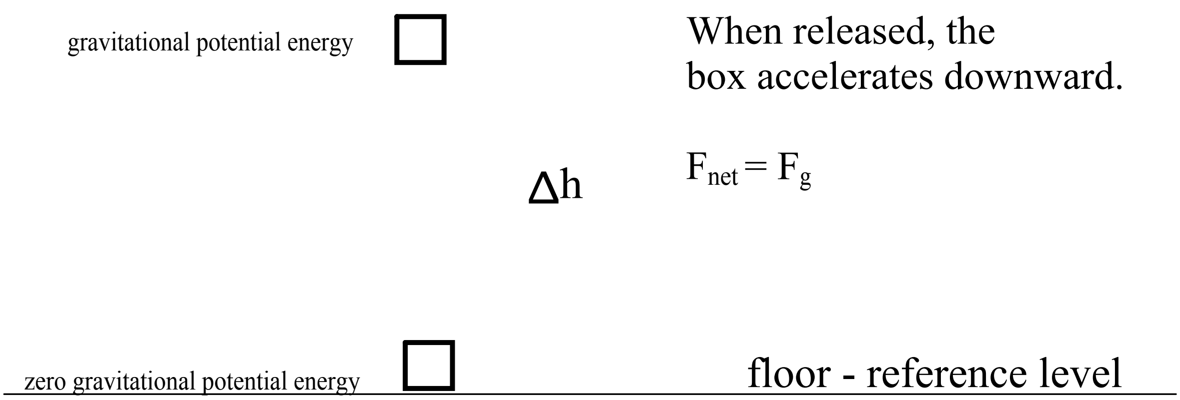
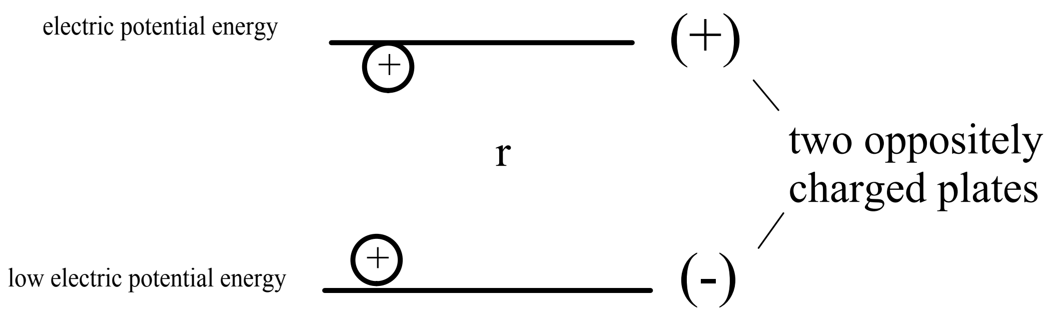
Electric Potential Energy

Review - Gravitational Potential Energy

$$E_g = mg\Delta h$$



New Situation - Electric Potential Energy



When released, the charged particle accelerates downward.

$$F_{net} = F_e$$

Electric potential energy, E_Q, is zero at infinity (reference level).

Formula for Electric Potential Energy

Remember: $W = Fd \longrightarrow W = Fr$

W -> work (J)
F -> force (N)
r -> displacement (m)

So:

$$W = Fr$$

$$W = \frac{kqq_t\, r}{r^2}$$

$$W = \frac{kqq_t}{r}$$

$$\boxed{E_Q = \frac{kqq_t}{r}}$$

E_Q -> electric potential energy (J)
k -> $9.0 \times 10^9 \frac{Nm^2}{C^2}$
q -> source charge (C)
q_t -> test charge (C)
r -> distance between charges (m)

In this formula include the signs of q and q_t.

If q and q_t have the same sign, $E_Q > 0J$.

If q and q_t have different signs, $E_Q < 0J$.

We can describe electric fields in terms of electric potential energy. Electric potential difference (voltage) is defined as the work done against an electric field in moving a positive test charge from infinity to a point in an electric field.

$$V = \frac{W}{q_t}$$

$$V = \frac{E_Q}{q_t}$$

$$V = \frac{kqq_t}{rq_t}$$

$$V = \frac{kq}{r}$$

V -> electric potential difference or voltage (J/C = V)

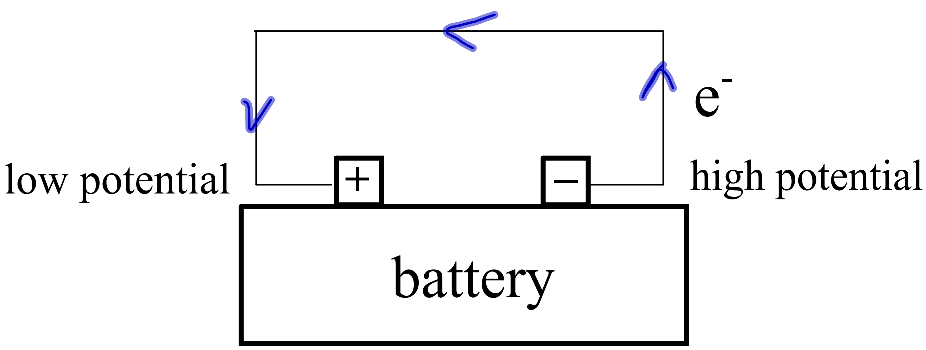
k -> $9.0 \times 10^9 \frac{Nm^2}{C^2}$

q -> source charge (C) ** include the sign

r -> distance from source charge to point in field (m)

☆

A battery is a source of potential difference. It can be considered to be an electron pump - it increases the electric potential energy of electrons. (e^- -> electron)



Electric Current
(Chapter 15 - Page 694)

In an electric conductor, current (I), is described as a quantity of charge (q) passing a point during an interval of time (t).

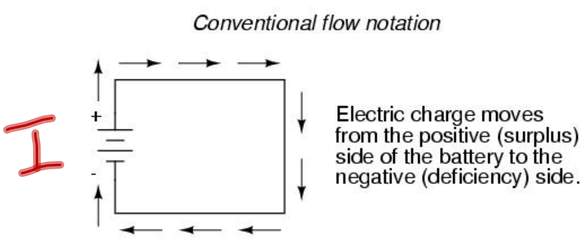
$$I = \frac{q}{t}$$

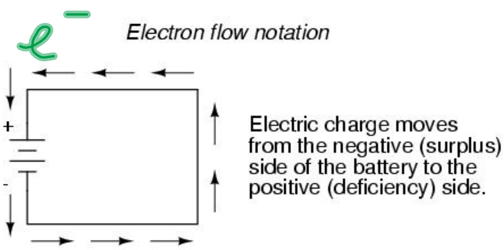
I -> C/s = A (ampere)
q -> C
t -> s

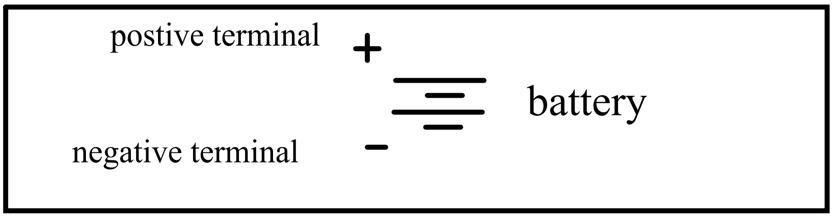
Textbook: Page 696, #4-10

Conventional Current vs. Electron Flow

Conventional current means the flow of positive charge in a circuit. The flow of negative charge is called electron flow.







The *anode* of a device is the terminal where current flows in. The *cathode* of a device is the terminal where current flows out.

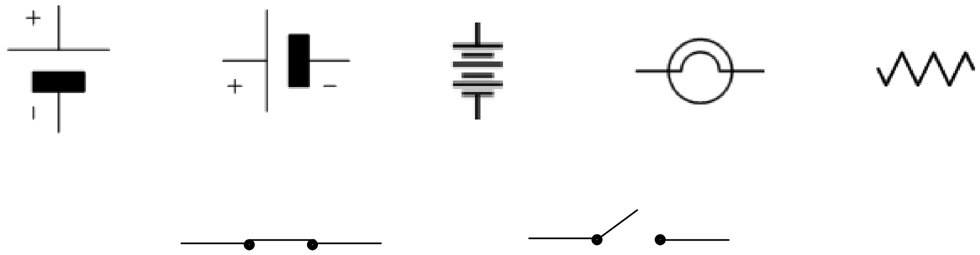
★

Symbols and Types of Electric Circuits

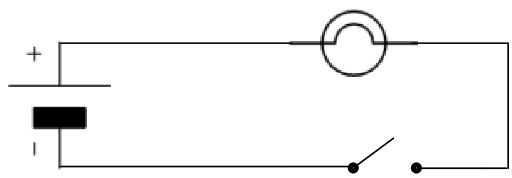
Imagine a power supply such as a battery is connected to a load such as a light bulb. A switch allows you to open and close the circuit.

Symbols are used to represent the **elements of a circuit**.

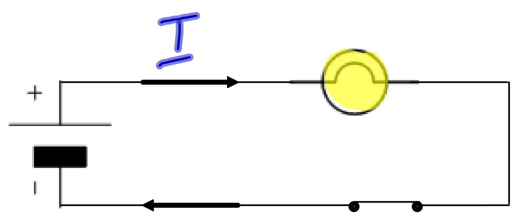
See Page 701 for more symbols.



An **open circuit** means there is a break in the circuit that prevents current from flowing.



A **closed circuit** means that all connections are complete. A closed or continuous path exists allowing current to move around the circuit.

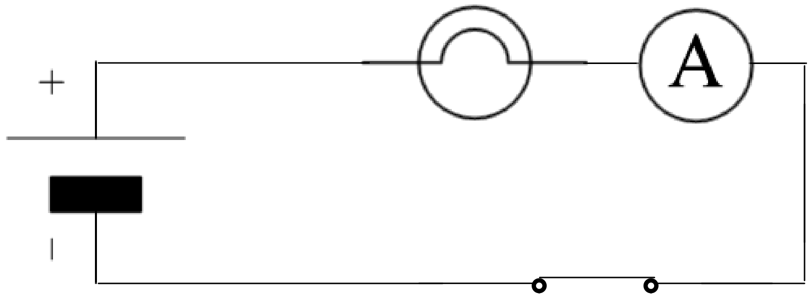


Ammeters vs Voltmeters

Meters are used to measure current and potential difference and are connected in such a way that they will not interfere with the operation of the circuit.

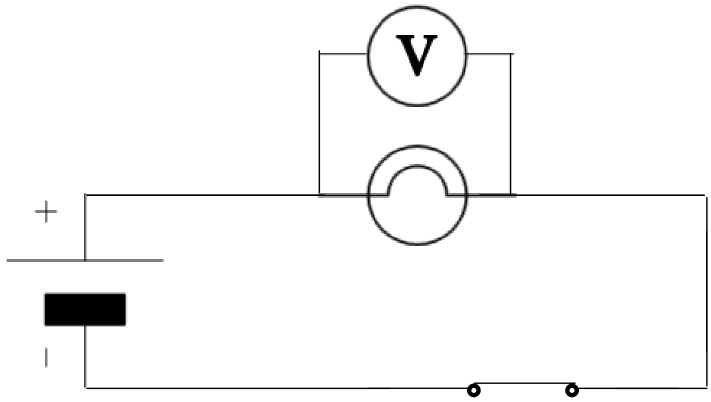
An **ammeter** measures the **electric current** through a circuit element. It is connected in what is called a series connection since the current moves through the circuit element and the ammeter one after the other.

ammeter 



A **voltmeter** measures the **electric potential difference** across a circuit element. It is connected in what is called a parallel connection since the voltmeter presents a path that runs beside the circuit element.

voltmeter 



Resistance to Flow of Charge

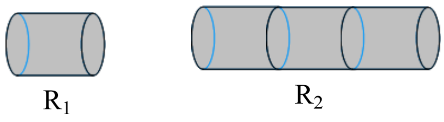
Frictional effects in conductors offer resistance to the current passing through them.

Factors Affecting Resistance

1. Resistance and Length

Resistance increases proportionately with the length of a conductor. Assume a fixed diameter.

$$R \alpha L$$

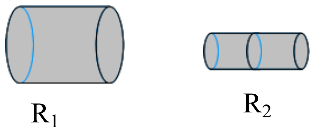


$R_1 < R_2$

2. Resistance and Cross-Sectional Area

Resistance is inversely proportional to the cross-sectional area of a conductor. Assume equal length.

$$R \alpha \frac{1}{A}$$



$R_1 < R_2$

3. Temperature

$$R \alpha T$$

We will assume temperature is constant.

The result of combining the first two relationships above is:

$$R \alpha \frac{L}{A}$$

This proportionality can be written as an equality if a proportionality constant is included. In the case of resistance, the symbol used for the proportionality constant is the Greek letter rho (ρ) and it is called **resistivity**. It is a property of the material from which the conductor is made.

$$R = \rho \frac{L}{A}$$

R -> resistance (Ω)
ρ -> resistivity (Ωm)
L -> length (m)
A -> area (m^2)

Finally, the *temperature* of the conductor affects the resistance. The electrons that move inside a metallic conductor are the electrons from the outermost orbit of the atoms of the metal. Thus, they are the electrons that are most loosely held by the atoms of

the metal. These outermost electrons of good conductors can move quite freely within the metal, behaving much like the molecules of a gas. As you heat the metal, these electrons begin to move more randomly at higher speeds inside the metal. As a result, it is more difficult to organize them into a current. Near 20°C, copper increases its resistance by about 0.39% for each degree of temperature increase. Conversely, lowering the temperature reduces the resistance.

PHYSICS FILE

The thickness of wire is called its "gauge." As the gauge of a wire increases, the wire becomes thinner. When electricians wire the circuits of a house, they usually use 14 gauge wire, while the lighter wire in the cord of a small appliance might be 18 gauge wire.

Diameters/Resistances of Some Gauges of Copper Wire

Gauge	Diameter (mm)	Resistance ($\times 10^{-3}\Omega$/m)
0	9.35	0.31
10	2.59	2.20
14	1.63	8.54
18	1.02	21.90
22	0.64	51.70

The resistance of a conductor with a particular length and cross-sectional area depends on the *material* from which it is made. At room temperature, copper is one of the best conducting (lowest resistance) metals. Table 15.1 includes resistivity values for carbon and germanium, which are semiconductors, and for glass, which is an insulator. Insulators are sometimes thought of as conductors with extremely high resistances. By examining Table 15.1, you can see that glass has about 10^{18} to 10^{22} times the resistance of copper.

Table 15.1 Resistivity of Some Conductor Materials

Material	*Resistivity, ρ ($\Omega \cdot$ m)
silver	1.6×10^{-8}
copper	1.7×10^{-8}
aluminum	2.7×10^{-8}
tungsten	5.6×10^{-8}
Nichrome™	100×10^{-8}
carbon	3500×10^{-8}
germanium	0.46
glass	10^{10} to 10^{14}

*Values given for a temperature of 20°C

Textbook: Page 708, #16-20

$$V = \frac{W}{q} \qquad I = \frac{q}{t}$$

Ohm's Law (Page 712)

In 1826, German physicist Georg Simon Ohm conducted the original experiments in resistance in electric circuits, using many lengths and thicknesses of wire. He studied the current passing through the wire when a known potential difference was applied across it. From his data he developed the mathematical relationship that is known as Ohm's Law.

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

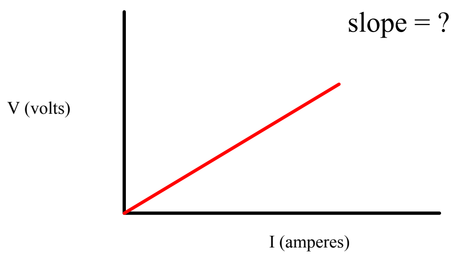
R -> resistance (Ω)
V -> potential difference (V)
I -> current (A)

NOTE: The ohm is defined in accordance with Ohm's Law.

$$1\ \Omega = \frac{1\ V}{1\ A}$$

Study the graph below. What is the significance of the slope of the line?

Potential Difference vs Current



The formula is often written in the form

$$V = IR$$

The usefulness of the formula is limited to metal conductors at stable temperatures. When a load does not obey Ohm's Law, the graph of potential difference versus current is not a straight line. Devices and materials that do not obey Ohm's Law are said to be **non-linear** or **non-ohmic**.

Textbook: Page 714, #21-26

$$* \ V = \frac{W}{q_t} = \frac{E_Q}{q_t}$$

Electric Power (Page 734)

Every appliance is rated for its power output or wattage, P. This is the rate at which it can transform electric energy to a desired form (light, sound, heat, etc.).

Examples:

electric range	> 12 000 W
electric clothes dryer	5000 W
electric shaver	15 W
electric clock	5 W

The power output or wattage of a light bulb tells you how fast it will convert electric energy into heat and light.

Figure 15.26 The power rating (sometimes called the "wattage") of a light bulb tells you how fast it will convert electric energy into heat and light. For an incandescent bulb, only about 2 percent of the transformed energy is actually emitted as light; the rest is emitted as heat. A fluorescent bulb, on the other hand, converts about 9.5 percent of its energy into light, making it more than four times as efficient as an incandescent bulb.

Chapter 15 Electric Energy and Circuits • MHR **735**

Last year we defined power as work done per unit time or energy transformed or transferred per unit time.

$$P = \frac{W}{\Delta t}$$

P - power
W - work done
Δt - time interval

$$P = \frac{E}{\Delta t}$$

P - power
E - energy transformed
Δt - time interval

When working with electric circuits and systems, you typically work with potential difference, current and resistance. It would be convenient to have relationships between power and these commonly used variables.

$$P = IV$$

P - power (W)
I - current (A)
V - voltage (V)

If we use V = IR, we can obtain two more equations for power.

Substitute IR for V in P = IV.

$$P = IV$$
$$P = I(IR)$$

$$\boxed{P = I^2R}$$

Rearrange V = IR for I.

$$V = IR$$
$$I = \frac{V}{R}$$

Substitute V/R for I in P = IV.

$$P = IV$$
$$P = \frac{V}{R}(V)$$

$$\boxed{P = \frac{V^2}{R}}$$

Textbook: Page 737, #40-42
Page 744, #46-50

Series Circuits (Page 716)

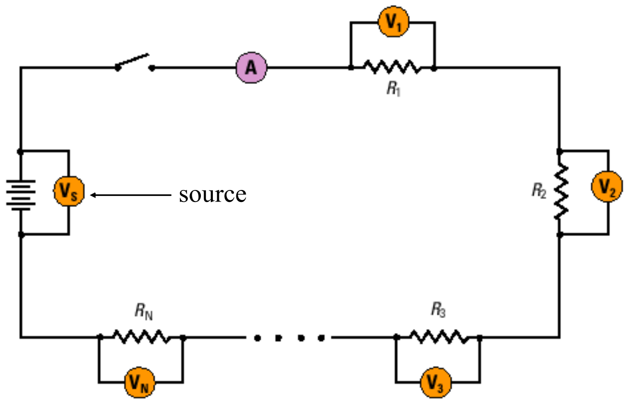


Figure 15.19 A circuit might consist of any number of loads. If this circuit had eight loads, R_N would represent R_8, and eight loads would be connected in series.

Chapter 15 Electric Energy and Circuits • MHR 717

A series circuit consists of loads (resistances) connected in series.

The current that leaves the battery has only one path to follow. All of the current that leaves the battery must pass through each of the loads.

An ammeter could be connected at any point in the circuit and each reading would be the same.

$$I = I_1 = I_2 = I_3 = I_N$$

The potential difference of the battery must be shared over all the loads. A portion of the electric potential of the battery must be used to push the current through each load. If each load had a voltmeter connected across it, the total of the potential differences across the individual loads must equal the potential difference across the battery.

$$V = V_1 + V_2 + V_3 + ... + V_N$$

The equivalent resistance, R_{eq}, of the circuit is the calculated total resistance of the resistors in the circuit. For resistors connected in series:

$$R_{eq} = R_1 + R_2 + R_3 + ... + R_N$$

Example - Model Problem Page 718 (MHR)

MODEL PROBLEM

Resistances in Series

Four loads (3.0 Ω, 5.0 Ω, 7.0 Ω, and 9.0 Ω) are connected in series to a 12 V battery. Find

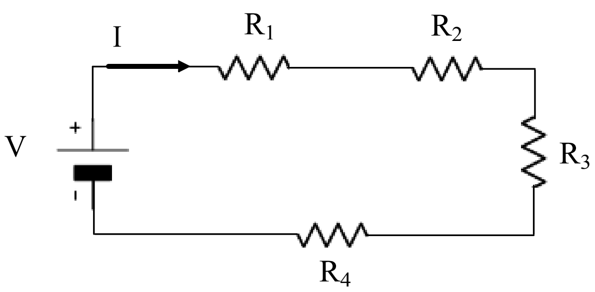
(a) the equivalent resistance of the circuit

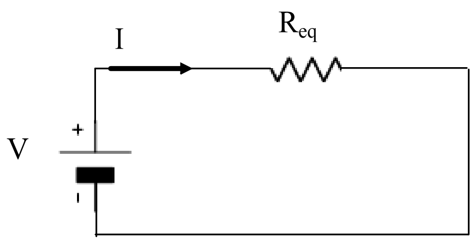
(b) the total current in the circuit

(c) the potential difference across the 7.0 Ω load

718 MHR • Unit 6 Electric, Gravitational, and Magnetic Fields

Textbook: Page 719, #27-31





	V	I	R
R_1			3.0 Ω
R_2			5.0 Ω
R_3			7.0 Ω
R_4			9.0 Ω
Total	12 V		

Parallel Circuits (Page 720)

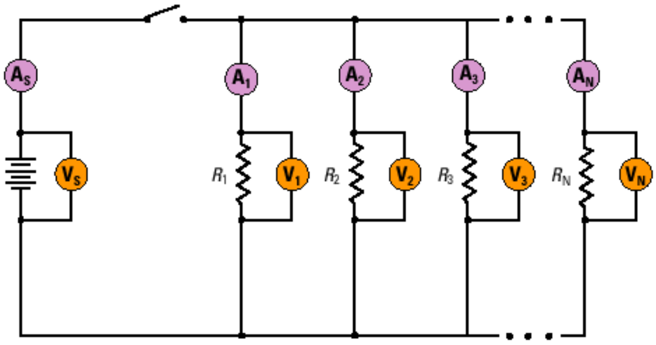


Figure 15.21 The *N* loads in this circuit are all connected in parallel with each other. The dots indicate where any number of additional loads could be connected in parallel with those present.

Chapter 15 Electric Energy and Circuits • MHR **721**

A parallel circuit consists of loads connected in parallel.

The current that leaves the battery has more than one path to follow. When the current leaving the battery, I_S, comes to a point in the circuit where the path splits into two or more paths, the current must split so that a portion of it follows each path. After passing through the loads, the currents combine before returning to the battery. The sum of the currents in parallel paths must equal the current entering and leaving the battery.

$$I = I_1 + I_2 + I_3 + ... + I_N$$

The potential difference across each of the individual loads in a parallel circuit must be the same as the total potential difference across the battery, V_S.

$$V = V_1 = V_2 = V_3 = V_N$$

For resistors connected in parallel, the equivalent resistance, R_{eq}, is given by:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_N} + ...$$

R_{eq} < all the individual resistances

<u>Example - Model Problem Page 722 (MHR)</u>

MODEL PROBLEM

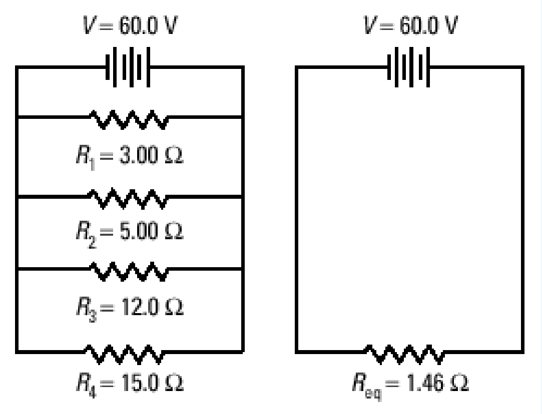
Resistors in Parallel

A 60 V battery is connected to four loads of 3.0 Ω, 5.0 Ω, 12.0 Ω, and 15.0 Ω in parallel.

(a) Find the equivalent resistance of the four combined loads.

(b) Find the total current leaving the battery.

(c) Find the current through the 12.0 Ω load.



	V	I	R
R_1			
R_2			
R_3			
R_4			
Total			

Textbook: Page 724, #32-35

Example - Model Problem Page 722 (MHR)

MODEL PROBLEM

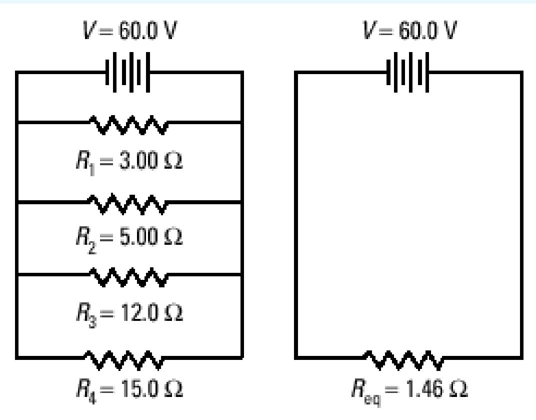
Resistors in Parallel

A 60 V battery is connected to four loads of 3.0 Ω, 5.0 Ω, 12.0 Ω, and 15.0 Ω in parallel.

(a) Find the equivalent resistance of the four combined loads.

(b) Find the total current leaving the battery.

(c) Find the current through the 12.0 Ω load.



Textbook: Page 724, #32-35

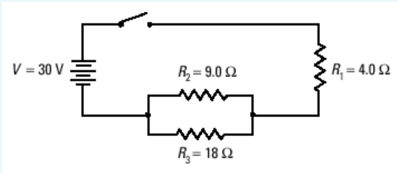
<u>Combination or Complex Circuits (Page 725)</u>

Many practical circuits consist of loads in a combination of parallel and series connections. To determine the characteristics of the circuit, you must analyze the circuit and recognize the way that different loads are connected in relation to each other.

MODEL PROBLEM

Resistors in Parallel

Find the equivalent resistance of the entire circuit shown in the diagram, as well as the current through, and the potential difference across, each load.



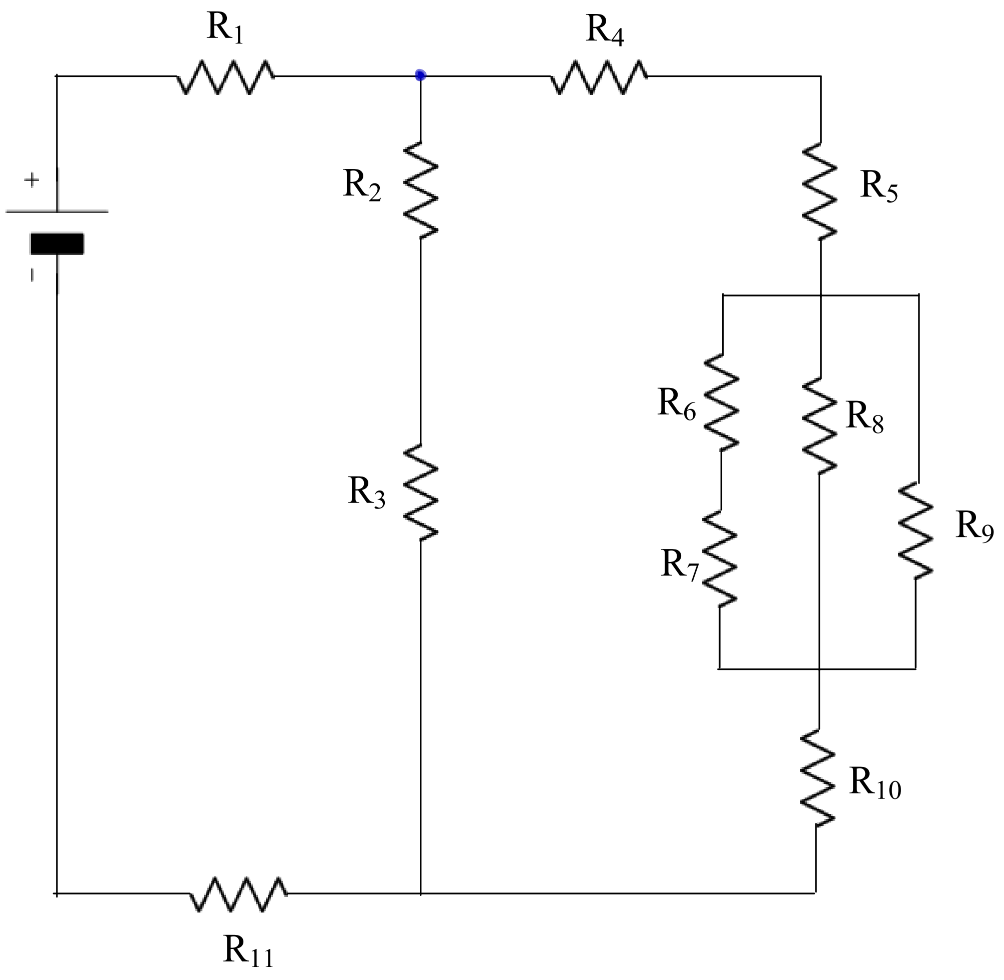
Chapter 15 Electric Energy and Circuits • MHR **725**

Textbook: Page 728, #36-37
Textbook: Page 749, #33-34

	V	I	R
R_1			4.0 Ω
R_2			9.0 Ω
R_3			18 Ω
Total	30 V		

Physics 122
Circuit #1

If V = 12.0 V, and R_1 = 1.00 Ω, R_2 = 2.00 Ω, R_3 = 3.00 Ω, etc., find R, I, the current through each resistor and the potential difference across each resistor.



Answers - Circuits #1 and #2

Circuit #1

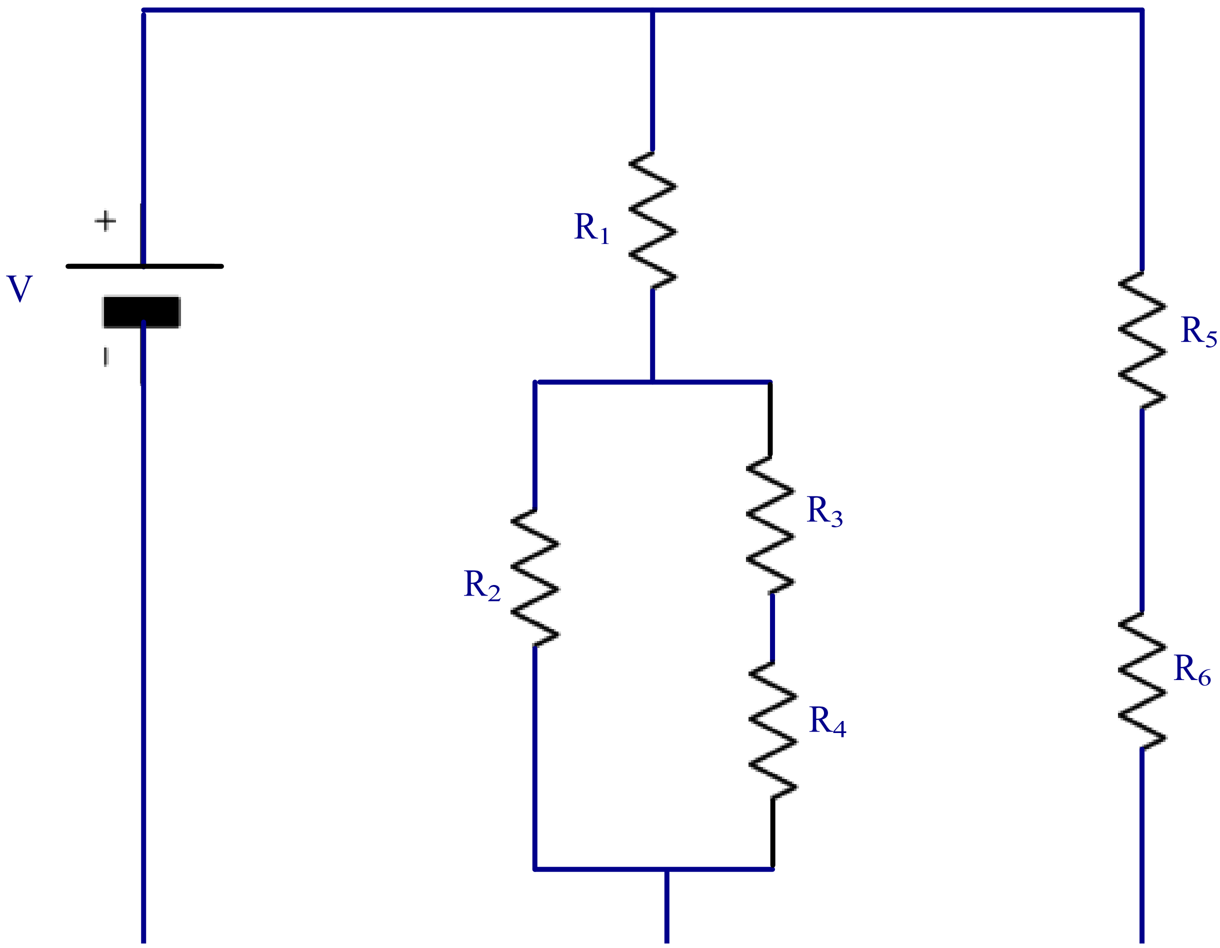
	V (V)	I (A)	R (Ω)
R_1	0.745	0.745	1.0
R_2	1.22	0.612	2.0
R_3	1.84	0.612	3.0
R_4	0.552	0.138	4.0
R_5	0.69	0.138	5.0
R_6	0.207	0.0345	6.0
R_7	0.242	0.0345	7.0
R_8	0.438	0.0548	8.0
R_9	0.438	0.0487	9.0
R_{10}	1.38	0.138	10.0
R_{11}	8.20	0.745	11.0
Total	12.0	0.745	16.1

Circuit #2

	V (V)	I (A)	R (Ω)
R_1	26	26	1.0
R_2	8.0	4.0	2.0
R_3	4.5	1.5	3.0
R_4	6.0	1.5	4.0
R_5	7.5	1.5	5.0
R_6	15	2.5	6.0
R_7	3.0	0.43	7.0
R_x	3.0	2.07	1.4
R_8	240	30	8.0
Total	266	30	8.9

Physics 122/121
Complex Circuit

Use the circuit to complete a VIR chart if V = 30.0 V and R_1 = 1.00 Ω, R_2 = 2.00 Ω, R_3 = 3.00 Ω, etc. Write your answers, **to three significant digits**.



Attachments

Ohm Pictures.jpg