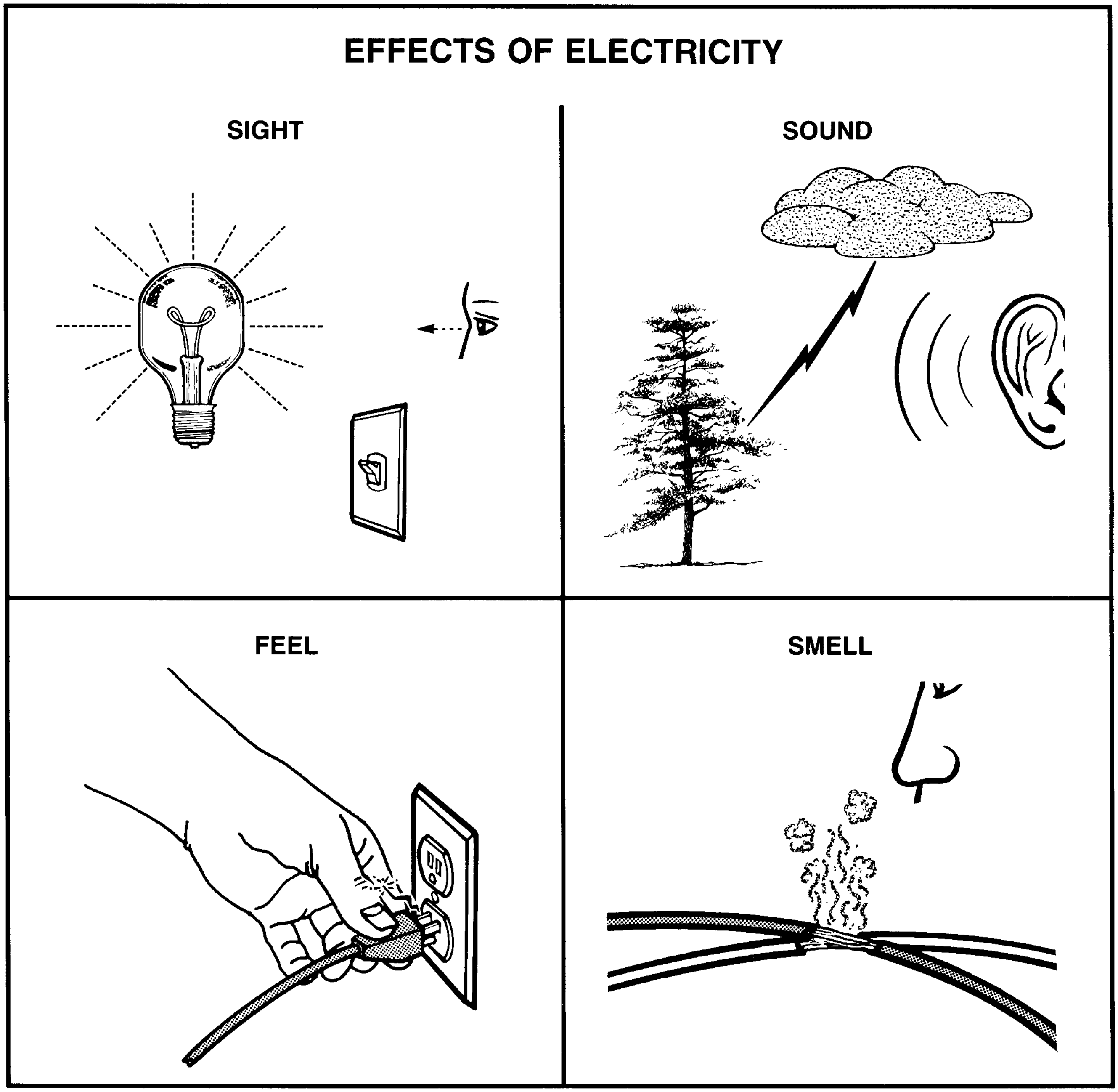
General

Electricity is a form of energy called electrical energy. It is sometimes called an "unseen" force because the energy itself cannot be seen, heard, touched, or smelled.

However, the effects of electricity can be seen ... a lamp gives off light; a motor turns; a cigarette lighter gets red hot; a buzzer makes noise.

The effects of electricity can also be heard, felt, and smelled. A loud crack of lightning is easily heard, while a fuse "blowing" may sound like a soft "pop" or "snap." With electricity flowing through them, some insulated wires may feel "warm" and bare wires may produce a "tingling" or, worse, quite a "shock." And, of course, the odor of burned wire insulation is easily smelled.



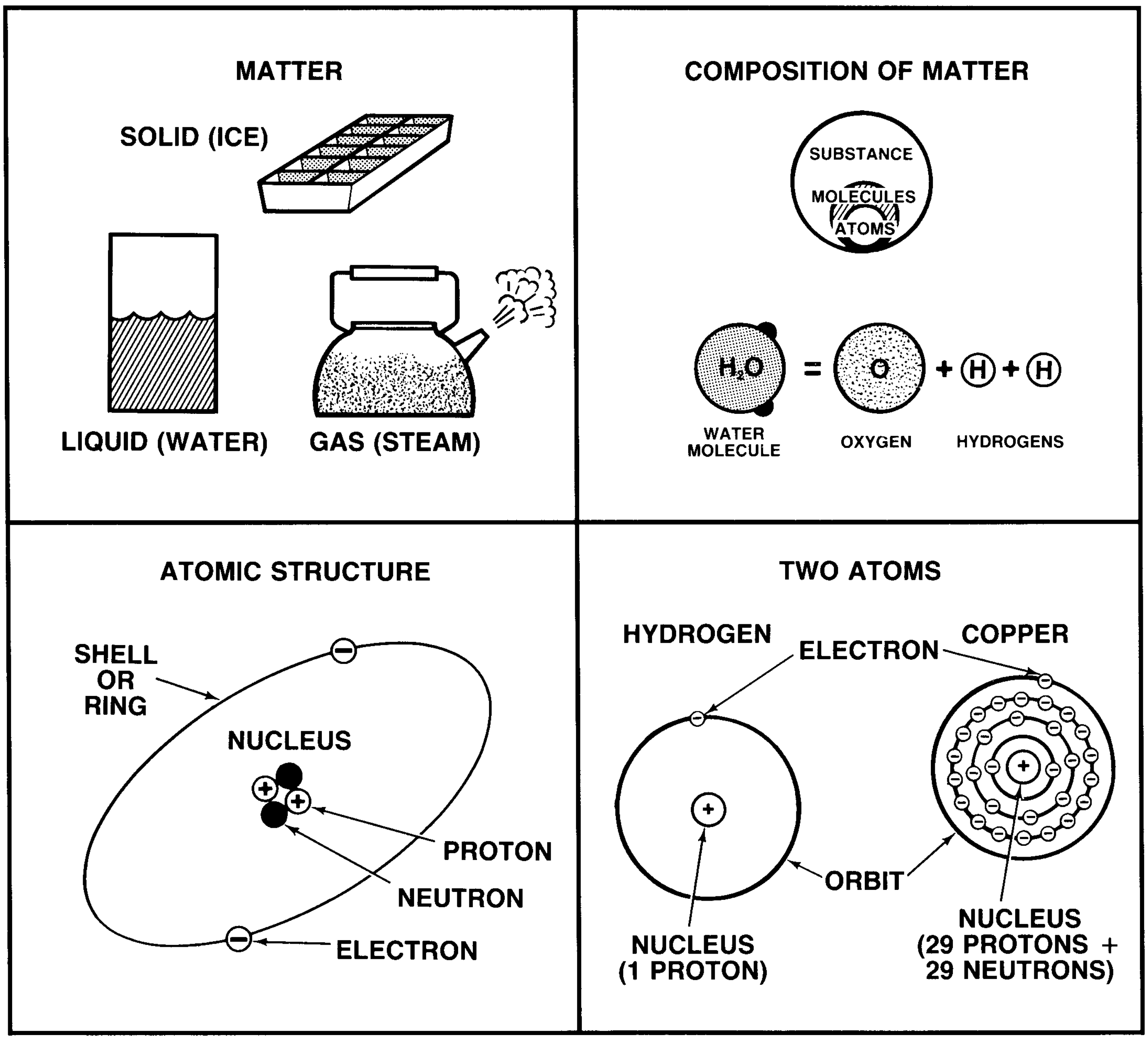
Electron Theory

Electron theory helps to explain electricity. The basic building block for matter, anything that has mass and occupies space, is the atom. All matter - solid, liquid, or gas - is made up of molecules, or atoms joined together. These atoms are the smallest particles into which an element or substance can be divided without losing its properties. There are only about 100 different atoms that make up everything in our world. The features that make one atom different from another also determine its electrical properties.

ATOMIC STRUCTURE

An atom is like a tiny solar system. The center is called the nucleus, made up of tiny particles called protons and neutrons. The nucleus is surrounded by clouds of other tiny particles called electrons. The electrons rotate about the nucleus in fixed paths called shells or rings.

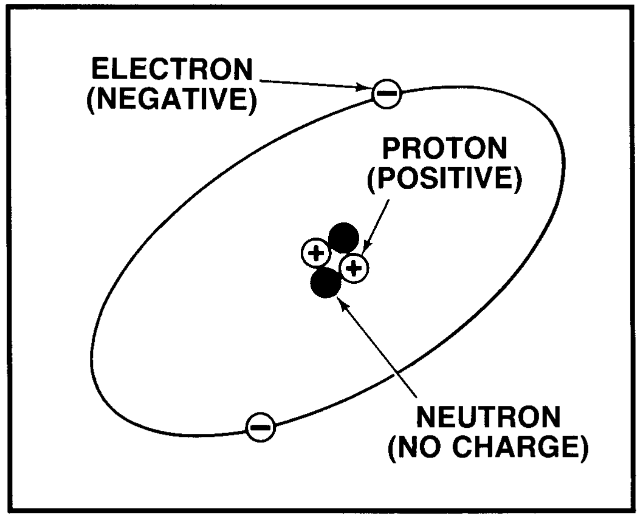
Hydrogen has the simplest atom with one proton in the nucleus and one electron rotating around it. Copper is more complex with 29 electrons in four different rings rotating around a nucleus that has 29 protons and 29 neutrons. Other elements have different atomic structures.



ATOMS AND ELECTRICAL CHARGES

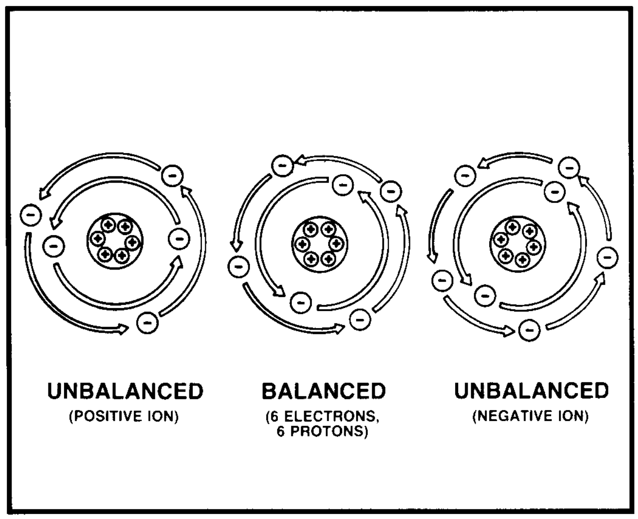
Each atomic particle has an electrical charge. Electrons have a negative (-) charge. Protons have a positive charge. Neutrons have no charge; they are neutral.

In a **balanced atom**, the number of electrons equals the number of protons. The balance of the opposing negative and positive charges holds the atom together. Like charges repel, unlike charges attract. The positive protons hold the electrons in orbit. **Centrifugal force** prevents the electrons from moving inward. And, the neutrons cancel the repelling force between protons to hold the atom's core together.



POSITIVE AND NEGATIVE IONS

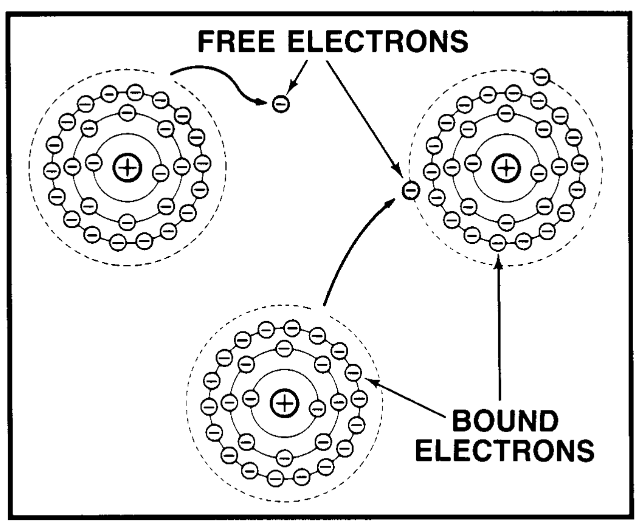
If an atom gains electrons, it becomes a **negative ion**. If an atom loses electrons, it becomes a **positive ion**. Positive ions attract electrons from neighboring atoms to become balanced. This causes electron flow.

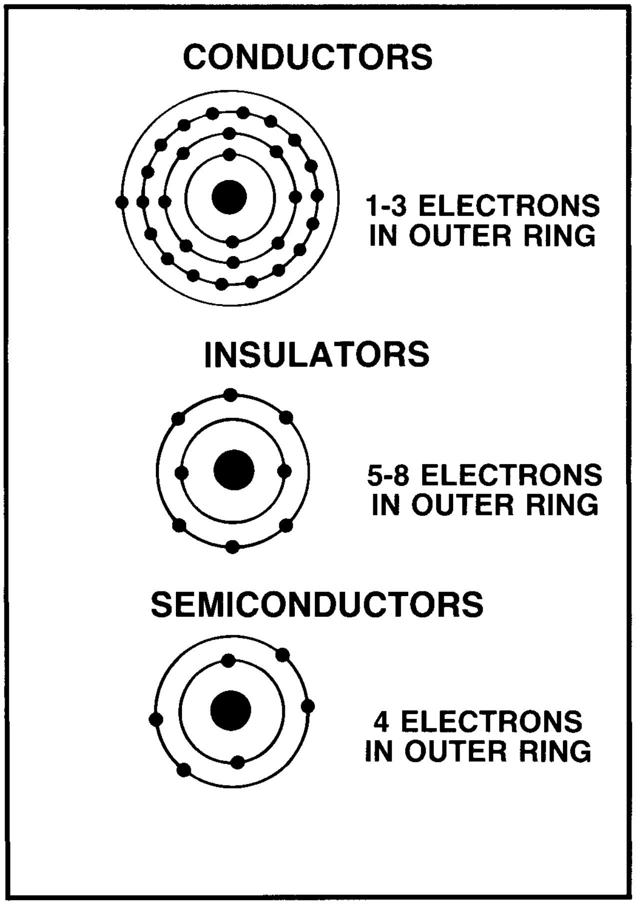


ELECTRON FLOW

The number of electrons in the outer orbit (**valence** shell or ring) determines the atom's ability to conduct electricity. Electrons in the inner rings are closer to the core, strongly attracted to the protons, and are called **bound electrons**. Electrons in the outer ring are further away from the core, less strongly attracted to the protons, and are called **free electrons**.

Electrons can be freed by forces such as friction, heat, light, pressure, chemical action, or magnetic action. These freed electrons move away from the **electromotive force**, or EMF ("electron moving force"), from one atom to the next. A stream of free electrons forms an electrical **current**.





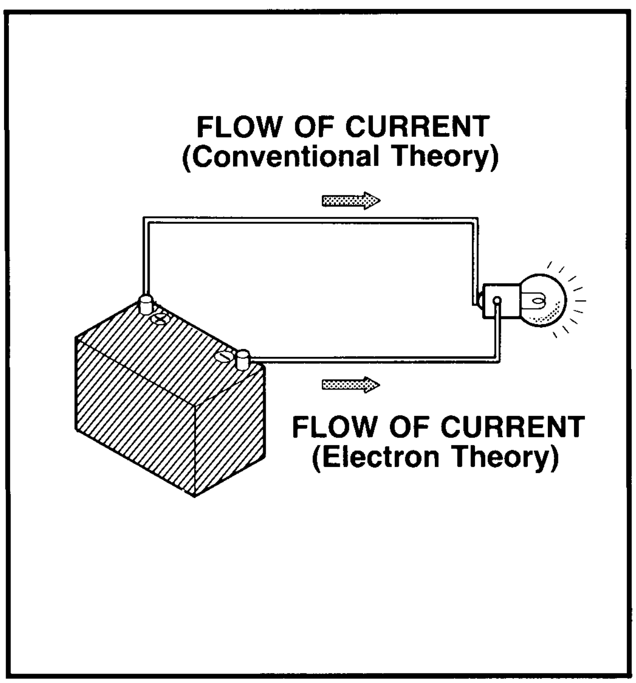
CONDUCTORS, INSULATORS, SEMICONDUCTORS

The electrical properties of various materials are determined by the number of electrons in the outer ring of their atoms.

• **CONDUCTORS** - Materials with 1 to 3 electrons in the atom's outer ring make good conductors. The electrons are held loosely, there's room for more, and a low EMF will cause a flow of free electrons.

• **INSULATORS** - Materials with 5 to 8 electrons in the atom's outer ring are insulators. The electrons are held tightly, the ring's fairly full, and a very high EMF is needed to cause any electron flow at all. Such materials include glass, rubber, and certain plastics.

• **SEMICONDUCTORS** - Materials with exactly 4 electrons in the atom's outer ring are called semiconductors. They are neither good conductors, nor good insulators. Such materials include carbon, germanium, and silicon.



CURRENT FLOW THEORIES

Two theories describe current flow. The **conventional theory**, commonly used for automotive systems, says current flows from (+) to (-) ... excess electrons flow from an area of high potential to one of low potential (-). The **electron theory**, commonly used for electronics, says current flows from (-) to (+) ... excess electrons cause an area of negative potential (-) and flow toward an area lacking electrons, an area of positive potential (+), to balance the charges.

While the direction of current flow makes a difference in the operation of some devices, such as diodes, the direction makes no difference to the three measurable units of electricity: voltage, current, and resistance.

Terms Of Electricity

Electricity cannot be weighed on a scale or measured into a container. But, certain electrical "actions" can be measured.

These actions or "terms" are used to describe electricity; **voltage, current, resistance,** and **power**.

Voltage is pressure

Current is flow.

Resistance opposes flow.

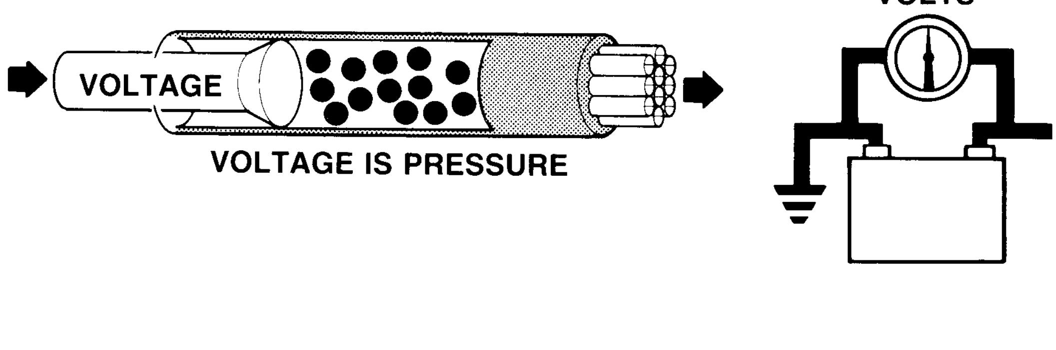
Power is the amount of work performed. It depends on the amount of pressure and the volume of flow.

VOLTAGE

Voltage is electrical pressure, a **potential force** or difference in electrical charge between two points. It can push electrical current through a wire, but not through its insulation.

Voltage is measured in **volts**. One volt can push a certain amount of current, two volts twice as much, and so on. A **voltmeter** measures the difference in electrical pressure between two points in volts. A **voltmeter** is used in parallel.

Voltage	Basic Unit	Units for Very Small Amounts		Units for Very Large Amounts	
Symbol	V	μV	mV	kV	MV
Pronounced As	Volt	Micro-volt	Milli-volt	Kilo-volt	Mega-volt
Multiplier	1	0.000001	0.001	1,000	1,000,000

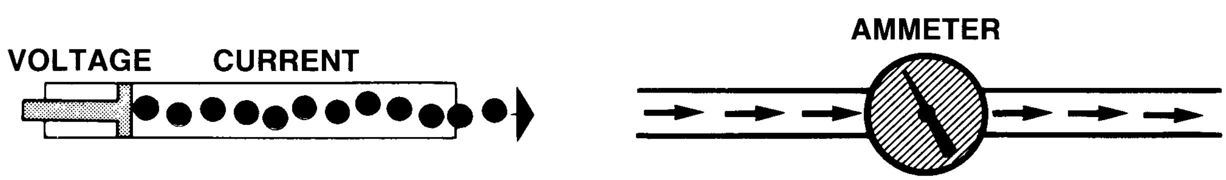


CURRENT

Current is electrical flow moving through a wire. Current flows in a wire pushed by voltage.

Current is measured in amperes, or amps, for short. An ammeter measures current flow in amps. It is inserted into the path of current flow, or in series, in a circuit.

Current	Basic Unit	Units for Very Small Amounts		Units for Very Large Amounts	
Symbol	A	μA	mA	kA	MA
Pronounced As	Ampere (Amp)	Micro-ampere	Milli-ampere	Kilo-ampere	Mega-ampere
Multiplier	1	0.000001	0.001	1,000	1,000,000

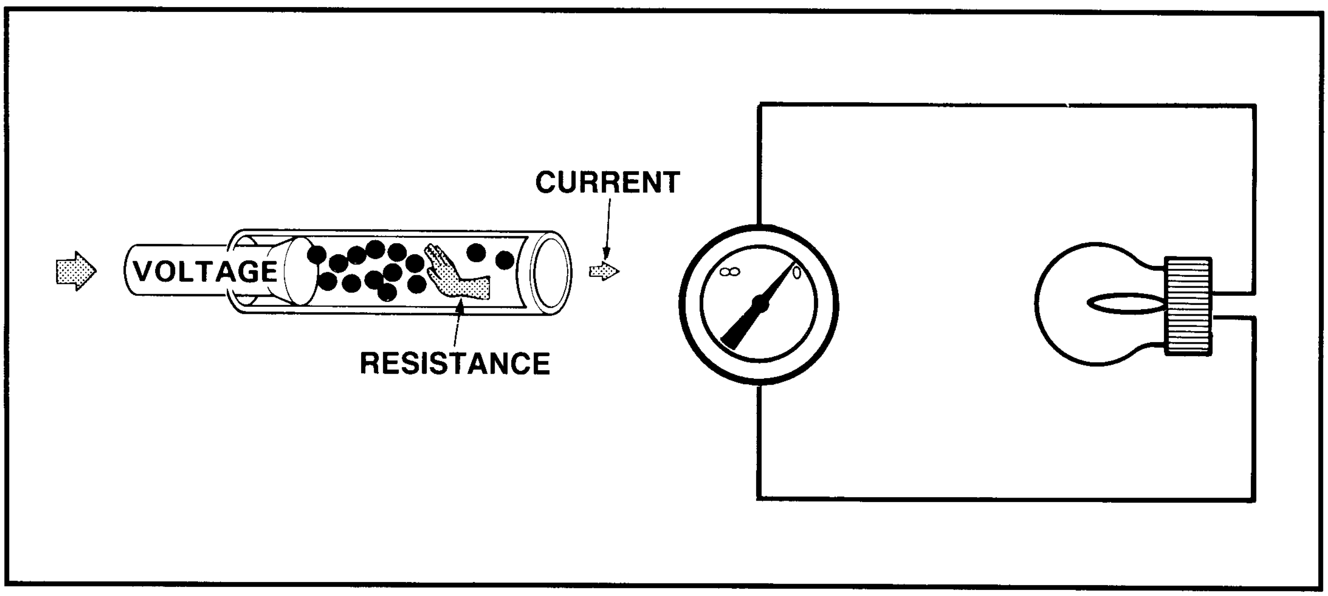


RESISTANCE

Resistance opposes current flow. It is like electrical "friction." This resistance slows the flow of current. Every electrical component or circuit has resistance. And, this resistance changes electrical energy into another form of energy - heat, light, motion.

Resistance is measured in ohms. A special meter, called an **ohmmeter**, can measure the resistance of a device in ohms when no current is flowing.

Resistance	Basic Unit	Units for Very Small Amounts		Units for Very Large Amounts	
Symbol	Ω	μΩ	mΩ	kΩ	MΩ
Pronounced As	Ohm	Micro-ohm	Milli-ohm	Kilo-ohm	Mega-ohm
Multiplier	1	0.000001	0.001	1,000	1,000,000



Factors Affecting Resistance

Five factors determine the resistance of conductors. These factors are length of the conductor, diameter, temperature, physical condition and conductor material. The filament of a lamp, the windings of a motor or coil, and the bimetal elements in sensors are conductors. So, these factors apply to circuit wiring as well as working devices or loads.

LENGTH

Electrons in motion are constantly colliding as voltage pushes them through a conductor. If two wires are the same material and diameter, the longer wire will have more resistance than the shorter wire. Wire resistance is often listed in ohms per foot (e.g., spark plug cables at 5Ω per foot). Length must be considered when replacing wires.

DIAMETER

Large conductors allow more current flow with less voltage. If two wires are the same material and length, the thinner wire will have more resistance than the thicker wire. Wire resistance tables list ohms per foot for wires of various thicknesses (e.g., size or gauge ... 1, 2, 3 are thicker with less resistance and more current capacity; 18, 20, 22 are thinner with more resistance and less current capacity). Replacement wires and splices must be the proper size for the circuit current.

TEMPERATURE

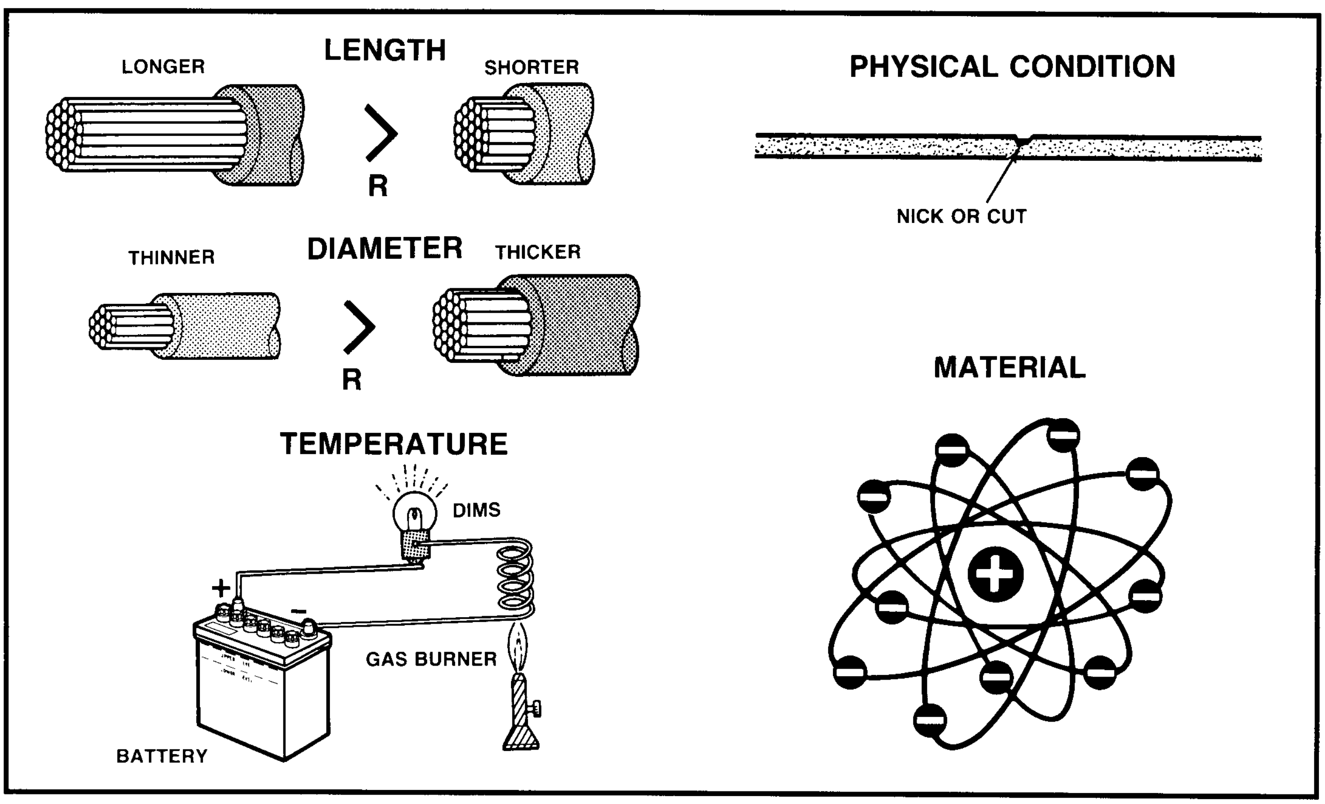
In most conductors, resistance increases as the wire temperature increases. Electrons move faster, but not necessarily in the right direction. Most insulators have less resistance at higher temperatures. Semiconductor devices called thermistors have negative temperature coefficients (NTC) resistance decreases as temperature increases. Toyota's EFI coolant temperature sensor has an NTC thermistor. Other devices use PTC thermistors.

PHYSICAL CONDITION

Partially cut or nicked wire will act like smaller wire with high resistance in the damaged area. A kink in the wire, poor splices, and loose or corroded connections also increase resistance. Take care not to damage wires during testing or stripping insulation.

MATERIAL

Materials with many free electrons are good conductors with low resistance to current flow. Materials with many bound electrons are poor conductors (insulators) with high resistance to current flow. Copper, aluminum, gold, and silver have low resistance; rubber, glass, paper, ceramics, plastics, and air have high resistance.



Voltage, Current, And Resistance In Circuits

A simple relationship exists between voltage, current, and resistance in electrical circuits. Understanding this relationship is important for fast, accurate electrical problem diagnosis and repair.

OHM'S LAW

Ohm's Law says: The current in a circuit is directly proportional to the applied voltage and inversely proportional to the amount of resistance.

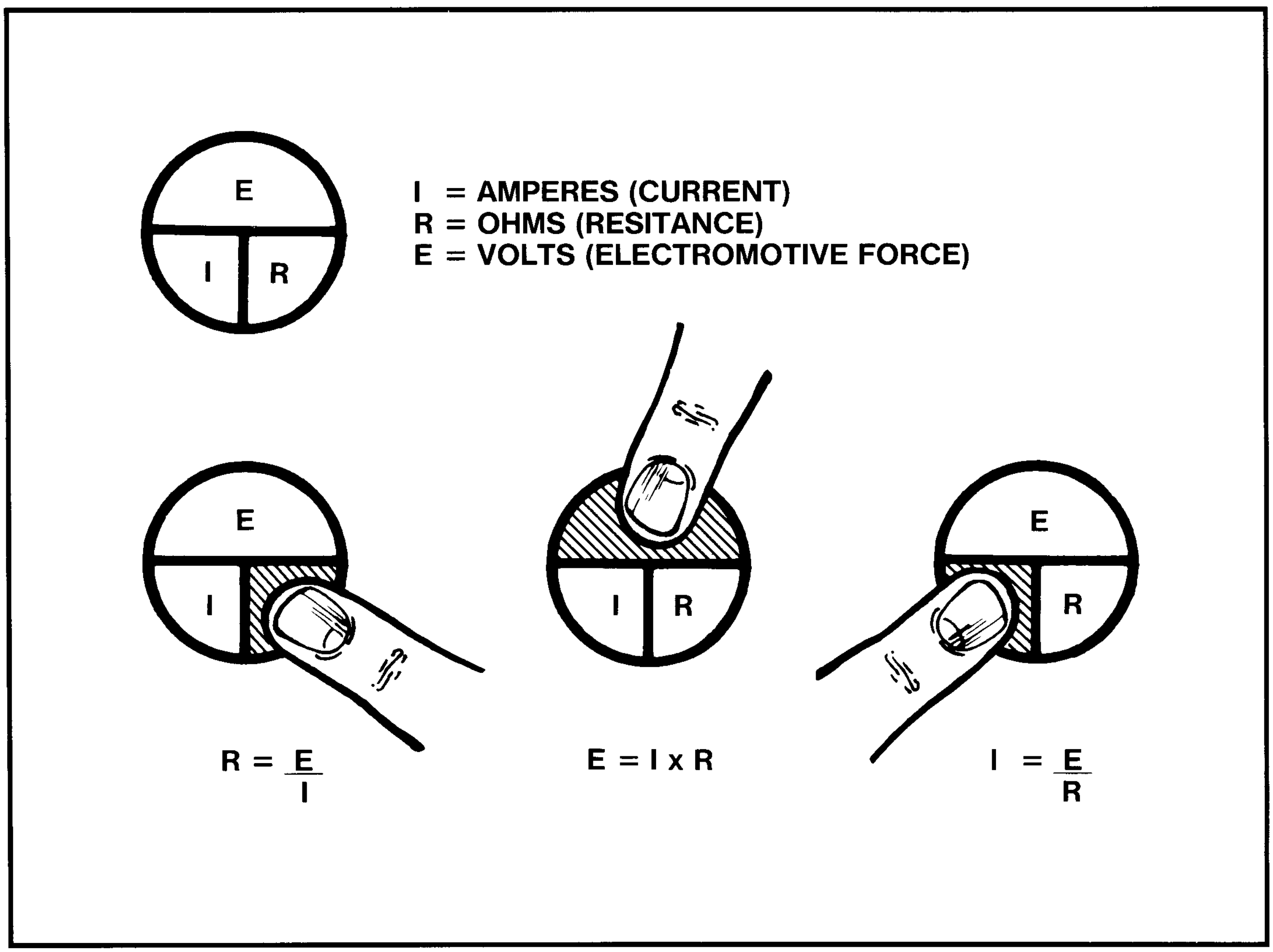
This means that if the voltage goes up, the current flow will go up, and vice versa. Also, as the resistance goes up, the current goes down, and vice versa.

Ohm's Law can be put to good use in electrical troubleshooting. But, calculating precise values for voltage, current, and resistance is not always practical ... nor, really needed. A more practical, less time-consuming use of Ohm's Law would be to simply apply the concepts involved:

SOURCE VOLTAGE is not affected by either current or resistance. It is either too low, normal, or too high. If it is too low, current will be low. If it is normal, current will be high if resistance is low or current will be low if resistance is high. If voltage is too high, current will be high.

CURRENT is affected by either voltage or resistance. If the voltage is high or the resistance is low, current will be high. If the voltage is low or the resistance is high, current will be low.

RESISTANCE is not affected by either voltage or current. It is either too low, okay, or too high. If resistance is too low, current will be high at any voltage. If resistance is too high, current will be low if voltage is okay.



ELECTRIC POWER AND WORK

Voltage and current are not measurements of electric power and work. Power, in watts, is a measure of electrical energy ... power (P) equals current in amps (1) times voltage in volts (E), P = I x E. Work, in wattseconds or watt-hours, is a measure of the energy used in a period of time ... work equals power in wafts (W) times time in seconds (s) or hours (h), W = P x time. Electrical energy performs work when it is changed into thermal (heat) energy, radiant (light) energy, audio (sound) energy, mechanical (motive) energy, and chemical energy. It can be measured with a waft-hour meter.

Power	**Basic Unit**	**Units for Very Small Values**	**Units for Very Large Values**	
Symbol	W	mW	kW	MW
Pronounced As	Watt	Milliwatt	Kilowatt	Megawatt
Multiplier	1	0.001	1,000	1,000,000

Actions Of Current

Current flow has the following effects; motion, light or heat generation, chemical reaction, and electromagnetism.

HEAT GENERATION

When current flows through a lamp filament, defroster grid, or cigarette lighter, heat is generated by changing electrical energy to thermal energy. Fuses melt from the heat generated when too much current flows.

CHEMICAL REACTION

In a simple battery, a chemical reaction between two different metals and a mixture of acid and water causes a potential energy, or voltage. When the battery is connected to an external load, current will flow. The current will continue flowing until the two metals become similar and the mixture becomes mostly water.

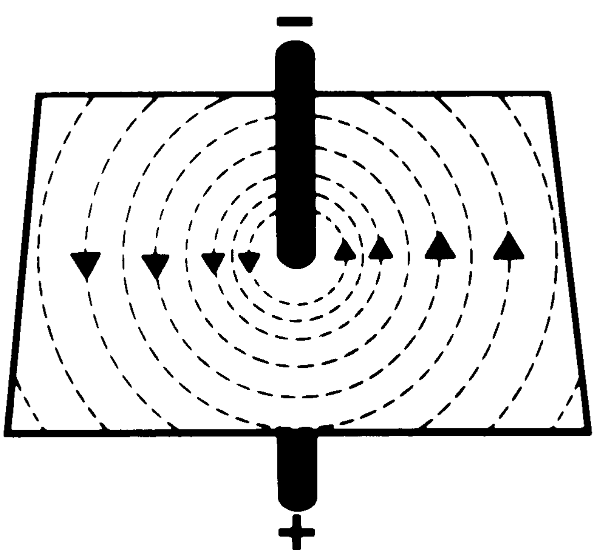
When current is sent into the battery by an alternator or a battery charger, however, the reaction is reversed. This is a chemical reaction caused by current flow. The current causes an electrochemical reaction that restores the metals and the acid-water mixture.

ELECTROMAGNETISM

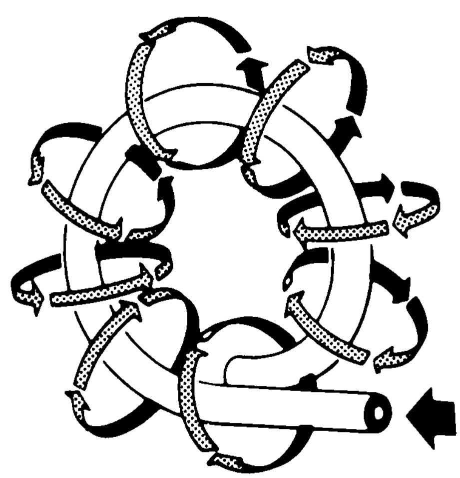
Electricity and magnetism are closely related. Magnetism can be used to produce electricity. And, electricity can be used to produce magnetism.

All conductors carrying current create a magnetic field. The magnetic field strength is changed by changing current ... stronger (more current), weaker (less current).

With a straight conductor, the magnetic field surrounds it as a series of circular lines of force. With a looped (coil) conductor, the lines of force can be concentrated to make a very strong field. The field strength can be increased by increasing the current, the number of coil turns, or both. A strong electromagnet can be made by placing an iron core inside a coil. Electromagnetism is used in many ways.



DIRECTION OF CURRENT FLOW



DIRECTION OF CURRENT FLOW

Types Of Electricity

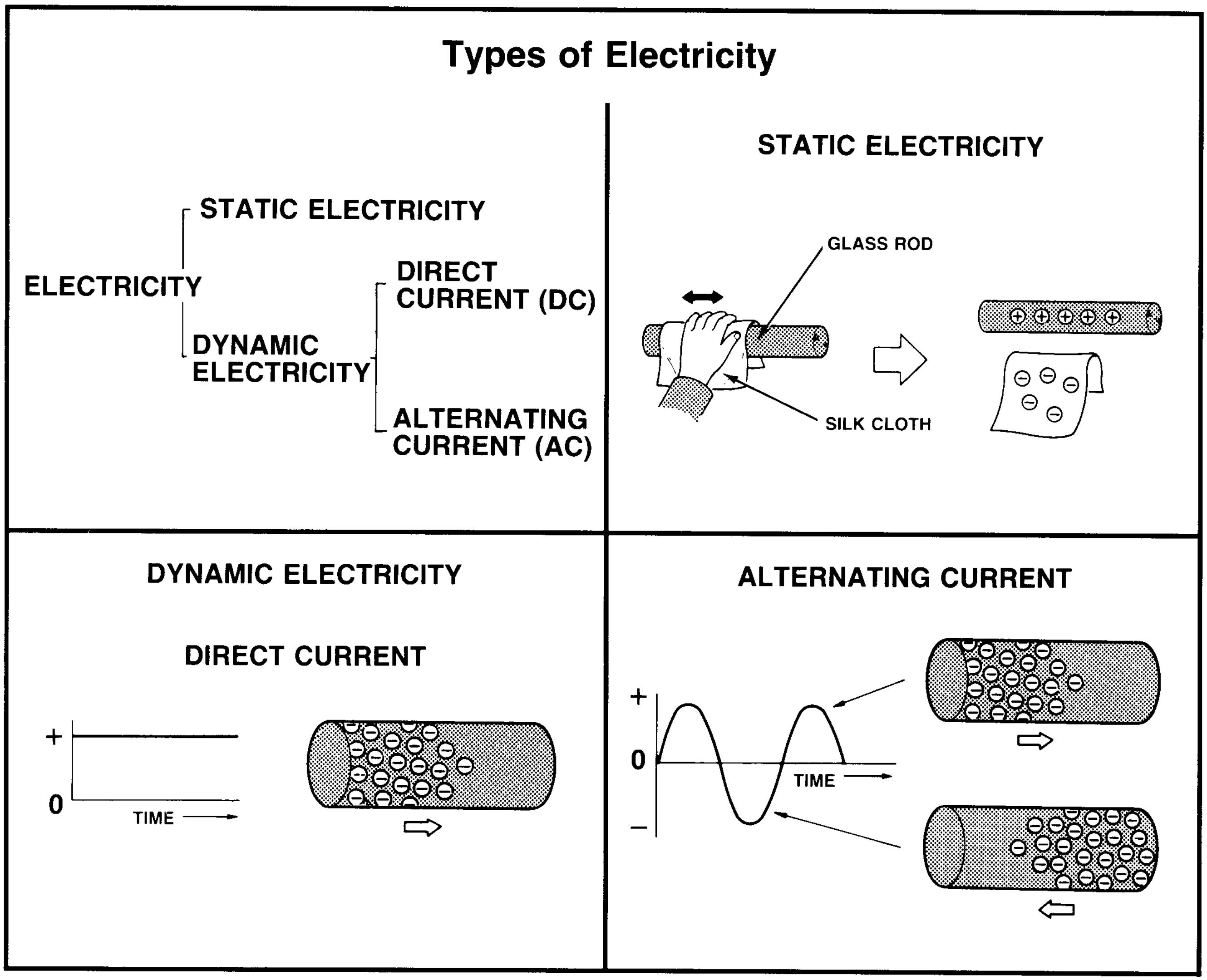
There are two types of electricity: static and dynamic. Dynamic electricity can be either direct current (DC) or alternating current (AC).

STATIC ELECTRICITY

When two non conductors - such as a silk cloth and glass rod - are rubbed together, some electrons are freed. Both materials become electrically charged. One is lacking electrons and is positively charged. The other has extra electrons and is negatively charged. These charges remain on the surface of the material and do not move unless the two materials touch or are connected by a conductor. Since there is no electron flow, this is called static electricity.

DYNAMIC ELECTRICITY

When electrons are freed from their atoms and flow in a material, this is called dynamic electricity. If the free electrons flow in one direction, the electricity is called direct current (DC). This is the type of current produced by the vehicle's battery. If the free electrons change direction from positive to negative and back repeatedly with time, the electricity is called alternating current (AC). This is the type of current produced by the vehicle's alternator. It is changed to DC for powering the vehicle's electrical system and for charging the battery.



ASSIGNMENT ***NAME:***________________________________

1. Describe the atomic structure of an atom and name all it's components.
2. Explain how an ION differs from an atom.
3. Explain the difference between "bound" and "free" electrons.
4 Explain the function of the "Valence ring"
5. Define the following items: Conductors, Insulators, and Semiconductors.
6. Describe the two theories of electron flow.
7. Define in detail "voltage" and how is it measured.
8. Define in detail "current" and how is it measured.
9. Define in detail "resistance" and how is it measured.
10. Explain the relationship between current and resistance.
11. List and describe the various factors that effect resistance.
12. Explain what ohms law is and how it can be used.
13. Describe the effects of "current flow" through a conductor.
14. Describe in detail the two general categories of "electricity".
15. Describe the two types of "dynamic electricity".

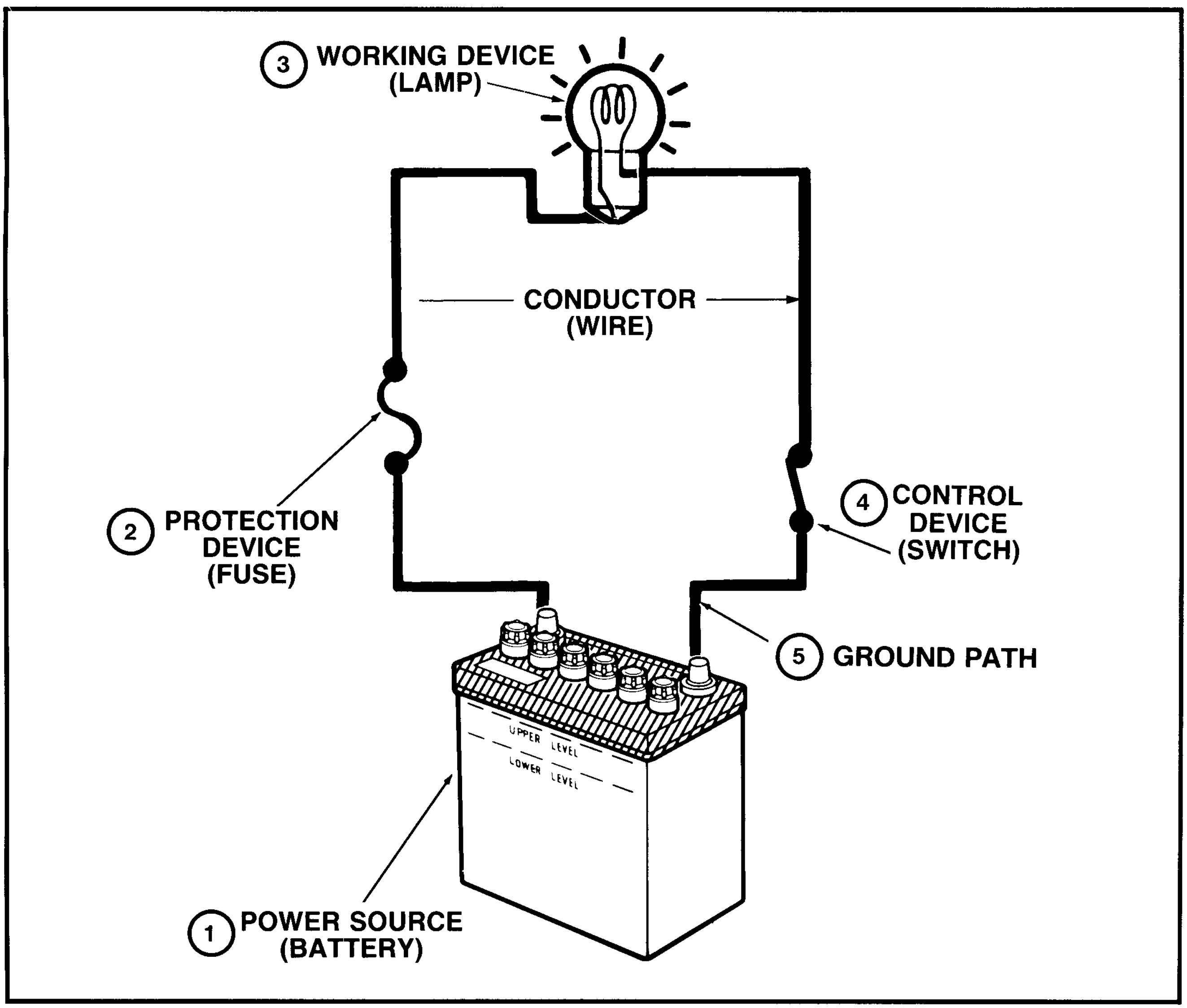
Electrical Circuits

A complete path, or circuit, is needed before voltage can cause a current flow through resistances to perform work.

There are several types of circuits, but all require the same basic components. A **power** source (battery or alternator) produces voltage, or electrical potential. **Conductors** (wires, printed circuit boards) provide a path for current flow. **Working devices**, or **loads** (lamps, motors), change the electrical energy into another form of energy to perform work. **Control devices** (switches, relays) turn the current flow on and off. And, **protection devices** (fuses, circuit breakers) interrupt the current path if too much current flows. Too much current is called an **overload**, which could damage conductors and working devices.
A list of five things to look for in any circuit:

1. Source of Voltage
2. Protection Device
3. Load
4. Control
5. Ground

We will be identifying these items when we look at Automotive Circuits a little later in this book.

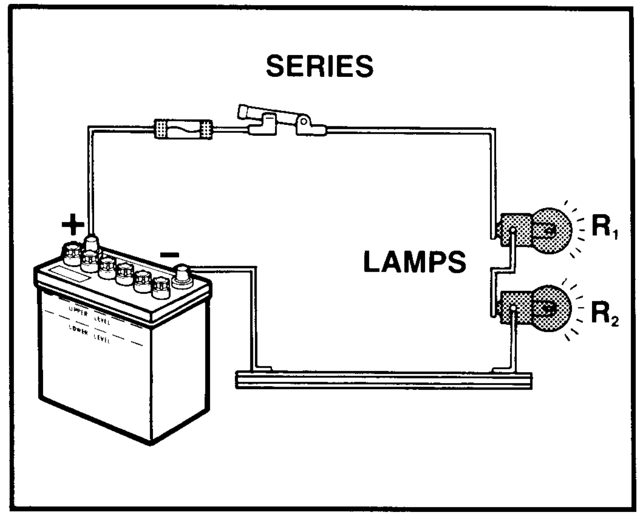


Types Of Circuits

There are three basic types of circuits: **series, parallel**, and **series-parallel**. The type of circuit is determined by how the power source, conductors, loads, and control or protective devices are connected.

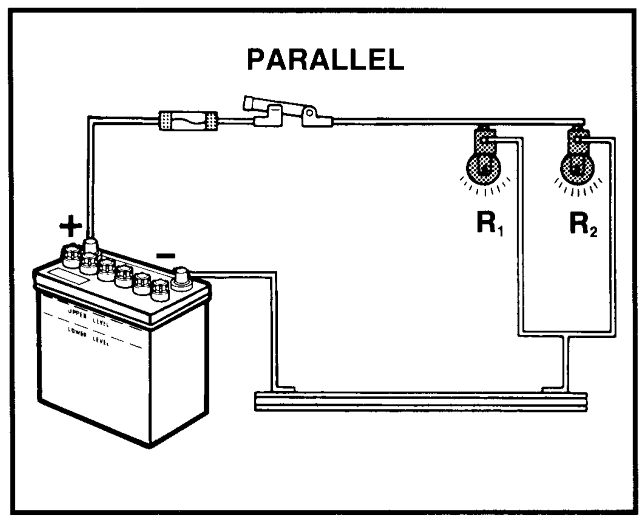
SERIES CIRCUIT

A series circuit is the simplest circuit. The conductors, control and protection devices, loads, and power source are connected with only one path for current. The resistance of each device can be different. The same amount of current will flow through each. The voltage across each will be different. If the path is broken, no current flows.



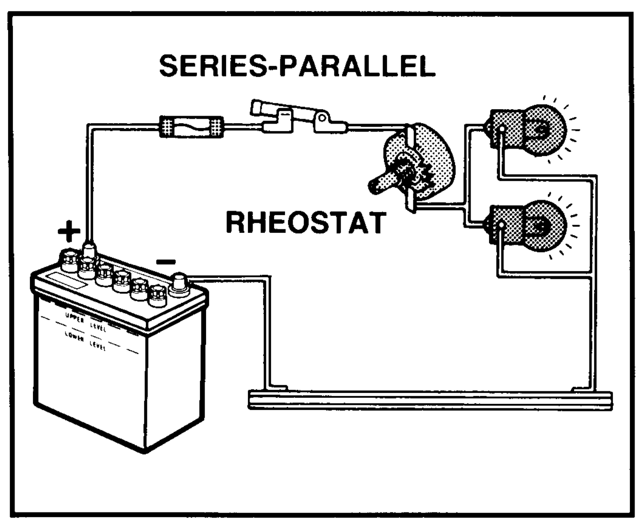
PARALLEL CIRCUIT

A parallel circuit has more than one path for current flow. The same voltage is applied across each branch. If the load resistance in each branch is the same, the current in each branch will be the same. If the load resistance in each branch is different, the current in each branch will be different. If one branch is broken, current will continue flowing to the other branches.



SERIES-PARALLEL CIRCUIT

A series-parallel circuit has some components in series and others in parallel. The power source and control or protection devices are usually in series; the loads are usually in parallel. The same current flows in the series portion, different currents in the parallel portion. The same voltage is applied to parallel devices, different voltages to series devices. If the series portion is broken, current stops flowing in the entire circuit. If a parallel branch is broken, current continues flowing in the series portion and the remaining branches.



SERIES CIRCUITS

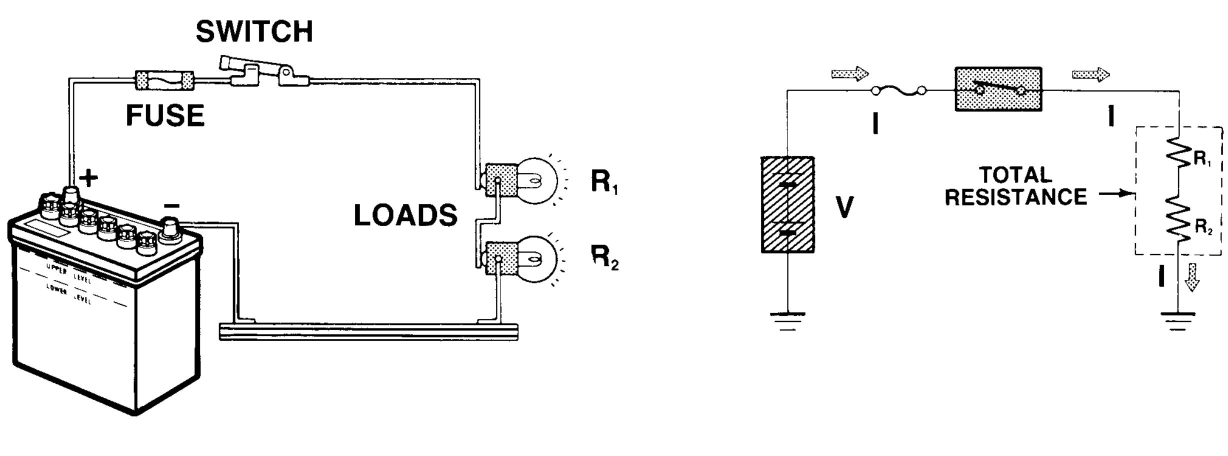
In a series circuit, current has only one path. All the circuit components are connected so that the same amount of current flows through each. The circuit must have continuity. If a wire is disconnected or broken, current stops flowing. If one load is open, none of the loads will work.

Use of Ohm's Law

Applying Ohm's Law to series circuits is easy. Simply add up the load resistances and divide the total resistance into the available voltage to find the current. The voltage drops across the load resistances are then found by multiplying the current by each load resistance. For calculation examples, see page 6 in the Ohms law section. Voltage drop is the difference in voltage (pressure) on one side of a load compared to the voltage on the other side of the load. The drop or loss in voltage is proportional to the amount of resistance. The higher the resistance, the higher the voltage drop.

When troubleshooting, then, you can see that more resistance will reduce current and less resistance will increase current. Low voltage would also reduce current and high voltage would increase current. Reduced current will affect component operation (dim lamps, slow motors). But, increased current will also affect component operation (early failure, blown fuses). And, of course, no current at all would mean that the entire circuit would not operate. There are electrical faults that can cause such problems and knowing the relationship between voltage, current, and resistance will help to identify the cause of the problem.

SERIES CIRCUITS



KEY FEATURES

- **Current through each load resistance is the same.**
- **Total resistance in the circuit is the sum of load resistances.**
- **Total voltage drop equals the source voltage.**

PARALLEL CIRCUITS

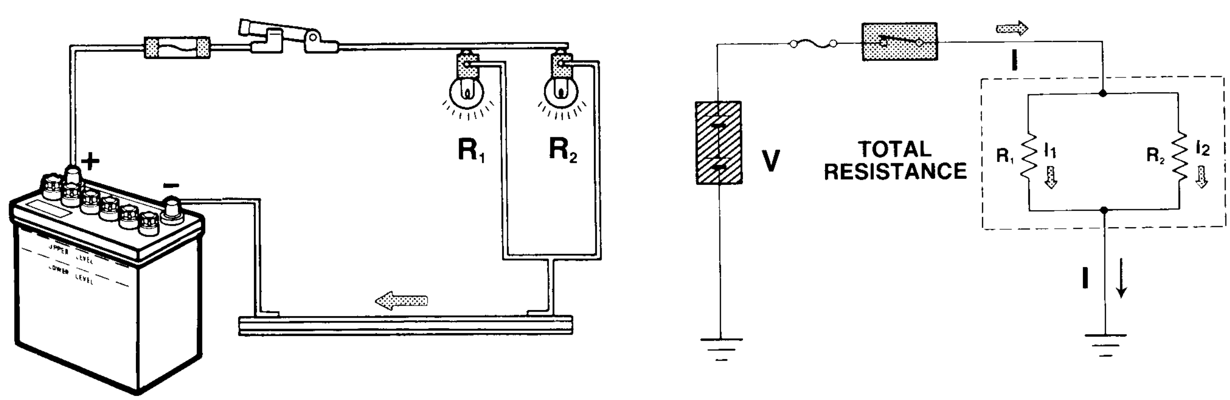
In a parallel circuit, current can flow through more than one path from and to the power source. The circuit loads are connected in parallel legs, or branches, across a power source. The points where the current paths split and rejoin are called **junctions**. The separate current paths are called branch circuits or **shunt** circuits. Each branch operates independent of the others. If one load opens, the others continue operating.

Use of Ohm's Law

Applying Ohm's Law to parallel circuits is a bit more difficult than with series circuits. The reason is that the branch resistances must be combined to find an equivalent resistance. Just remember that the total resistance in a parallel circuit is less than the smallest load resistance. This makes sense because current can flow through more than one path. Also, remember that the voltage drop across each branch will be the same because the source voltage is applied to each branch. For examples of how to calculate parallel resistance, see page 6.

When troubleshooting a parallel circuit, the loss of one or more legs will reduce current because the number of paths is reduced. The addition of one or more legs will increase current because the number of paths is increased. Current can also be reduced by low source voltage or by resistance in the path before the branches. And, current can be increased by high source voltage or by one or more legs being bypassed. High resistance in one leg would affect component operation only in that leg.

PARALLEL CIRCUITS



KEY FEATURES

- **Voltage across each load resistance is the same.**
- **Current flow through each load will be different if the load resistances are different.**
- **Equivalent resistance of the circuit is less than the lowest load resistance.**
- **Total current in the circuit equals the sum of the branch currents.**

SERIES-PARALLEL CIRCUITS

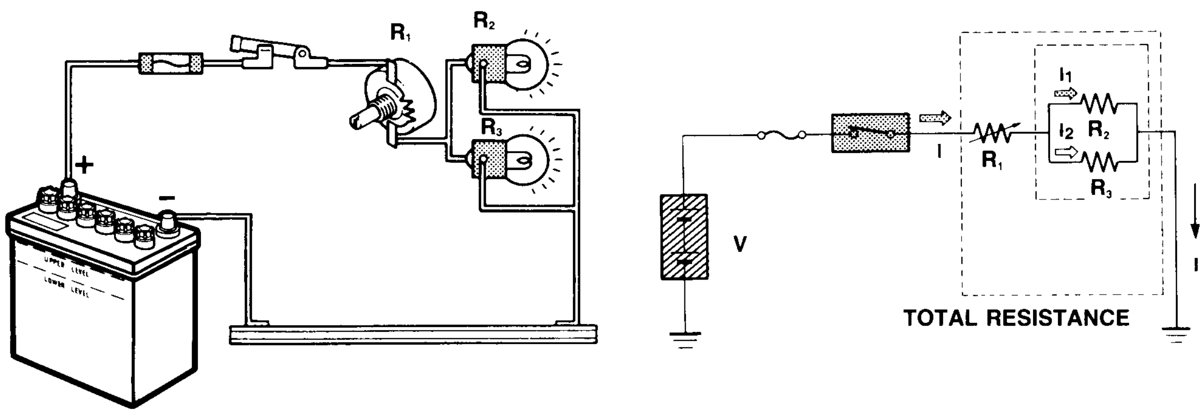
In a series-parallel circuit, current flows through the series portion of the circuit and then splits to flow through the parallel branches of the circuit. Some components are wired in series, others in parallel. Most automotive circuits are series-parallel, and the same relationship between voltage, current, and resistance exists.

Use of Ohm's Law

Applying Ohm's Law to series-parallel circuits is a matter of simply combining the rules seen for series circuits and parallel circuits. First, calculate the equivalent resistance of the parallel loads and add it to the resistances of the loads in series. The total resistance is then divided into the source voltage to find current. Voltage drop across series loads is current times resistance. Current in branches is voltage divided by resistance. For calculation examples, see page 6.

When troubleshooting a series-parallel circuit, problems in the series portion can shut down the entire circuit while a problem in one leg of the parallel portion may or may not affect the entire circuit, depending on the problem. Very high resistance in one leg would reduce total circuit current, but increase current in other legs. Very low resistance in one leg would increase total circuit current and possibly have the effect of bypassing other legs.

SERIES-PARALLEL CIRCUITS



KEY FEATURES

- **Current in the series portion of the circuit equals the sum of branch currents.**
- **Circuit resistance is the sum of the parallel equivalent resistance and any series resistances.**
- **Voltage applied to the parallel branches is the source voltage minus any voltage drop across loads wired in series.**

Ohm's Law

Fast, accurate electrical troubleshooting is easy when you know how voltage, current, and resistance are related. Ohm's Law explains the relationship:

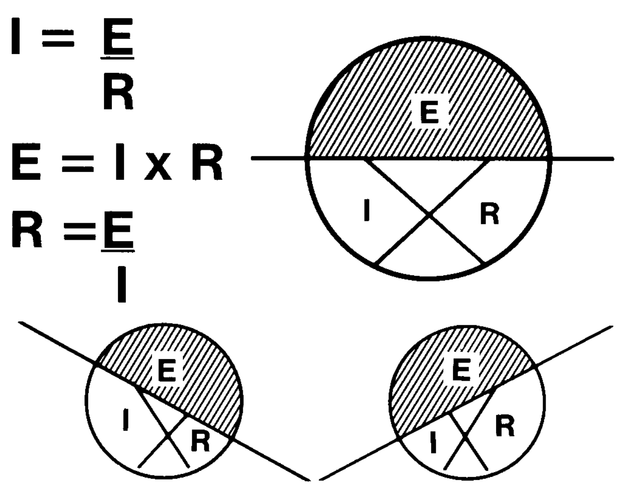
- Current (amps) equals voltage (volts) divided by resistance (ohms) ... I = E ÷ R.
- Voltage (volts) equals current (amps) times resistance (ohms) ... E = I X R.
- Resistance (ohms) equals voltage (volts) divided by current (amps) ... R ÷ E = 1.

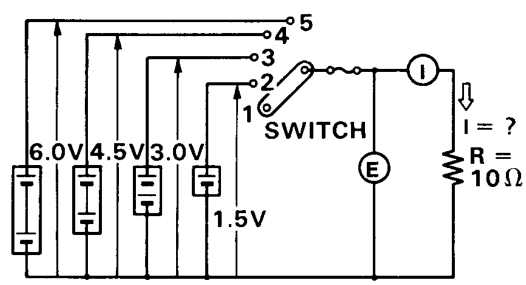
USING OHM'S LAW

The effects of different voltages and different resistances on current flow can be seen in the sample circuits. Current found by dividing voltage by resistance. This can be very helpful when diagnosing electrical problems:

- When the resistance stays the same ... current goes up as voltage goes up, and current goes down as voltage goes down. A discharged battery has low voltage which reduces current. Some devices may fail to operate (slow motor speed). An unregulated alternator may produce too much voltage which increases current. Some devices may fail early (burned-out lamps).

- When the voltage stays the same ... current goes up as resistance goes down, and current goes down as resistance goes up. Bypassed devices reduce resistance, causing high current. Loose connections increase resistance, causing low current.

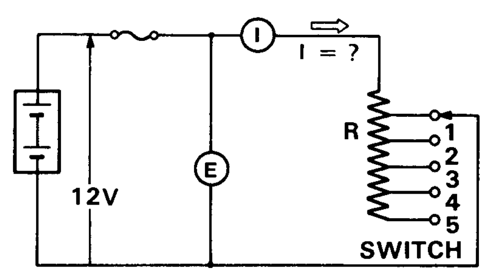




TERMINAL NO.	1	2	3	4	5
VOLTAGE (E)	0	1.5	3.0	4.5	6.0
CURRENT (I)	0	0.15	0.30	0.45	0.6

CONSTANT RESISTANCE: 10Ω

VOLTAGE	RESISTANCE	CURRENT
UP	DOWN	UP
UP	SAME	UP
UP	UP	SAME
SAME	DOWN	UP
SAME	SAME	SAME
SAME	UP	DOWN
DOWN	DOWN	SAME
DOWN	UP	DOWN
DOWN	SAME	DOWN



TERMINAL NO.	1	2	3	4	5
RESISTANCE (Ω)	10	20	30	40	50
CURRENT (I)	1.2	0.6	0.4	0.3	0.24

CONSTANT VOLTAGE: 12 V

SAMPLE CALCULATIONS

Here are some basic formulas you will find helpful in solving more complex electrical problems. They provide the knowledge required for confidence and thorough understanding of basic electricity.

The following abbreviations are used in the formulas:

E = VOLTS
I = AMPS
R = OHMS
P = WATTS

• Ohm's Law

Scientifically stated, it says: "The intensity Of the current in amperes in any electrical circuit is equal to the difference in potential in volts across the circuit divided by the resistance in ohms of the circuit." Simply put it means that current is equal to volts divided by ohms, or expressed as a formula, the law becomes:

I = E / R

or it can be written:

E = I X R

This is important because if you know any two of the quantities, the third may be found by applying the equation.

Ohm's law includes these two ideas:

1. In a circuit, if resistance is constant, current varies directly with voltage.

Now what this means is that if you take a component with a fixed resistance, say a light bulb, and double the voltage you double the current flowing through it. Anyone who has hooked a six-volt bulb to a twelve-volt circuit has experienced this. But it wasn't "too many volts" that burned out the bulb, it was too much current. More about that later.

2. In a circuit, if voltage is constant, current varies inversely with resistance.

This second idea states that when resistance goes up, current goes down. That's why corroded connectors cause very dim lights - not enough current.

• Watts

A watt is an electrical measurement of power or work. It directly relates to horsepower. In fact, in the SI metric standards that most of the world uses, engine power is given in watts or kilowatts.

Electrical power is easily calculated by the formula:

P = E X I

For instance, a halogen high-beam headlight is rated or 5 amps of current. Figuring 12 volts in the system, we could write:

P = E X I
P = 12 X 5
P = 60 watts

