

Electrical Circuits

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

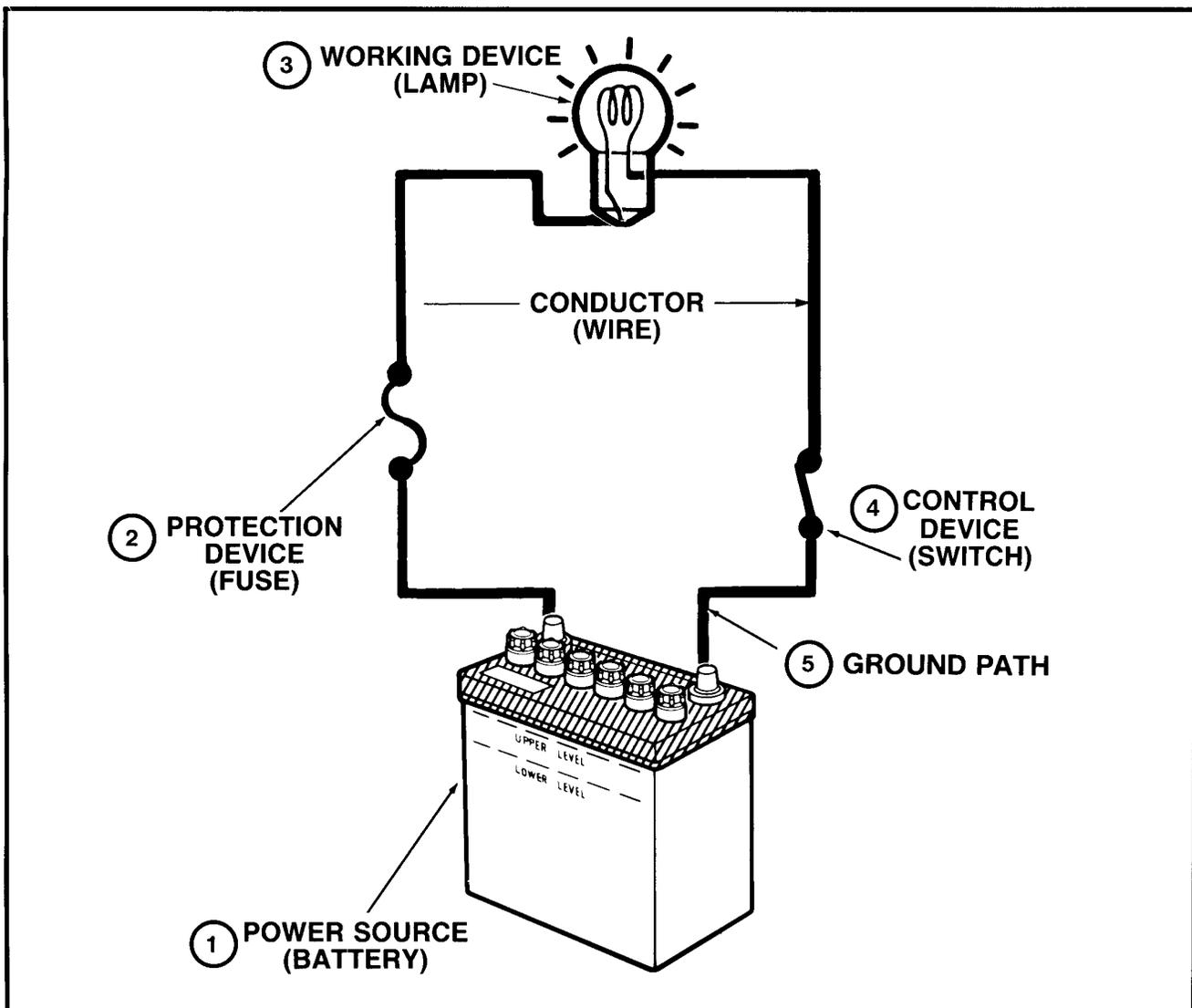
There are several types of circuits, but all require the same basic components. A **power** source (battery or alternator) produces voltage, or electrical potential. **Conductors** (wires, printed circuit boards) provide a path for current flow. **Working devices**, or **loads** (lamps, motors), change 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

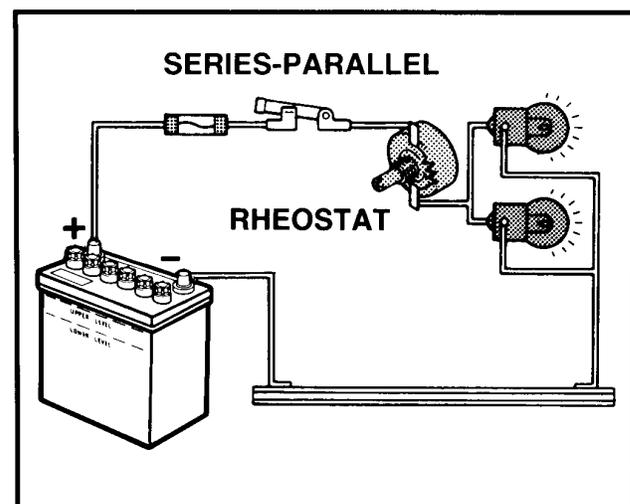
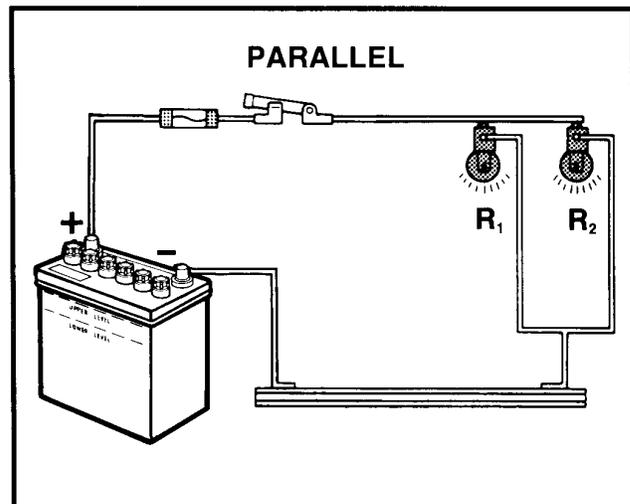
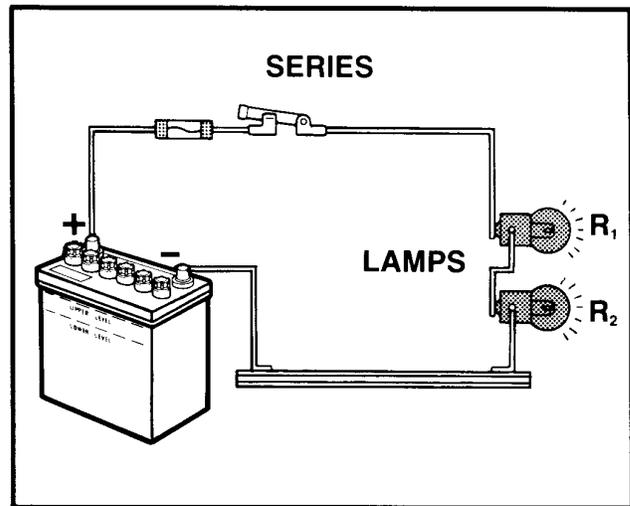
A series circuit is the simplest circuit. The conductors, control and protection devices, loads, and power source are connected with only one path for current. The resistance of each device can be different. The same amount of current will flow through each. The voltage across each will be different. 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

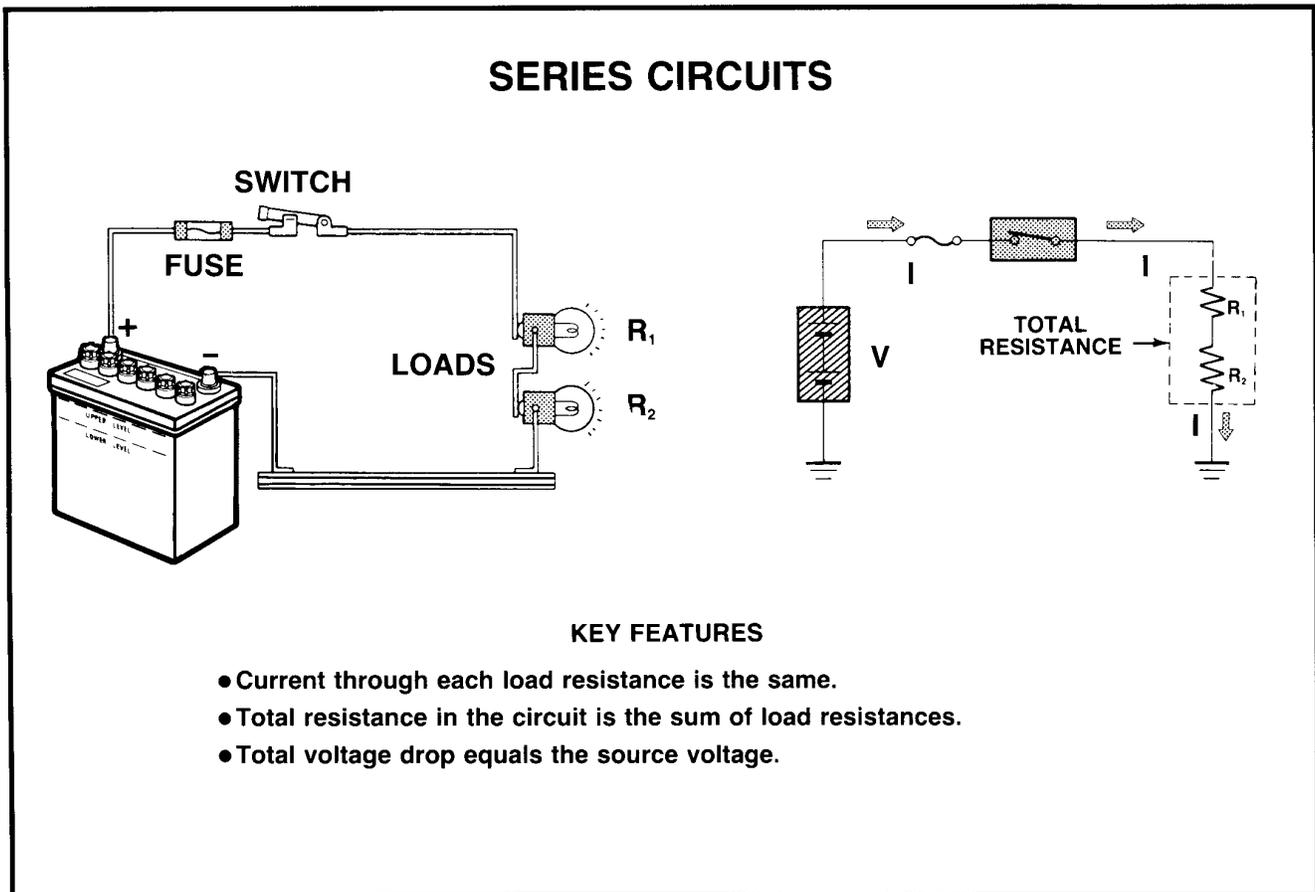
In a series circuit, current has only one path. All the circuit components are connected so that the same amount of current flows through each. The circuit must have continuity. If a wire is disconnected or broken, current stops flowing. If one load is open, none of the loads will work.

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.



PARALLEL CIRCUITS

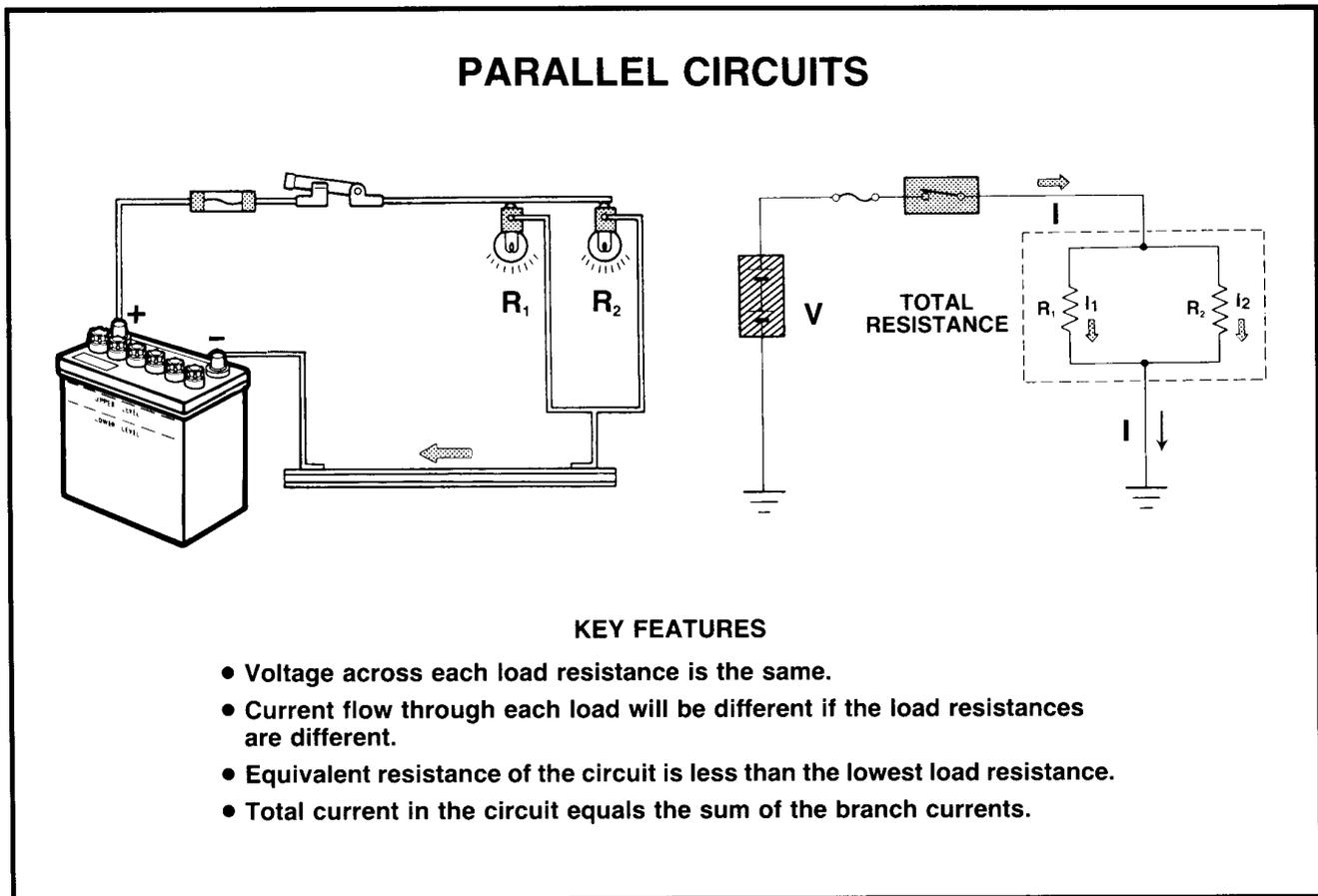
In a parallel circuit, current can flow through more than one path from and to the power source. The circuit loads are connected in parallel legs, or branches, across a power source. The points where the current paths split and rejoin are called **junctions**. The separate current paths are called branch 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.



SERIES-PARALLEL CIRCUITS

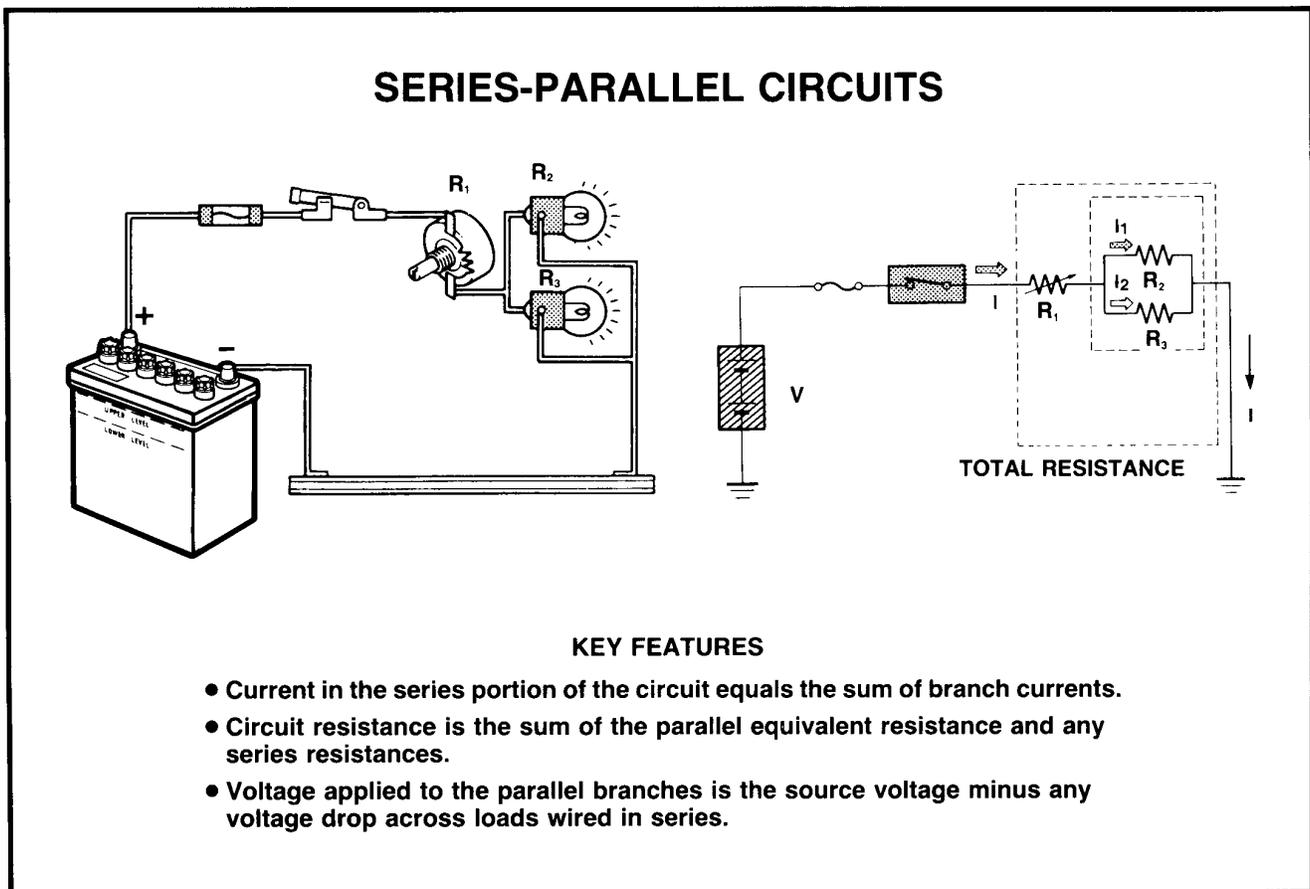
In a series-parallel circuit, current flows through the series portion of the circuit and then splits to flow through the parallel branches of the circuit. Some components are wired in series, others in parallel. Most automotive circuits are series-parallel, and the same relationship between voltage,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



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) ... $I = E \div R$.
- Voltage (volts) equals current (amps) times resistance (ohms) ... $E = I \times R$.
- Resistance (ohms) equals voltage (volts) divided by current (amps) ... $R \div E = 1$.

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.

$I = \frac{E}{R}$

$E = I \times R$

$R = \frac{E}{I}$

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: 10 Ω

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

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

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:

$$E = I \times R$$

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:

$$P = E \times I$$

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

$$P = E \times I$$
$$P = 12 \times 5$$
$$P = 60 \text{ watts}$$

RESISTANCE

The effect of individual resistors on the total resistance of a circuit depends on whether the circuit is series or parallel.

Series Circuits

In a series circuit, the total resistance is equal to the sum of the individual resistors:

SERIES:

$$\text{total R} = R1 + R2 + R3 + \dots$$

That is the basis of the concept of voltage drop. For example, if you had a circuit with three loads in series (a bulb, resistor, and corroded ground) you would add the three together to get total resistance. And, of course, the voltage would drop across each load according to its value.

Parallel Circuits

Parallel circuits are a different story. In a parallel circuit, there are three ways to find total resistance. Method A works in all cases. Method B works only if there are two branches, equal or not. Method C works only if the branches are of equal resistance.

A. The total resistance is equal to one over the sum of the reciprocals of the individual resistors. That sounds confusing, but looking at the formula will make it clearer:

PARALLEL:

$$\text{total R} = \frac{1}{1/R1 + 1/R2 + 1/R3 + \dots}$$

An example will make it even clearer. Suppose there is a circuit with three resistors in parallel: 4 ohms, 2 ohms, and 1 ohm. The formula would look like this:

$$\text{total R} = \frac{1}{1/4 + 1/2 + 1/1}$$

That becomes:

$$\text{total R} = \frac{1}{1/4 + 2/4 + 4/4}$$

Which becomes:

$$\text{total R} = \frac{1}{7/4} = 4/7 = 0.57 \text{ ohms}$$

So there is a little more than one-half ohm resistance in the circuit. You can see that the more resistors in parallel, the less the resistance.

In fact, the total resistance is always less than the smallest resistor. This is why a fuse will blow if you add too many circuits to the fuse. There are so many paths for the current to follow that the total resistance of the circuit is very low. That means the current is very high - so high that the fuse can no longer handle the load.

B. For two resistors:

$$\text{total R} = \frac{R1 \times R2}{R1 + R2}$$

For a 3 ohm and a 5 ohm resistor that would be:

$$\text{total R} = \frac{R1 \times R2}{R1 + R2} = \frac{3 \times 5}{3 + 5} = \frac{15}{8} = 1.88 \text{ ohms}$$

C. For several identical resistors, divide the value of one resistor by the number of resistors, or:

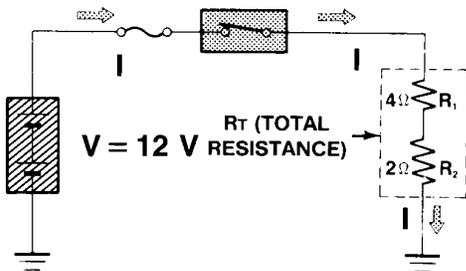
$$\text{total R} = \frac{R1}{n}$$

Where R1 is the value of one resistor and n is the number of resistors. So if you had three 4 ohm resistors in parallel it would be:

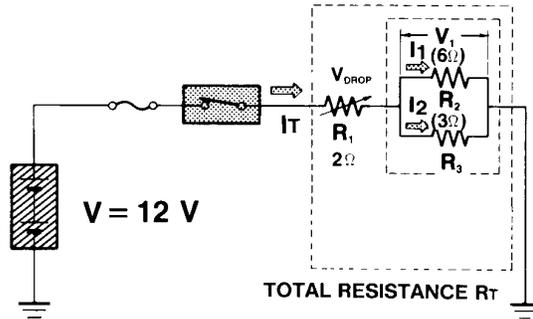
$$\text{total R} = \frac{4}{3} = 1.3 \text{ ohms}$$

Optional Problems: Electrical Essentials

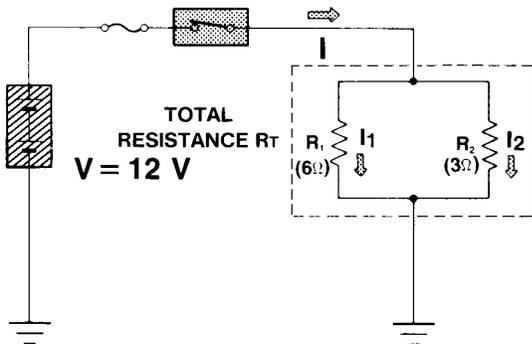
For an additional challenge and extra skill practice on **Electrical Essentials**, try these more advanced optional problems. These will take a little more time and thought, but each will be a good test of your knowledge.



1. In the above circuit, what is the total resistance (R_T) and the amount of current flow (I)? ____
- A. 1.33 ohms and 9 amps
 - B. 4 ohms and 2 amps
 - C. 2 ohms and 6 amps
 - D. 6 ohms and 2 amps



3. In the above circuit, what is the total current flow (I_T), combined resistance (R_T), and the branch currents (I_1 and I_2)? _____
- A. 3 amps, 4 ohms, 1 amp, and 2 amps
 - B. 6 amps, 2 ohms, 2 amps, and 4 amps
 - C. 4 amps, 3 ohms, 3 amps, and 1 amp
 - D. 2 amps, 6 ohms, $\frac{1}{2}$ amp, and $1\frac{1}{2}$ amp



2. In the above circuit, what is the total resistance (R_T) and what are the branch currents (I_1 and I_2)? ____
- A. 18 ohms, 2 amps, and 4 amps
 - B. 2 ohms, 6 amps, and 3 amps
 - C. 2 ohms, 2 amps, and 4 amps
 - D. 1.5 ohms, 4 amps, and 8 amps

ELECTRICAL CIRCUITS

ASSIGNMENT

NAME: _____

1. Draw and label the parts of a Series Circuit and a Parallel Circuit.
2. Explain the characteristics of “Voltage” and how it differs between a Series Circuit and a Parallel Circuit.
3. Explain the characteristics of “Current” and how it differs between a Series Circuit and a Parallel Circuit.
4. Explain the characteristics of “Resistance” and how it differs between a Series Circuit and a Parallel Circuit.