacts that open when current passes through the electromagnetic coil.

SOLENOID A solenoid is an example of an electromagnetic switch. A solenoid uses a movable core rather than a movable arm and is generally used in higher-amperage applications. A solenoid can be a separate unit or attached to a starter such as a starter solenoid. ● **SEE FIGURE 47–16.**