Physics 17 Part L

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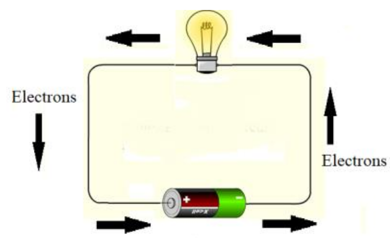
Electric Circuits

Batteries store chemical energy. When the battery is used to operate an electrical device, such as a lightbulb, a smoke alarm, or an automobile starter motor, the chemical energy is converted to electrical energy, which in turn is used to operate the device.		

Electric Current



In 10 seconds, 2×10^{19} electrons leave the negative terminal of the battery above, travel around the circuit and arrive at the positive terminal, and the cycle is repeated. The absolute value of this charge is

$Q = (2 \times 10^{19})\ |-1.6 \times 10^{-19}\ C|$

$= 3.2\ C$

The "current" from a battery is the absolute value of the number of coulombs of charge exiting the negative terminal *each second.*

Current = 3.2 C / 10 s

= 0.32 C/s

Let 1.0 "ampere" (A) = 1.0 C/s

I = 0.32 A

The "ampere" is the standard unit for current; this word is sometimes abbreviated as "amps."

Battery Voltage

Batteries are rated according to a property called "voltage," symbolized as "V." The voltage of a battery is the energy given to each coulomb of charge that leaves the battery:

The units of battery voltage are "volts."

1.0 volt = 1.0 joule/coulomb

<u>Example:</u>

How much chemical energy is expended by a 12-volt battery as it outputs 25 coulombs of charge?

12 volts = 12 joules/coulomb

(12 joules/coulomb) (25 coulombs) = 300 J

Output Power of a Battery

$$\text{Power} = \frac{\text{Joules}}{\text{Second}}$$

$$= \frac{\text{Coulomb}}{\text{Second}} \times \frac{\text{Joules}}{\text{Coulomb}}$$

$$= \text{Amperes} \times \text{Voltage}$$

$$P = IV$$

This equation for battery power output may be used for any battery in *any* circuit. A second battery power output equation will be provided in the next few pages; it will be one that is only valid for simple circuits—circuits with only one battery and one resistor.

Example:

The current out of a 10-volt battery is 6.0 amperes. What is its power output?

$$P = IV$$
$$= (6.0)\ (10)$$
$$= 60 \text{ watts}$$

Example:

The energy stored in a new 9 V battery is about 20,000 J. The current out of the battery is 0.015 amperes.

After how many hours will this battery be drained of all of its energy?

Solution:

$$P = IV$$
$$= (0.015)(9)$$
$$= 0.135 \text{ watts}$$
$$= 0.135 \text{ J/s}$$

Each second of operation, 0.135 joules of chemical energy is used up.

$$\text{Time} = (\text{Energy}) / (\text{Energy / Second})$$
$$= (20{,}000 \text{ J}) / (0.135 \text{ J/s})$$
$$= 148{,}148 \text{ s}$$
$$= 41 \text{ hours}$$

Resistance

Objects through which current pass have a property called "resistance," so-called because these "resistors" resist, or inhibit, current:

The greater the resistance, the smaller the current from the battery.

The symbol for a resistance is R.

The units of resistance are "ohms" (Ω).

Examples

Object	R (Ω)
100 W light bulb	144
60 W light bulb	240
dry human	100,000
wet human	1,000
1 m copper wire	0.02
AA battery	0.10

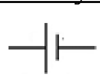
Typical resistor (one inch long) found in electronic circuits. Color bands indicate the resistance.

Circuit Symbols

We diagram our circuits using the following symbols:

Resistor Symbol:

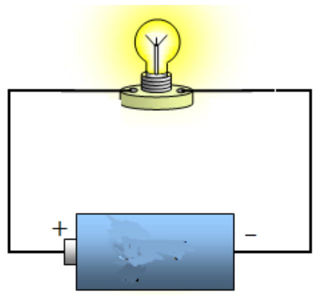
Battery Symbol:

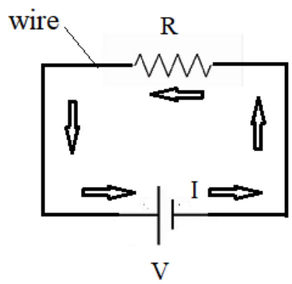


Connecting Wire

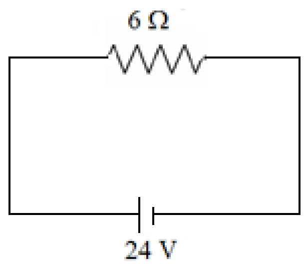
Simple Circuit

A “simple” circuit contains one battery and one resistor (a lightbulb, for example), and connecting wires. The arrow represents the flow of electrons (the current) leaving the negative terminal of the battery, and then circulating around the circuit, finding its way back to the battery, and the process is repeated.





Ohm’s Law
Ohm’s Law applies only to the simplest circuit--a circuit containing <u>one</u> battery and <u>one</u> resistor, like the one above. $I = V/R$

Example A:	Solution:
A 6 Ω resistor is connected to the terminals of a 24 V battery in the simple circuit below. What is the power output of the battery? 	We may use Ohm's Law because this is a simple circuit. Ohm's Law may be used only for simple circuit--circuits with only one battery and one resistor. I = V/R = 24/6 = 4 A P = IV = 4 (24) = 96 watts

Alternative Battery Power Output Equation

I = V/R (simple circuit)
P = IV

P = (V/R) V

$P = V^2/R$

This equation derived above assumes Ohm's Law is valid; that law is valid only for simple circuits, or circuits that can be made equivalent to a simple circuit. Therefore, this alternative power output equation may only be used in circuits in which there is only one battery and one resistor, i.e., simple circuits.

Example B:

Use the V^2/R equation to find the power output of the battery in the simple circuit shown in Example A.

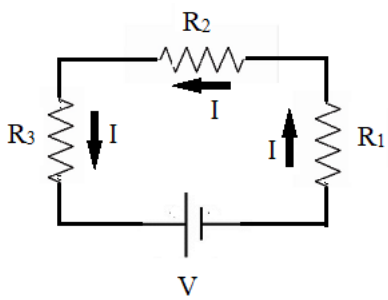
$P = 24^2 / 6$
$= 96$ watts

Resistors Connected in Series

(non-simple circuits)

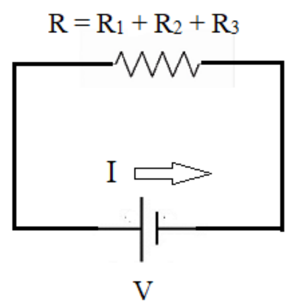
Two or more resistors are connected "in series" if all of the current that goes through one resistor has no other place to go except through the next one.

The three resistors below are in series. The current through R_1 has nowhere else to go except through R_2, and then through R_3.



Resistors connected in series have the same limiting effect on the current out of the battery as does a *single* resistor--called the "equivalent resistor"--whose resistance is the sum of resistances.

The series circuit below is equivalent to the one at the left, as far as the battery is concerned: The same current comes out of the battery in either case.

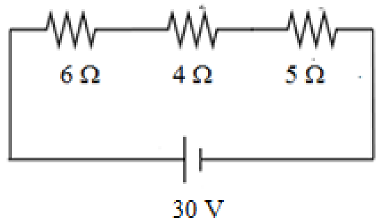


The value of the series resistance equation lies in its ability to simplify complex circuits with more than one resistor into a simple circuit which then can be analyzed using Ohm's Law.

The example below illustrates this type of simplification.

Example:

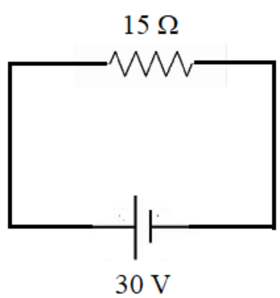
What is the power output of the battery in the circuit below?



The first step in the majority of circuit analysis problems is to find the "equivalent" simple circuit, and then apply the simple circuit Ohm's Law equation, I = V/R.

Solution:

The simple circuit below is equivalent to the one above, as far as the output current and battery output power is concerned:



I = 30/15
= 2 A
P = IV
= (2)(30)
= 60 watts

Power Consumed by a Resistor

Resistors (such as light bulbs and motors) are the consumers of the electrical energy that batteries produce. The power consumed by a resistor is

$$P = I^2R$$

<u>Example A</u>:

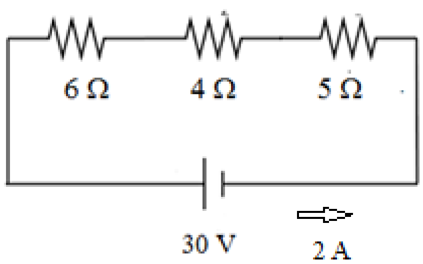
The power output of a battery is 100 W. One of the two resistors in the circuit consumes 65 W of power. What power is consumed by the other resistor?

Answer: 100 - 65 = 35 W

The power output of a battery equals the sum of the separate powers consumed by the resistors in the circuit.

<u>Example B</u>:

Determine the power output of the battery below, and confirm that the sum of the three powers consumed equals the battery output power.

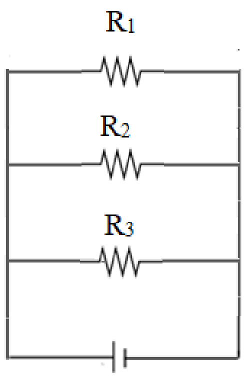


R (Ω)	I (A)	$P = I^2R$ (W)
6	2	24
4	2	16
5	2	20

24 + 16 + 20 = 60 W

The sum of the powers consumed equals the power produced.

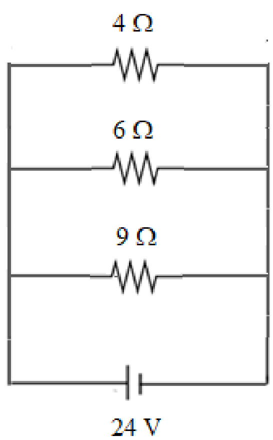
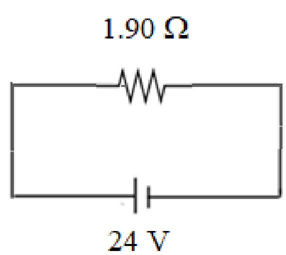
Resistors Connected in Parallel



Unlike series-connected resistors, the current through one resistor does not go through the other one. Instead, the current splits generally unequally among the various resistors, the resistors with less resistance get more current; the ones with more resistance get less.

Resistors connected in parallel have an equivalent resistor given by the "reciprocals equation":

$$1/R = 1/R_1 + 1/R_2 + 1/R_3$$

Example:	Solution:
What is the current from the battery?  	$1/R = 1/4 + 1/6 + 1/9$ $R = 1.90\ \Omega$ The simple circuit below is equivalent to the one at the left:  $I = 24/1.90$ $= 12.63$ A

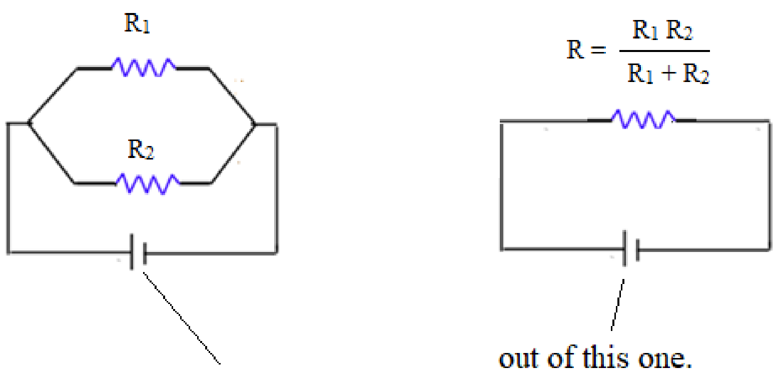
Alternative Parallel Resistors Equation

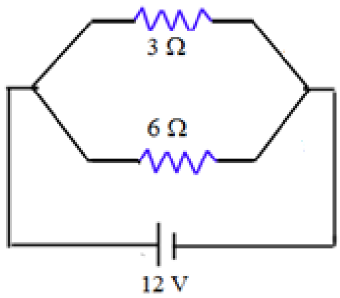
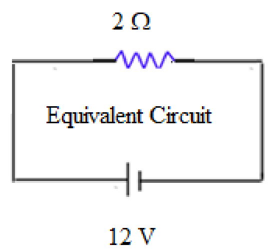
The parallel connection of *two* resistors occurs so often that it will be convenient to obtain the general expression for the equivalent resistance.

$$
\begin{aligned}
1/R &= 1/R_1 + 1/R_2 \\
&= R_2/(R_1R_2) + R_1/(R_1R_2) \\
&= (R_2 + R_1)/(R_1R)
\end{aligned}
$$

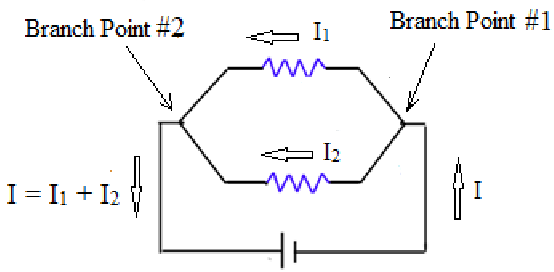
Reciprocate both sides:

$$R = \frac{R_1 R_2}{R_1 + R_2}$$



Example:	Solution:
What is the power output of the battery below?  	Equivalent Resistance: R = (3)(6)/(3+6) = 2 Ω  I = V/R = 12/2 = 6 A P = IV = (6) (12) = 72 W The power output of this battery is the same as the power output of the battery in the circuit at the left. Alternatively, the power output of the battery in the equivalent simple circuit above provides the same result: $P = V^2/R$ $= 12^2/2$ = 72 W

Current at Branch Points



A “branch point” in a circuit is where entering current splits into two branches, as shown at Branch Point #1, or where current from two branches combine, as shown in Branch Point #2.

The "Other Divided by the Sum Rule"

(Valid only for *two* resistors in parallel.)

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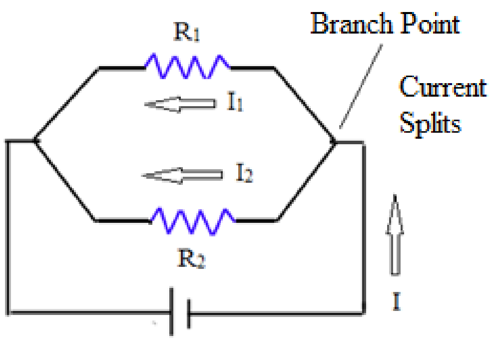

The current through one of the parallel-connected resistors equals *the other resistance, divided by the sum* of the resistances, times the current entering the branch point.

$I_1 = R_2/\,(R_1 + R_2)\ I$
$I_2 = R_1/\,(R_1 + R_2)\ I$
</td>
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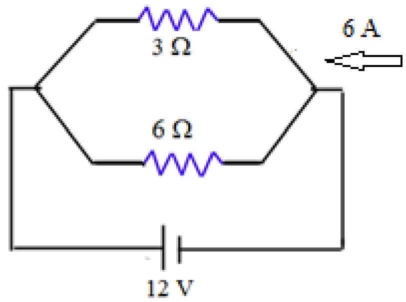
<u>Example</u>:

Calculate the currents in the resistors below:



Upper Branch: I = (6/9)(6)
= 4 A

Lower Branch: I = (3/9)(6)
= 2 A
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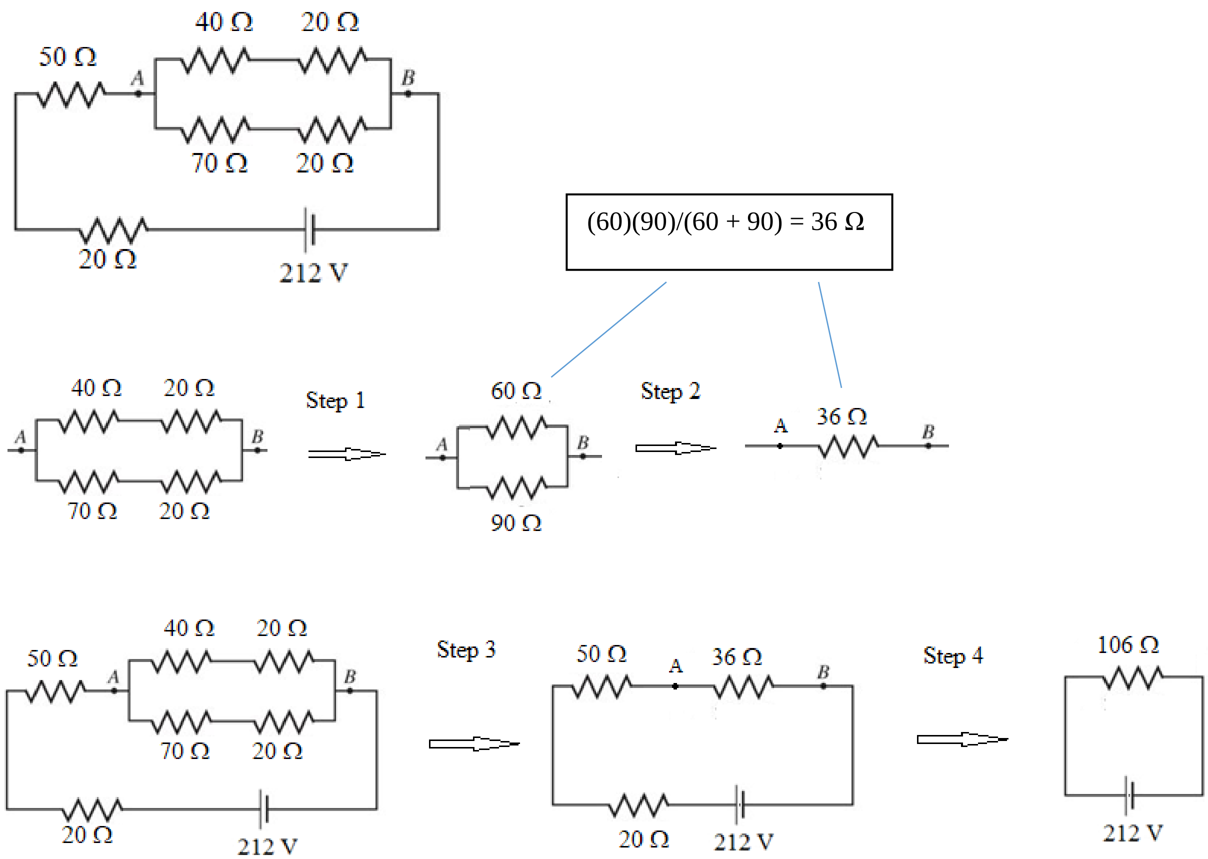
Hybrid Circuits: Resistors in Series and in Parallel

<u>Example</u>:

What is the power output of the battery below?

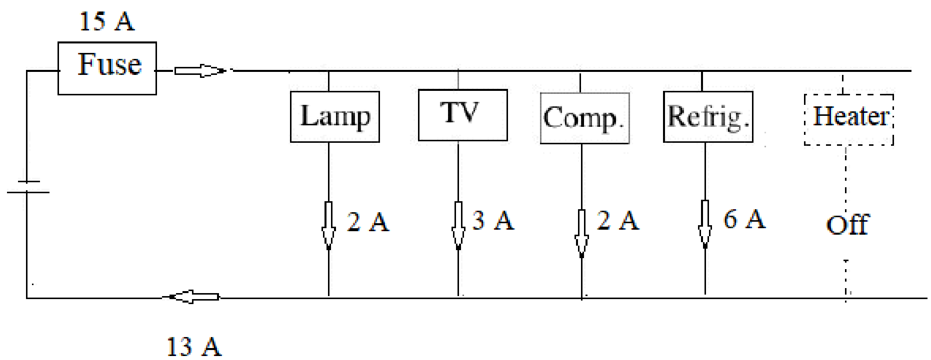


I = 212/106
= 2 A
P = (2)(212)
= 424 watts

What is the sum of the powers consumed by the six resistors?

Answer: 424 watts

House Wiring



The circuit above represents the wiring in one portion of a house. Four appliances are in operation, using a total of 13 A. Another appliance--a space heater--is off. A fuse will prevent current greater than 15 A leaving the power source.

When the heater is turned on, it tries to draw 3 A, which would make the current output to be 16 A; the fuse "blows," and *all* appliances lose power.

The power supply is indicated above as a "direct current" (DC) battery symbol; actual home power supplies are "AC" (alternating current) power supplies. Fuses are not commonly used anymore; instead, devices called "circuit breaker," shown below, are used.

Circuit Breaker