THE MASTER TECHNICIAN'S

# SERVICE REFERENCE BOOK

SESSION NO.
63-3

# Fundamentals of ELECTRICITY and MAGNETISM

MASTER TECHNICIANS SERVICE CONFERENCE
PREPARED BY CHRYSLER CORPORATION
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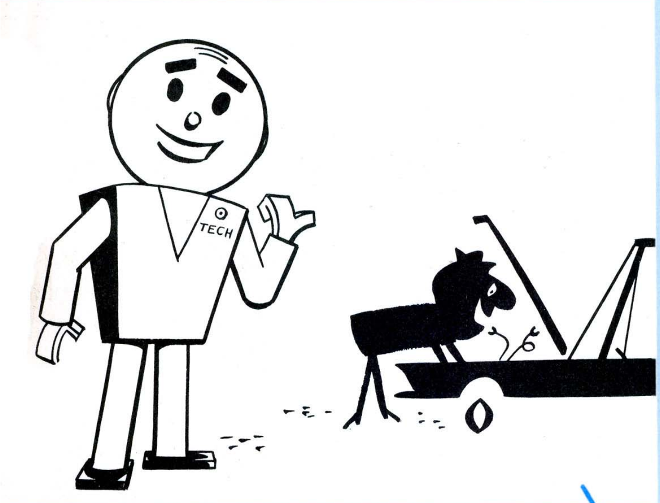
# A word from Tech...

Every model year new electrical units are added to make driving more comfortable, convenient or automatic. Small wonder that electrical diagnosis and service have become increasingly complicated. To that we should add, electrical service is bound to become increasingly important. Who knows how many of today's Master Technicians will become tomorrow's Master Electricians!

Fortunately, the fundamental laws of electricity and magnetism haven't changed. Every volt, ampere, ohm and line of magnetic force behave exactly the way they did before automobiles were invented. Now most of us have been exposed to the basic laws of electricity at one time or another. However, unless you've been specializing in electrical work regularly, some of your electrical knowledge has probably slipped away from you. It's high time most of you took an electrical "refresher."




This Tech session will give all of you an excellent chance to brush up on automotive electricity. The more thoroughly you understand electrical fundamentals, the better prepared you'll be to handle new electrical units and circuits as fast as they're introduced.

Who knows? You hydraulic brake experts may one day become Electronic Deceleration Specialists. Keep up on your electrical fundamentals . . . it looks like the electron is here to stay!

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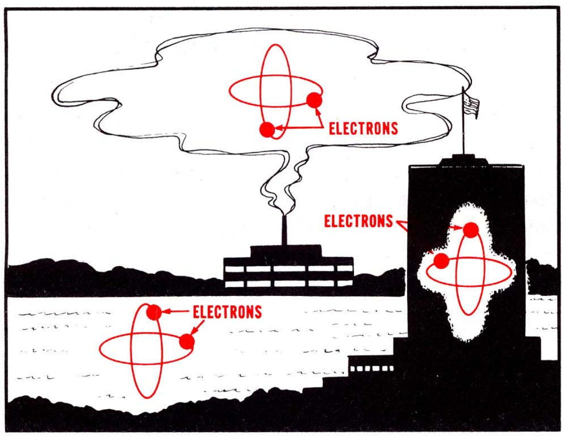
# FUNDAMENTALS OF ELECTRICITY

## ELECTRON THEORY

The behavior of electricity can be explained by recognizing the existence of a tiny particle called the ELECTRON. This is the theory that deals with the basic makeup of matter. It has been pretty well established that everything—all gases, liquids and solids—contain electrons. If we took time to try and explain the part electrons play in the structure of atoms, we wouldn't have room to talk about practical applications of the electron theory.



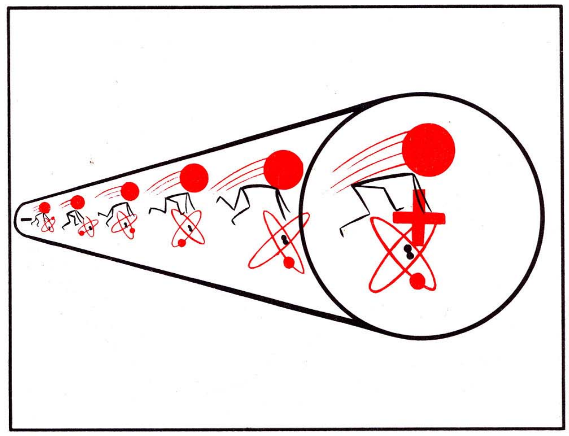

In order to go from electrons to automotive electricity in the shortest possible time, let's take the nuclear and atomic scientists' word for it! Electrons are everywhere and understanding how they behave makes it easier to understand the fundamentals of electricity.

In its simplest form, the electron theory states that all electrical effects are caused by the movement of electrons from place to place. Electrons move whenever there are too many of them in one place and too few in another.

## WHAT IS THE ELECTRON?

The electron is a tiny charged particle of negative electricity. All materials contain large quantities of these charged particles.

Current flow in a conductor is simply the mass movement of electrons. It has been definitely established that in every circuit the electron movement is from *negative to positive*. Let's clear up this question about the *direction of current flow*.



Before the advent of the electron theory, it was assumed that an electric current flowed from positive to negative. Today, we know for sure that electrons do flow from negative to positive. In present-day troubleshooting, don't worry about the direction of electron and current flow. Connect the battery correctly and the direction of current flow will take care of itself.

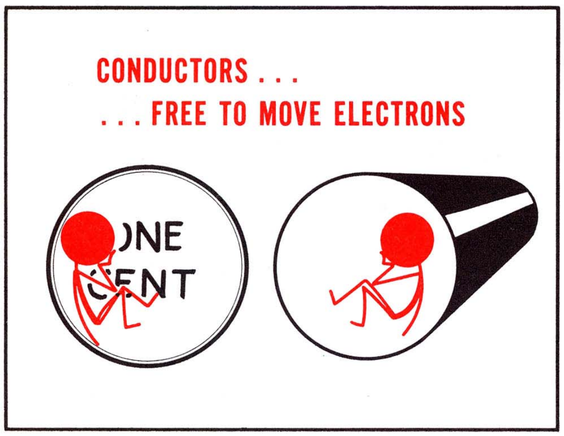
## CURRENT FLOW

An electrical current is electrons in motion. When current starts to flow in a wire, electrons throughout the length of the wire start to move at nearly the same time. Each free electron in the wire moves slightly and pushes or exerts a force on the next electron. This effect continues throughout the wire.

The actual number of electrons flowing is enormous. For example, it has been calculated that more than 6 million billion electrons move past a given point in a wire when a single ampere flows for one second. This, in itself isn't important but it will help you understand how very small an electron really is.

## CONDUCTORS

There are a few things about conductors you should know in order to have a clear understanding of current flow. All materials contain electrons, but good conductors have a large number of electrons that can easily be set in motion. These free-to-move electrons are simply referred to as *free electrons*. Copper, aluminum and carbon, for example, are good conductors because they contain many *free electrons*.




There are just as many free electrons in a copper penny as there are in a copper wire made of the same copper alloy. In other words, free electrons are always present in a conductor regardless of whether or not that conductor is ever used in an electrical circuit.

## INSULATORS

Any material which offers a large amount of opposition to the flow of current is usually considered to be an insulator. It is easier to understand the exact nature of an insulator if we think of it as a material that lacks the necessary free electrons to conduct a current. Glass, rubber and plastics are used as insulators because they have very few free electrons.

## VOLTAGE

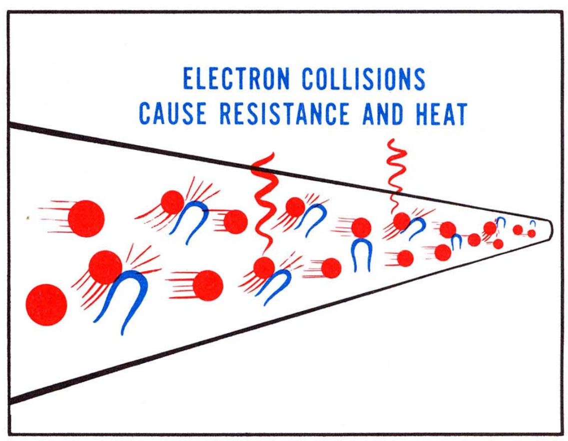
Voltage is the pressure that causes electrons to move through a conductor. In an automobile, the battery, alternator or generator supplies the necessary pressure to produce electron movement. Actually, a battery, alternator or generator doesn't *create* electricity any more than a water pump creates water. They produce a supply of surplus electrons. When an excess of electrons is applied to one end of a conductor in a circuit and there is a deficiency of electrons at the other end, the result is a difference in electrical pressure. This pressure difference causes a current to flow from the high point of pressure to the low point of pressure.

***The unit used to measure electrical pressure is the volt.***

## RESISTANCE

None of the known materials or elements are perfect conductors. When current flows, the free electrons frequently collide with some of the atoms of which the conductor is made. These collisions interfere with electron movement and account for the electrical resistance of the conductor.

Electrical resistance produces heat. As the temperature of the conductor increases, the movement of the free electrons and atoms also increases. This causes more frequent collisions between the electrons and atoms and, as a result, the resistance and temperature of the conductor increases even more.




The number of collisions between the electrons and atoms also increases when the number of electrons flowing is increased. This accounts for the fact that a conductor carrying a current is heated to some extent and is heated more when current flow is increased.

***The unit used for the measurement of electrical resistance is the ohm.***

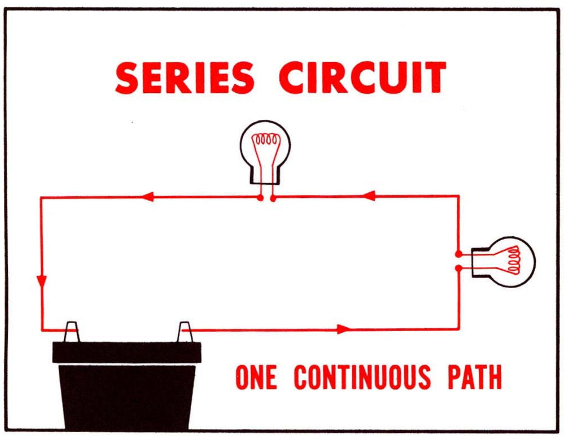
# BASIC ELECTRICAL CIRCUITS

The car's electrical system is a combination of inter-related circuits. Many of the electrical units in the system have self-contained circuits. The ability to understand and trace circuits is valuable in electrical troubleshooting.

The most basic type of circuit is one which contains a source of supply such as a battery, a resistance unit such as a lamp and connecting wires. This is called a simple circuit and, when properly connected, current flows from the battery, through the resistance and returns to the battery. This type of circuit is rarely found in an electrical system because most circuits have more than one resistance unit in operation at all times.

## SERIES CIRCUIT

A circuit which has more than one resistance unit connected to a source of voltage so that there is only one path for current to flow is called a series circuit.



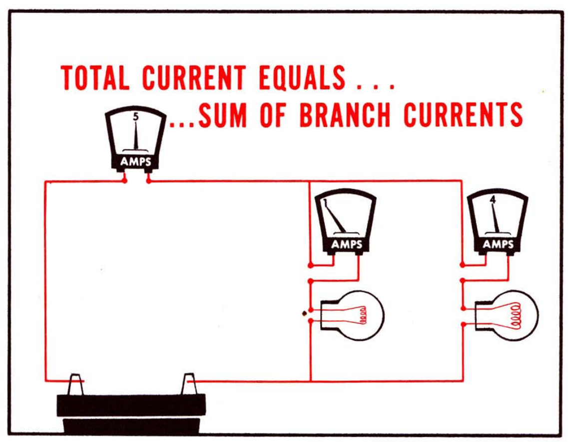

Since there is only one continuous path for current flow in a series circuit, all of the current must pass through each resistance in the circuit. The amount of current flowing depends on the total resistance of the circuit and the amount of voltage applied. Since current is the rate of electron flow, the current in amperes will be the same at all places in the series circuit. If more resistance is added to the circuit, fewer amperes will flow, and if resistance is reduced more amperes will flow.

The total *resistance* in a series circuit is equal to the sum of all the resistances in the circuit. In other words, simply add all of the resistances together to get the total resistance in a series circuit. As you'll see in a minute, the story is quite different in a parallel circuit.

## PARALLEL CIRCUIT

A circuit made up of two or more resistances which are connected so that there is more than one path for current flow is called a parallel circuit. When two or more resistance units are connected to a voltage source in parallel, the same voltage is applied to each resistance. The resistance of the individual units may or may not be of the same value.

Unlike a series circuit, the current is not always the same in all parts of a parallel circuit. That's because the current divides as it flows through the various branches of the circuit. The current flowing in each branch of the circuit varies, depending on the amount of resistance in that particular branch. However, the total current flowing in the entire circuit will always equal the sum of the currents flowing in all of the branches.



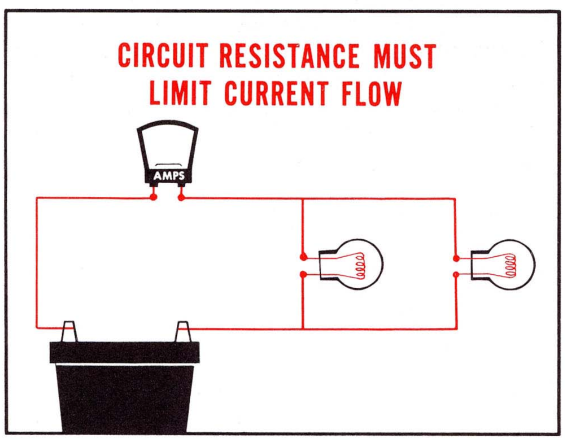
The total resistance of a parallel circuit is always less than any one resistance in the circuit. This is explained by the fact that the total opposition to current flow offered by the parallel resistance units is less than that of any one of the resistance units. In other words, each of two parallel paths will allow more current to flow than either of the individual paths or circuits.

### SERIES-PARALLEL CIRCUIT

Many of the circuits in an automobile are a combination of a series circuit and a parallel circuit. This is simply referred to as a series-parallel circuit. It is defined as one in which three or more resistances are connected partially in series and partially in parallel. In this combination-type circuit, the entire parallel portion of the circuit is connected in series with one or more series-connected resistance units.

### MEASURING CURRENT FLOW

In electrical troubleshooting it is often necessary to measure current flow. Since the ammeter must measure all of the current flowing in a circuit, the ammeter has very low resistance. Because it is a low-resistance instrument, it is very delicate and must be used and connected with care.




An ammeter is always connected directly into a circuit in series . . . it becomes part of the circuit. The circuit resistance must be high enough to limit current flow to an amount less than the maximum capacity or rating of the ammeter. In other words, the resistance of the units in the circuit must protect the ammeter against an overload.

***Never connect an ammeter across a circuit or full battery voltage will push excessive current through the meter and damage or destroy it.***

### VOLTAGE DROP

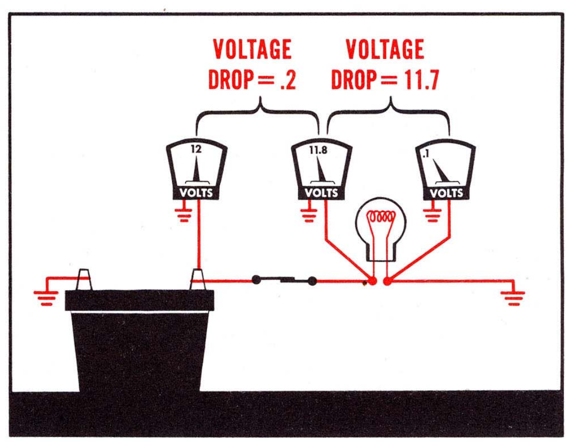
Voltage is gradually used up in pushing a current through a circuit. Each electrical unit, including the connecting wires, has some resistance. The electrical pressure that is expended in forcing electrons through these resistances is called "voltage drop". All circuits have a normal voltage drop. As long as the voltage drop is normal, the circuit will function properly. However, whenever voltage drop exceeds the maximum amount specified it spells trouble.

Loose or corroded connections, faulty switch contacts and dirty or improperly adjusted contact points are common causes of excessive voltage drop. Excessive resistance can be located quickly with a voltmeter.

### VOLTAGE MEASUREMENTS

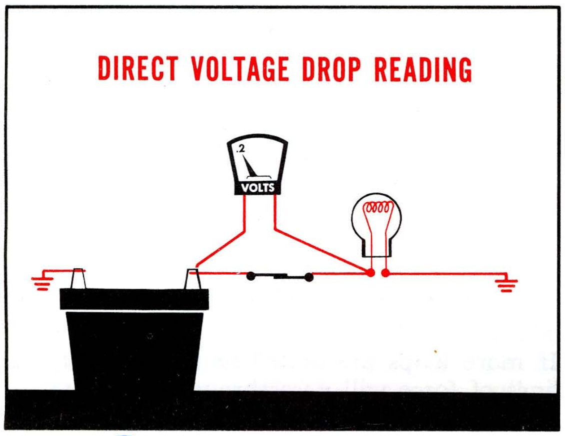
Unlike the low resistance ammeter, the voltmeter has high internal resistance. That's why it is not used or connected like an ammeter. Actually, there are two ways to connect and use a voltmeter depending on what you want to know about the circuit.

*Voltage Available.* To find the voltage available at any terminal in a circuit, connect the voltmeter from the circuit terminal to ground. It is important to remember that voltage is



not exactly the same at any two points in a circuit because a voltage drop always occurs when current is moved through a resistance.

The accompanying illustration represents voltmeters connected to measure the voltage available at several terminals in a circuit. In this same illustration, notice that the voltage drop between terminals is represented. Voltage drop is the difference between the voltage available at one point in a circuit and the voltage available at another point in the same circuit.

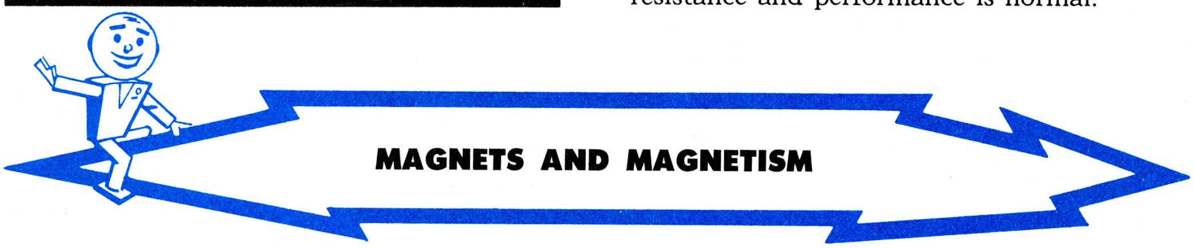



*Direct Voltage Drop Measurement.* A direct voltage drop reading can be made by connecting the voltmeter across a part of the circuit. When a voltmeter is connected across a part of the circuit it registers voltage drop across that part of the circuit, not voltage available.

### OHM'S LAW

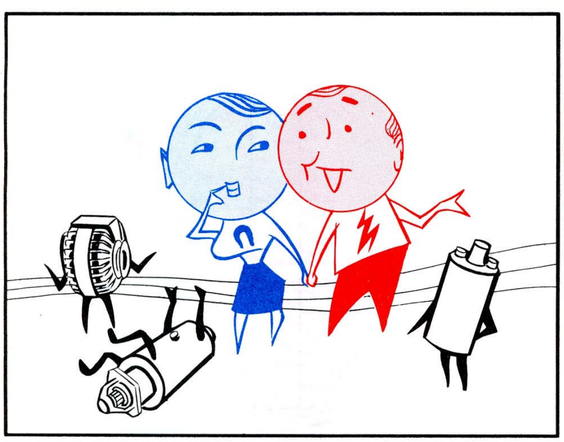
Ohm's Law states that one volt will move one ampere of current through a resistance of one ohm. This is the most fundamental equation in all electrical science. But let's be practical! In most automotive troubleshooting an ohmmeter is seldom used. Service manuals usually give circuit specifications in volts, voltage drop or amperage rather than in ohms. That's because it is easier to measure voltage and amperage than it is to use an ohmmeter to measure resistance.

The engineer who designed the circuit knew the resistance of the units. He used Ohm's Law to calculate the voltage needed, the allowable voltage drop and the normal current flow in amperes. That's why you can use a voltmeter and ammeter to find out if circuit resistance and performance is normal.



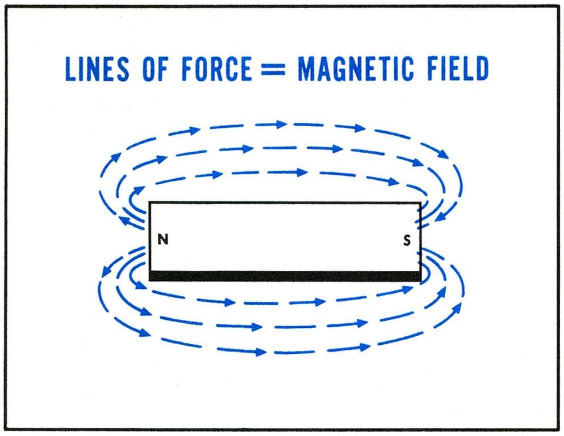
## MAGNETS AND MAGNETISM

If it weren't for magnetism, electrical energy would have very few practical automotive applications. Because magnetism is *essential* to the operation of the ignition voltage, generating and starting systems, a working knowledge of magnetism will help you understand and diagnose trouble in these circuits.



### PERMANENT MAGNETS

Magnetism is an invisible force and can be most readily understood in terms of the effects it produces. The simplest type of magnet is the bar magnet. Lines of force leave the magnet at the north pole and enter again at the south pole. Inside the magnet, the lines of force travel from the south pole to the north so that each line of magnetic force is continuous. The magnetic field is all of the space, outside of the magnet, that contains lines of magnetic force.




If a bar magnet is bent into the shape of a horseshoe, the field of force becomes stronger because the distance between the north and south poles is greatly reduced and the lines of force are more concentrated.

## CHARACTERISTICS OF PERMANENT MAGNETS

The following facts about permanent magnets and the materials of which they are made aren't essential to diagnosis but will provide you with a better understanding of permanent magnets and electromagnet core materials.

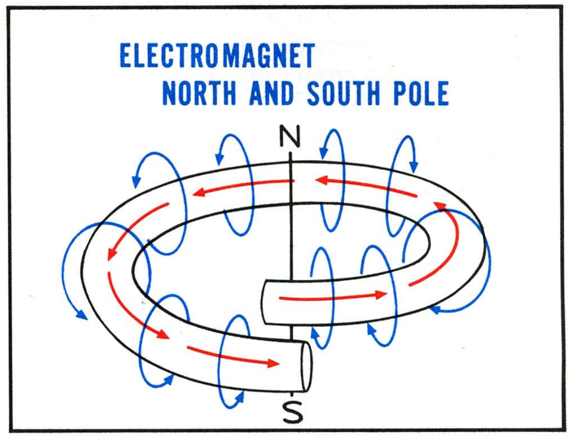
1. Hard steels or steel alloys are used in permanent magnets because they store or retain high magnetic strength when magnetized.
2. Residual magnetism is the magnetic strength stored in the magnet material after the magnetizing field or force has been removed.
3. Soft iron and soft, low alloy steels store or retain only a small amount of magnetic strength. For this reason they are commonly used in electromagnets where residual magnetism is undesirable.

## ELECTROMAGNETISM

Another type of magnetic field is produced by an electric current flowing through a conductor. When electrons move through a conductor, a magnetic field of force is created around the conductor. This field of force has no north or south poles—no polarity.

## MAGNETIC FIELD AROUND A COIL

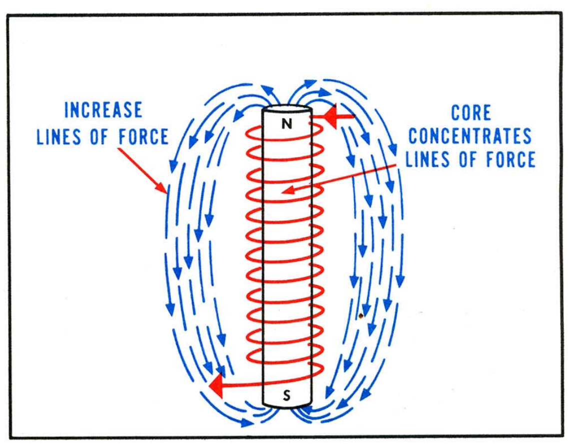
If a current-carrying conductor is formed into a loop, the lines of force around the conductor will all pass through the center of the loop. The result is a weak magnet with a north and south pole.



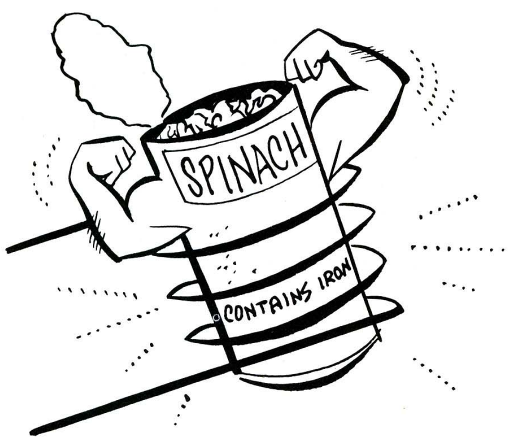

If more loops are added to form a coil, the lines of force will pass through the center of the coil, out the end and reenter at the other end. This produces the same field pattern as a bar magnet.

Thus, the magnetic effects of a conductor are greatly increased by forming it into a coil and concentrating the magnetic lines. However, the field formed by current flowing through a coil is still not strong enough for practical use in most electrical equipment.

## INCREASING THE STRENGTH OF ELECTROMAGNETS



The addition of an iron core to an electromagnet greatly increases its magnetic strength. That's because the iron core offers very little "magnetic resistance" (reluctance) as compared to an "air core".




The strength of an electromagnet can also be made greater by increasing either the amount of current flowing or the number of turns in the coil. In other words, the magnetic pull at the core of an electromagnet depends upon:

- The size, length and type of core material.
- The number of amperes flowing in the coil.
- The number of turns in the coil.

### THE BEHAVIOR OF MAGNETIC LINES

Magnetism is a force which follows definite rules. An understanding of the basic rules of magnetism will help you understand the uses to which magnetism is put in automotive electricity.

1. Magnetic lines pass through all materials and there is no known insulator against magnetism.
2. Magnetic lines pass easily through materials that can be magnetized, such as iron or steel—much less readily through air or across an "air gap".
3. Magnetic lines always form a closed loop.
4. Magnetic lines tend to lengthen and shorten as field strength is increased and decreased.
5. Magnetic lines never cross one another.
6. Unlike magnetic poles attract each other and like magnetic poles repel each other.

## ELECTRICITY AND MAGNETISM AT WORK

We know that electrons moving through a conductor create a magnetic field. This action can be reversed. A magnetic field can be used to make electrons move through a conductor. This is called inducing or generating electricity by magnetism.

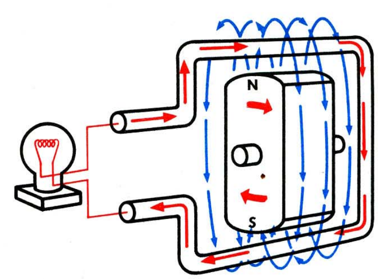
### INDUCED VOLTAGE

To induce a voltage in a conductor it is necessary to have relative motion between the magnetic lines and the conductor. In a DC generator, the magnetic field is stationary and the conductors (armature windings) are moved so that they cut across the lines of magnetic force. In an AC generator or alternator, the magnetic field is moved so that the lines of force cut across the conductors. The principle is the same in either case.

### A SIMPLE ALTERNATOR

If a permanent magnet is rotated inside a

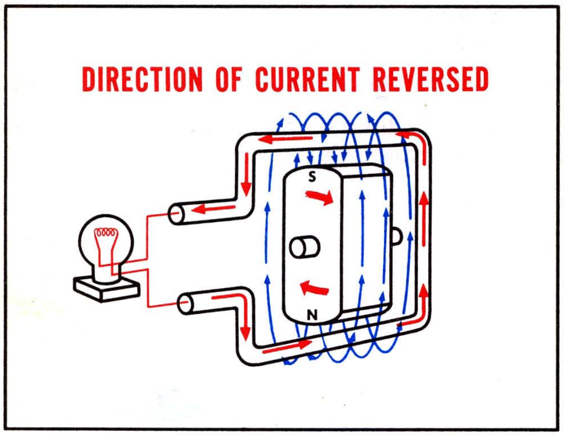
ELECTROMAGNETIC INDUCTION



loop of wire, the magnetic lines of force will cut across the wire or conductor. The moving lines of force cutting across the conductor cause the free electrons in the conductor to start moving. A voltage has been electromagnetically *induced* in the conductor.

### POLARITY CHANGES EVERY HALF-REVOLUTION

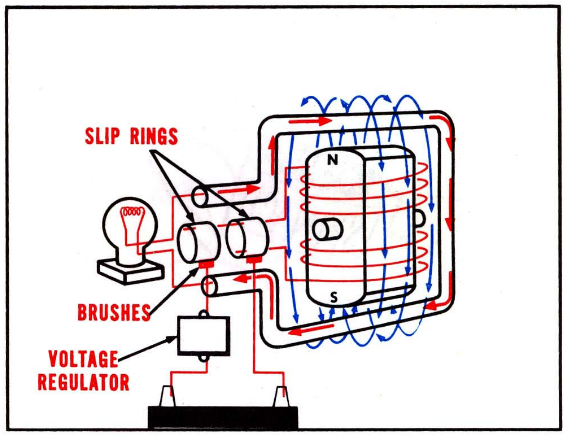
When the north pole is at the top and the south pole is at the bottom, the induced voltage will cause the current to flow in one direction. When the south pole reaches the top and the north pole is at the bottom, the induced voltage causes the current to flow in the opposite direction. The direction of current flow reverses every half-revolution.




### EXTERNALLY EXCITED FIELD

The output of an alternator having a permanent-magnet rotor would be difficult to control. One way to control the output of any generator is to control the strength of the magnetic field. In an alternator, the rotor core is wound with wire to form an electromagnet. The rotor windings are connected to an external source of direct current (the car's battery) through two slip rings and brushes. This arrangement represents a simplified version of the externally excited rotor field used in most alternators.

An externally excited generator is one which receives its field current from an external source such as a battery. Since the alternator rotor field is externally excited by direct current, one pole will always be "north" and the other "south", the same as a permanent magnet. As a result, current flow through the conductor or stator loop will reverse every half-revolution.




### FACTORS AFFECTING ALTERNATOR OUTPUT

We have explained how an alternating voltage is generated by a simple alternator. Let's consider the factors affecting the amount of voltage generated.

1. Voltage will increase as the speed of the rotor is increased because more lines of force will cut the stator or conductor in any given period of time.

2. Voltage will increase as the strength of the rotor's magnetic field is increased. The strength of the magnetic field is affected by:

   a. The number of turns and size of wire used in the windings.

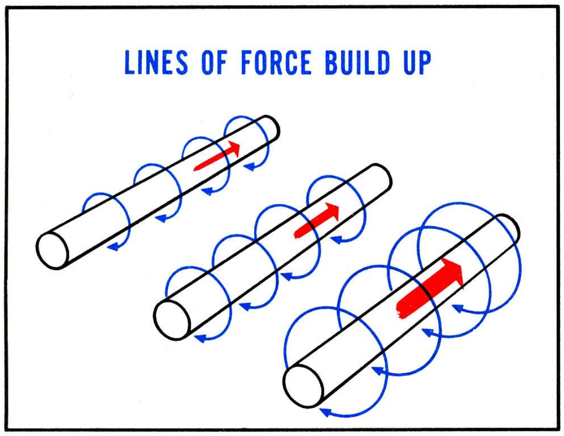
   b. The air gap between the rotor poles and the stator windings.

   c. The voltage applied to the stator windings through the slip rings and brushes. The voltage regulator controls alternator output by controlling this voltage.

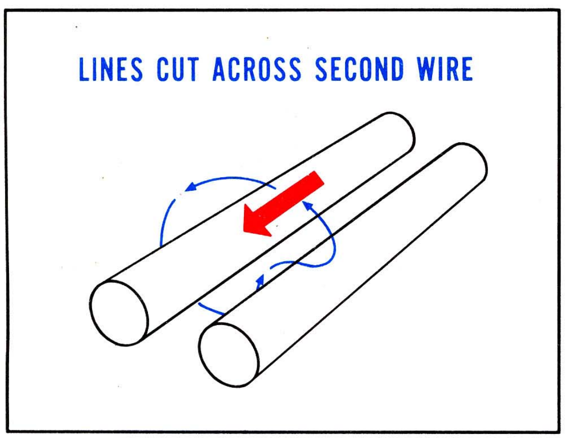
### INDUCTIVE REACTANCE

Another factor, commonly referred to as "Inductive Reactance", has an important bearing on alternator current control. Understanding inductive reactance will help you understand how maximum current output is controlled in Chrysler-built alternators.

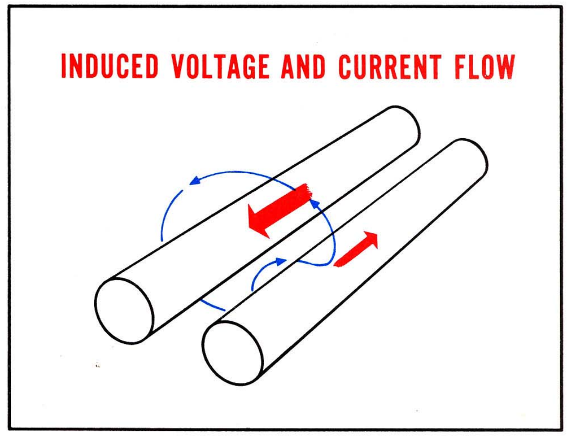
You already know that current flowing in a wire creates concentric lines of force around the wire. Actually, each circular line of force builds up and gets bigger and stronger as current flow through the conductor increases.



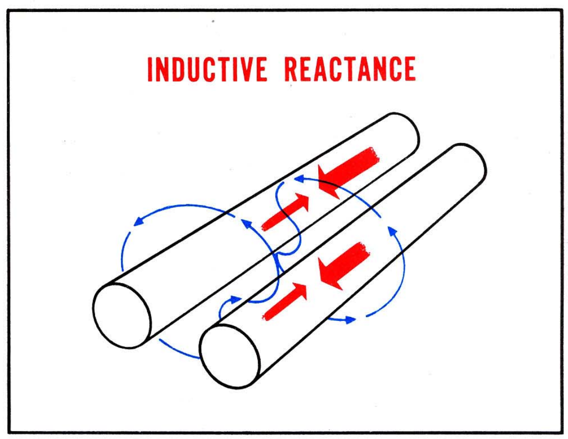

Now, if two wires are side by side and current is flowing in one wire, the lines of force from this wire will spread out and cut across the second wire. What happens when lines of force cut across a wire?

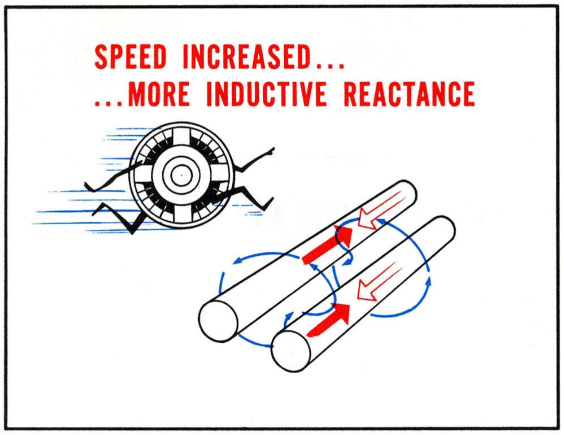



The lines of force cutting across the second wire induce a voltage and small current flow in the second wire. But notice, the currents in the two wires are going in opposite directions.




Now in an alternator stator, alternating current is flowing in all windings. Lines of force spread out from each wire and cut across the adjacent wire. This induces a voltage which opposes the original voltage and current flow. This is commonly called inductive reactance.




### INDUCTIVE REACTANCE LIMITS ALTERNATOR OUTPUT

In an alternator the frequency of the alternating current flowing in the stator windings increases in proportion to the speed of the rotor. Therefore, the opposition to current flow through the stator windings also increases as rotor speed increases.

Increased rotor speed generates higher voltage and tends to increase current flow through the stator windings. But, since inductive reactance also increases with rotor speed, the current output of the alternator is controlled automatically. Full advantage of this principle is taken in the design of the Chrysler-built alternator to automatically limit current, particularly at higher speeds. This eliminates the need of a separate current-regulating device.

### ALTERNATING CURRENT MUST BE RECTIFIED

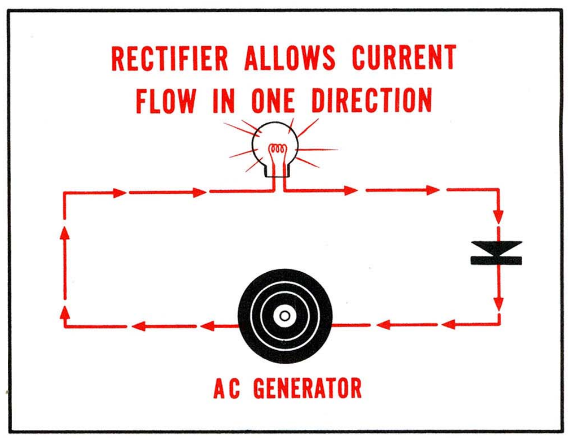
The battery and other units of an automotive electrical system (as presently designed), require direct current for their operation. In a conventional DC generator the alternating current flowing in the armature is changed into direct current by the commutator and brushes, a form of mechanical rectification. The alternating current flowing through the stator windings of an alternator is changed into direct current by the process of electrical rectification.

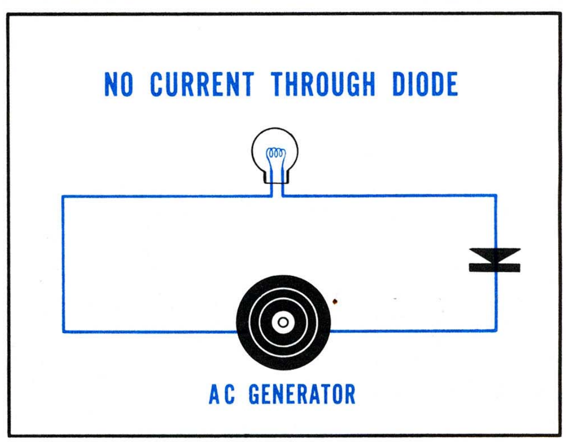
The output of an alternator can be changed into direct current by connecting the stator to an externally mounted rectifier, or by connecting the stator to rectifiers mounted *in* the alternator housing. If an external rectifier is used, AC is delivered by the alternator and DC is supplied from the rectifier. An alternator having integral rectifiers delivers DC from the alternator output terminal the same as a conventional DC generator.

### A RECTIFIER IS A ONE-WAY VALVE

Six integrally mounted rectifiers are used to change the output of the Chrysler-built alternator from alternating to direct current. A complete explanation of how these rectifiers change alternating current to direct current is too lengthy to cover in this session. However, this session on fundamentals would not be complete without an explanation of how a single rectifier works.

A rectifier allows current to flow in only one direction. If a rectifier is connected into the output circuit of an alternating current generator, a current will flow through the rectifier for part of a revolution.

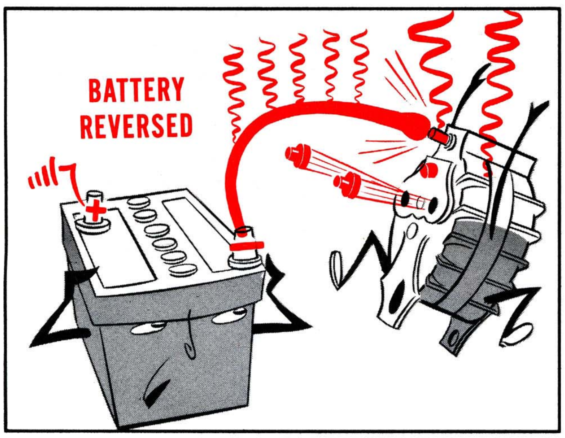


When the output current from an alternating current generator tries to change direction, no current can flow through the rectifier. For all practical purposes, the circuit is disconnected when current flow tries to reverse.

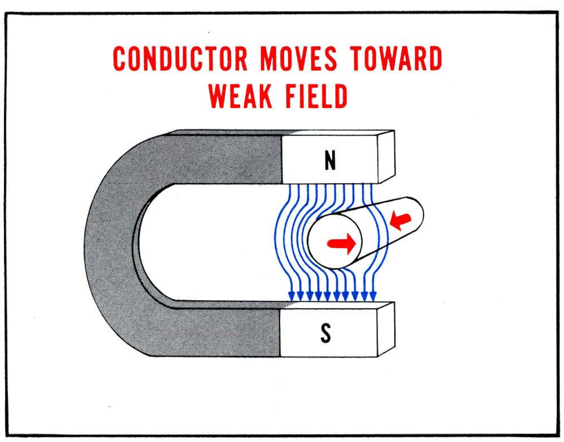
### IMPORTANCE OF BATTERY POLARITY

While we are discussing rectifiers let's take a minute to explain why reversing battery polarity will ruin a rectifier. If the battery connections are reversed, current will flow from the battery into the alternator stator windings. Full battery voltage will be impressed on the rectifier. The resulting high current flow in the wrong direction will damage the rectifier and may seriously overheat and damage the entire charging circuit.



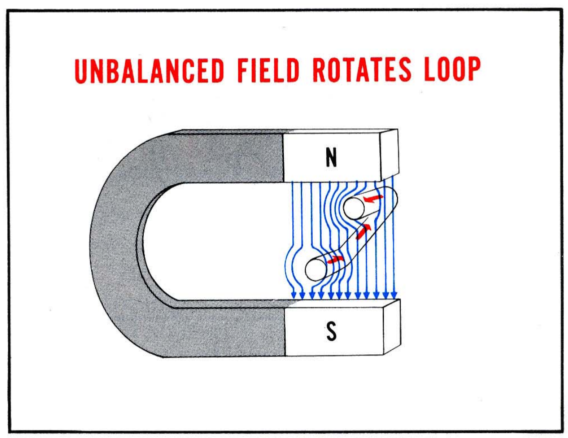

### THE BASIC PRINCIPLE OF A DC MOTOR

If a current-carrying conductor is placed in a magnetic field the concentric lines of force around the conductor react with the lines of force in the magnetic field. On one side of the conductor the concentric lines of force team up with the lines of force of the magnetic field. On the other side of the conductor the concentric lines of force oppose the magnetic field's lines of force. The unbalanced field condition pushes the conductor from the strong side toward the weak side. This basic electromagnetic principle is used in an electric motor to change electrical energy into mechanical energy.




### MAKING THE CONDUCTOR ROTATE

If a conductor is formed into a loop and placed in a magnetic field, current flowing in the loop will cause an unbalanced field condition at both the south and north pole ends of the field. These two unbalanced conditions *work together* and tend to make the entire loop rotate.




After the loop rotates one-quarter turn, the conductor is in the weakest part of the field. In addition, the unbalanced field condition at each side of the loop is no longer trying to rotate the conductor. Instead, it is trying to push the conductor outward . . . away from the field. The loop will stop rotating.

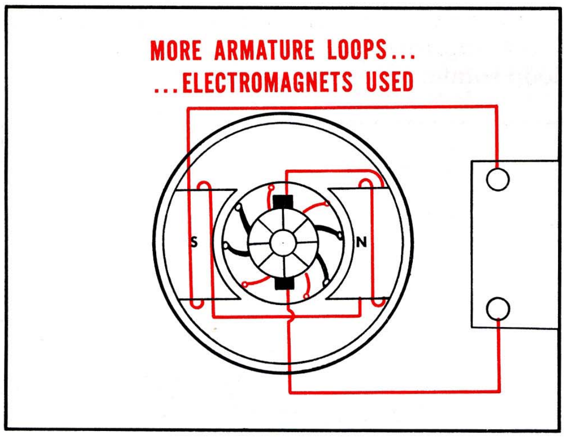
### ADD ANOTHER LOOP

If another loop is added at right angles to the first and the voltage source is connected to this new loop, it will tend to rotate through one-quarter of a revolution. By using two separate loops we have a simple motor that will rotate through one-half of a revolution.

### A COMMUTATOR IS A SWITCH

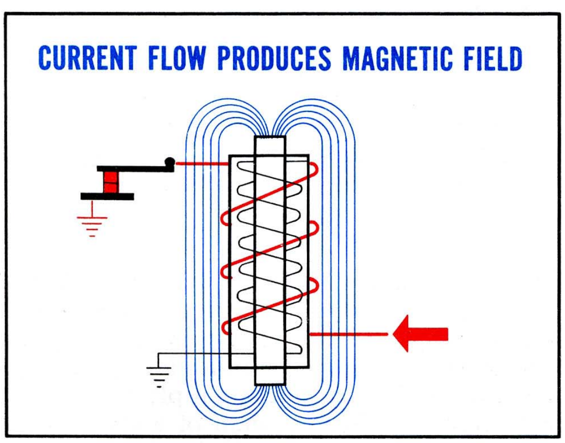
Let's see what happens if we use a separate contact bar or segment at the ends of each loop and two brushes to connect these contact segments to a voltage source. Current will flow through one loop for part of one revolution, then, through the other loop for part of a revolution. The four contact segments form a simple commutator. The commutator switches the current flow from one loop to the other loop four times for each revolution.

Of course a starting motor has more armature loops, more commutator segments, and electromagnets are used in place of permanent magnets. However, the basic principle remains the same.




### MUTUAL INDUCTANCE AND IGNITION COILS

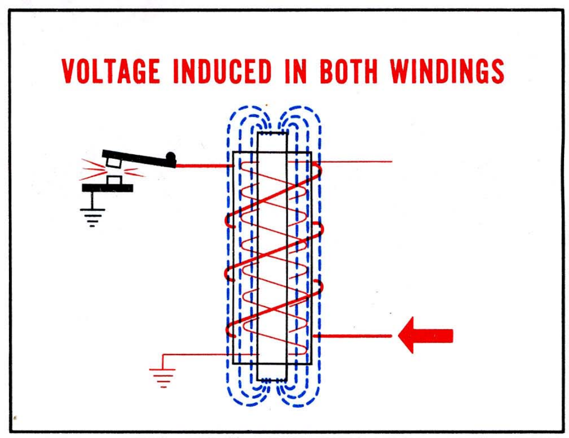
Earlier we explained that voltage can be induced in a conductor by moving lines of force

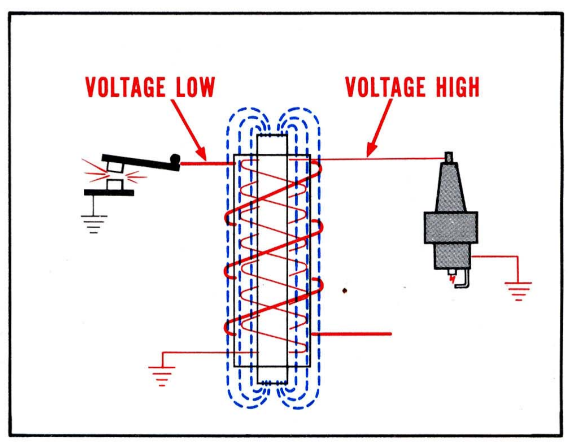



. . . without any *mechanical* movement. This is the basic principle used in an ignition coil. When two coils are close together, electrical energy is transferred from one coil to the other through a magnetic coupling. This is called "mutual induction" and is the action that occurs in an ignition coil.

Usually the two coils are wound on the same iron core. The primary winding has fewer turns of relatively heavy wire and is connected to a battery through a switch. The secondary winding, having many more turns of fine wire, is connected to an external circuit.

If the switch in the primary circuit is opened, the field collapses *rapidly*. As it does, the lines of magnetic force cut across both the primary and the secondary windings. A voltage is induced in both windings. The mutual induction which occurs when a field collapses is the basic principle used in designing an ignition coil.



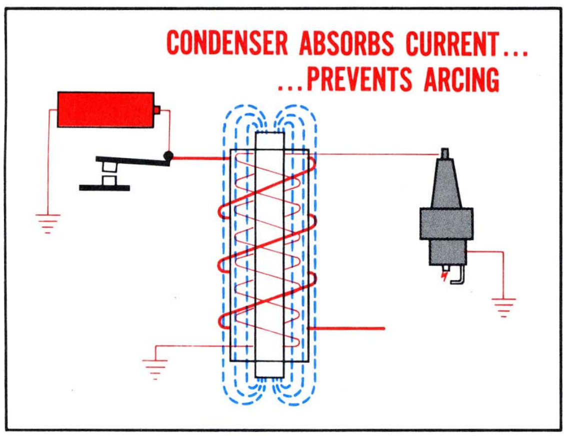



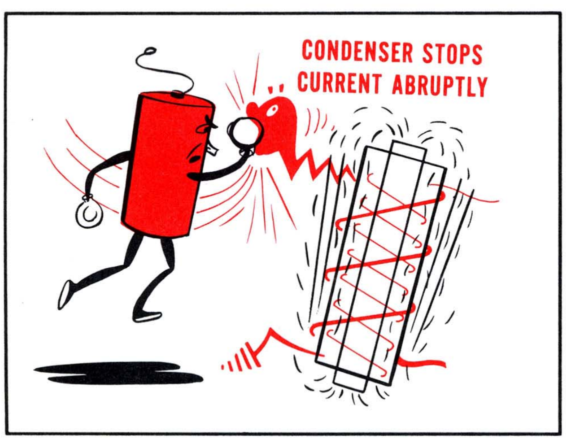
Since there are thousands of turns of fine wire in the secondary winding, the induced voltage is very high. High enough to jump a spark plug gap. Since there are far fewer turns in the primary winding, the voltage induced is *relatively* low.

### WHY A CONDENSER IS NEEDED

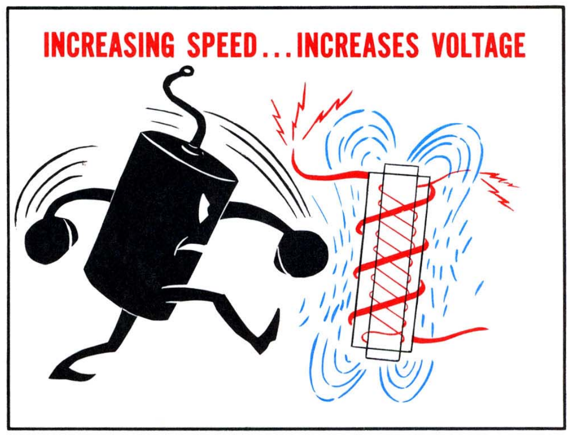
Although the voltage induced in the primary windings when the points open is *relatively* low, it may reach several hundred volts. This voltage is great enough to arc across ignition points and burn them. That's why an ignition condenser is needed.

The ignition condenser absorbs the current flow from the primary windings until the ignition points are opened far enough to prevent arcing. In other words, by the time the condenser is fully charged, the air gap between the points is great enough to eliminate arcing.




In addition to preventing arcing, the condenser stops current flow in the primary windings very abruptly. This in turn speeds up the collapse of the magnetic field, increasing the speed at which the lines of force cut the secondary windings. Increasing the speed of the collapsing magnetic lines increases the voltage induced in the secondary. You can see how important condenser action is to maximum ignition voltage and point life.




### THE BALLAST RESISTOR

As engine speed increases, the ignition contacts are closed for a shorter time. At high speeds, current doesn't flow through the primary windings long enough to produce maximum field strength. For this reason, the voltage from the coil secondary tends to decrease as engine speed increases.

To provide a greater safety margin of available voltage, a specially designed ignition coil and ballast resistor are used on Chrysler-built cars. The ballast resistor is a current-compensating device, consisting of a special alloy wire connected into the primary ignition circuit. At low speeds, current flows for longer periods of time. This heats up the resistor, thereby raising its resistance and reducing current flow. This action keeps the coil primary cooler and improves ignition contact life.

At high speeds, current flows for shorter periods of time. The resistor cools and allows more current to flow to the coil primary. This provides optimum voltage at the spark plug.

When starting the engine, the ballast resistor is bypassed and allows full current flow.

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