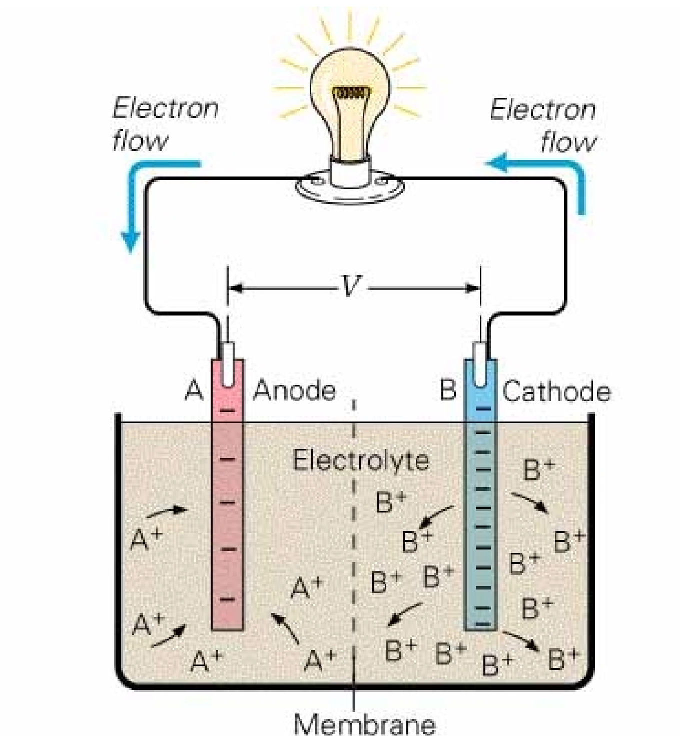
Chapter 21 Electric Current and Direct-Current Circuits

Chapter 21

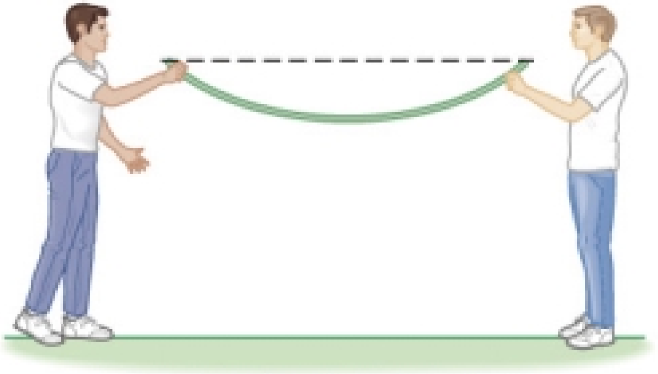
What is electricity?
What is electric current?
Why does it flow when we flick a switch?
Why do bulbs glow when current is supplied.
Why do the wires not glow?

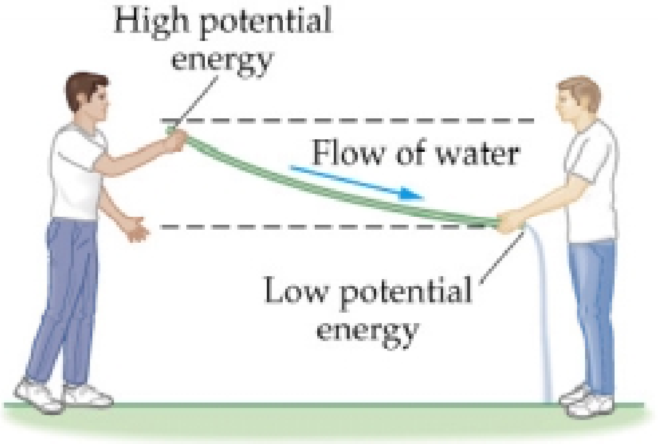


A battery

Figure 21–1 Water flow as analogy for electric current

Water can flow quite freely through a garden hose, but if both ends are at the same level (a) there is no flow. If the ends are held at different levels (b), the water flows from the region where the gravitational potential energy is high to the region where it is low.


(a)



(b)

Figure 21–2 The flashlight: A simple electrical circuit

(a) A simple flashlight, consisting of a battery, a switch, and a light bulb. (b) When the switch is in the open position the circuit is “broken,” and no charge can flow. When the switch is closed electrons flow through the circuit, and the light glows.

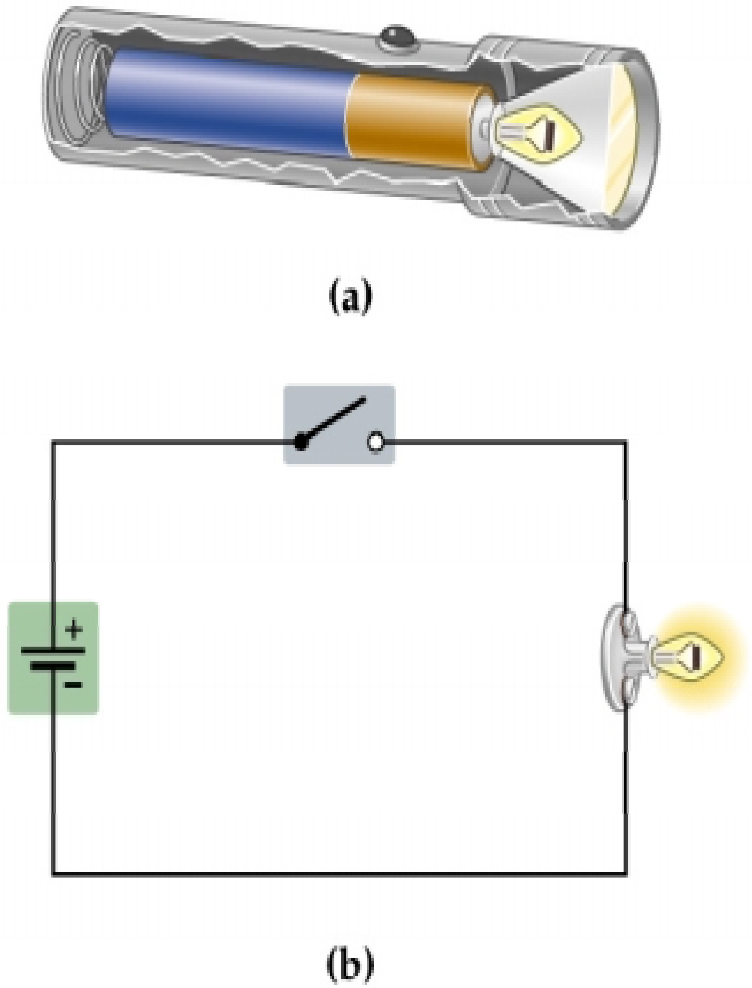
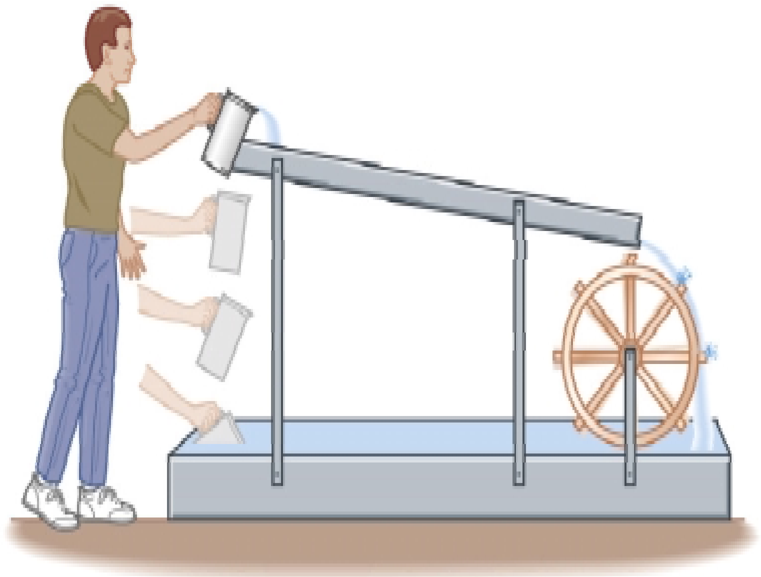
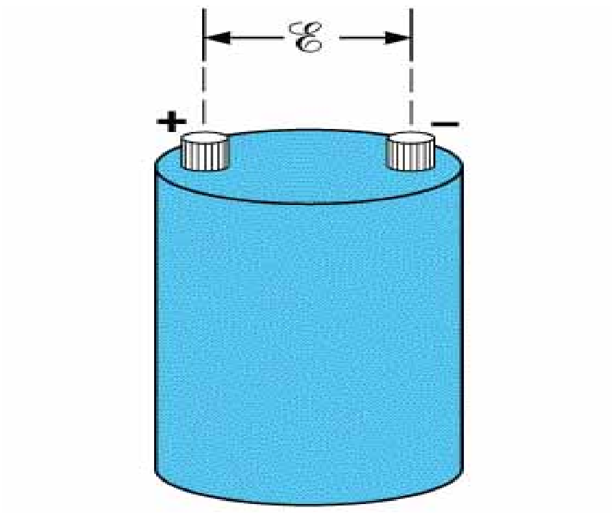


Figure 21–3 A mechanical analog to the flashlight circuit

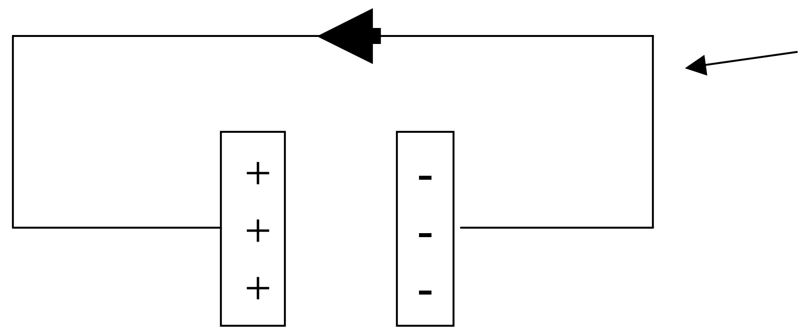
The person lifting the water corresponds to the battery in Figure 21–2, and the paddle wheel corresponds to the light bulb.



Electromotive force (emf)



(a) Electromotive force (emf)



$\Delta qV = qEd$

Think of a battery as a pair of plates that are continually charged up.

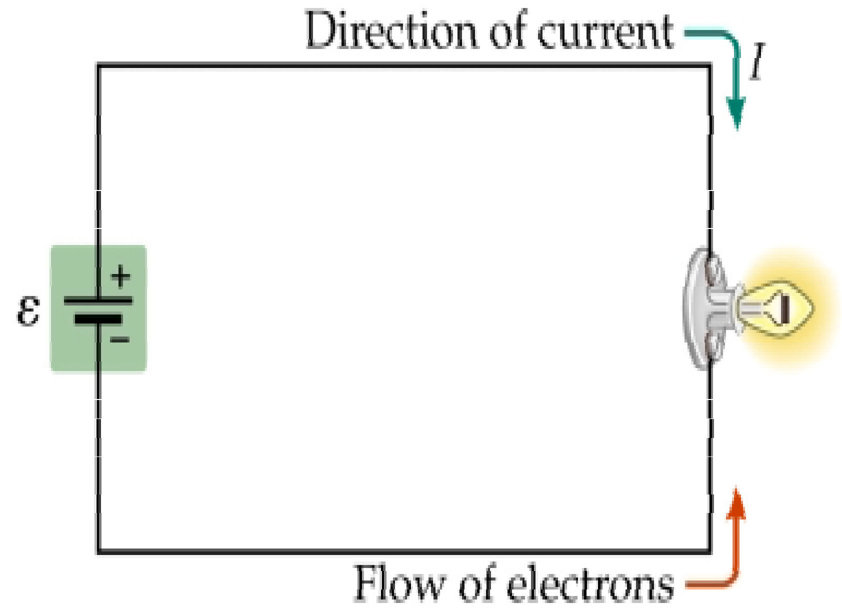
For a charge to go from one plate to the other it will give up energy = ΔqV.

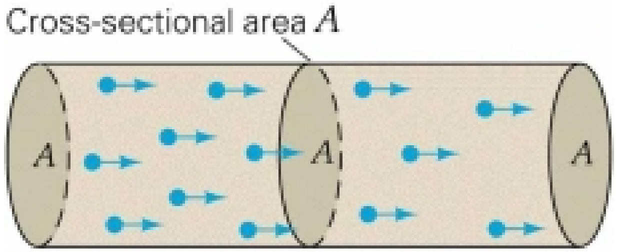
Figure 21–4 Direction of current and electron flow

- In the flashlight circuit, electrons flow from the negative terminal of the battery to the positive terminal. The direction of the current, I, is just the opposite: from the positive terminal to the negative terminal.

We will generally talk about

CONVENTIONAL current





Current: The number of charges that pass a given point each second. Just like water flow in a pipe: How much water passes a point each second is defined as current also.

$$Electric\ Current \quad I = \frac{\Delta q}{\Delta t}$$

$$Units: \frac{C}{s} \quad \text{or Amperes (A)}$$

1 A is quite a large current. Household currents are usually as large as several amps.

Also use microamps (10^{-6} A)
milliamps (10^{-3} A)

A CD-ROM uses a current of 0.5 A which is supplied by a 1.5 V battery. How much charge passes through the device in 2 minutes? How many electrons does this represent? How much energy is supplied by the battery?

$$I = \frac{\Delta q}{\Delta t} \quad \text{So} \quad \Delta q = I\Delta t = (0.5\ A)(120\ s) = 60\ C$$

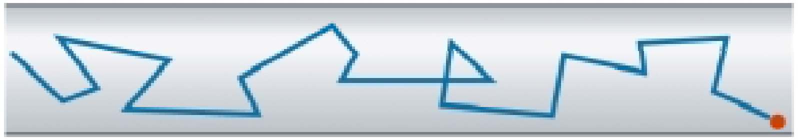
$$n = \frac{q}{e} = \frac{60\ C}{1.6\text{x}10^{-19}\ C} = 3.8\text{x}10^{20}\ electrons$$

$$W = V\Delta q = \varepsilon\Delta q = (1.5\ V)(60\ C) = 90\ J$$

That is:3.8x100 million billion electrons A physical wire contains many more electrons than this, however.

Figure 21–5 Path of an electron in a wire

- Typical path of an electron as it bounces off atoms in a metal wire. Because of the tortuous path the electron follows, its average velocity is rather small.



Summary

Electric current in a wire is analagous to water flow in a pipe.

Pressure produced by a water pump is like the voltage produced by a **battery**.

The higher the water pump **pressure** the higher the water **current.**

The higher the **voltage** the higher the electric **current**.

Voltage is proportional to **current**.

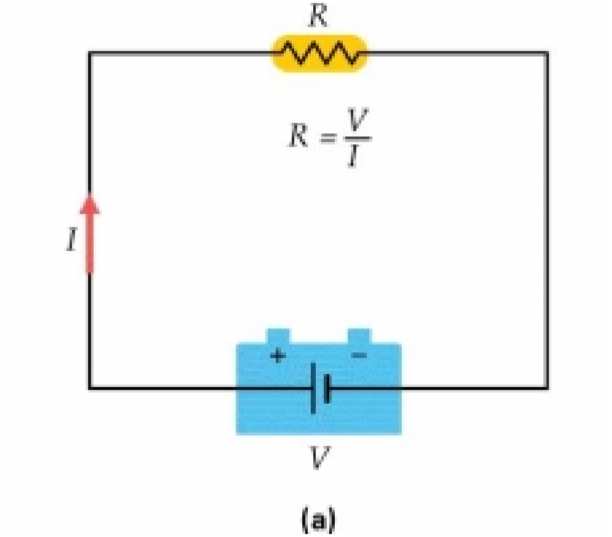
In water pipes the current depends on the length and diameter of the pipes.

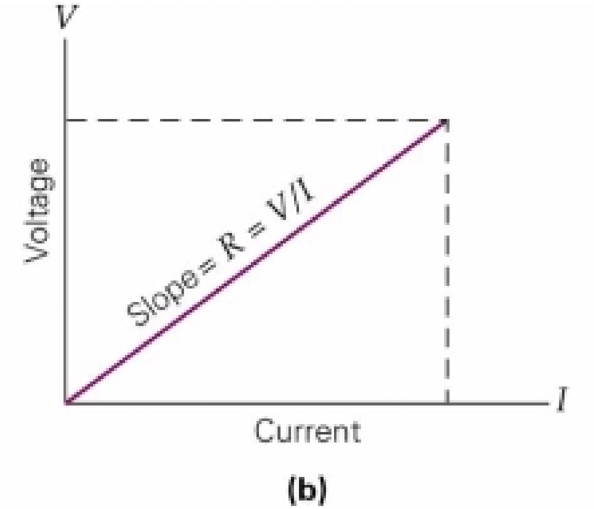
Narrow pipes (small area, large resistance) result in low currents.

(consider blood current in the aorta and a capillary)

Similarly narrow wires have high resistance to electron flow and result in low currents.

Ohm's Law





$$R = \frac{V}{I} \quad \text{or} \quad V = IR \quad \text{or} \quad I = \frac{V}{R}$$

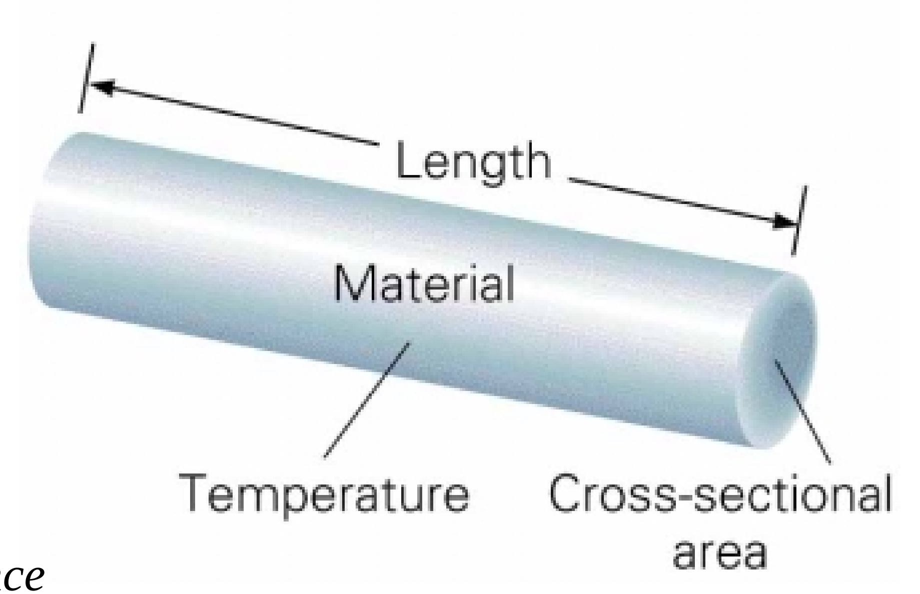
Constant for a given wire (see below).
Resistance measured in OHMS (Ω=V/A)

Obviously there is resistance to electron flow in a wire

Resistance of a wire depends on:

1 *The material* (*ρ*, *resistivity-see table 21.1*)
2 *The Area* (*A*)
3 *The length* (*L*)
4 *The temperature* (*T*)

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



Just like water in a pipe.
Narrow , long pipes have high resistance

Resistance of a wire is usually much less than the resistance of a light bulb.

***Resistivity depends on temperature*.**

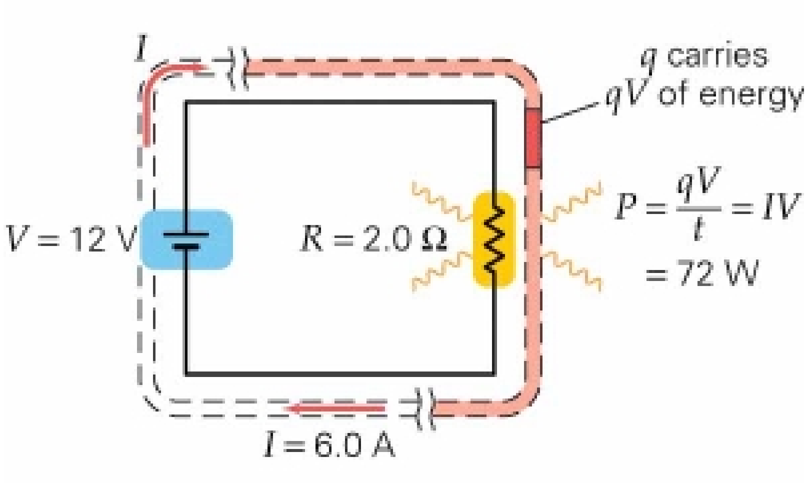
This allows us to construct electrical thermometers.

Power delivered by batteries and heating of resistors

A battery of V volts gives V joules of energy to 1 C of charge
A battery of 6 volts gives 6 joules of energy to 1 C of charge
A battery of 6 volts gives 12 joules of energy to 2 C of charge

Work done by a battery on a charge, Δq is W = ΔqV
The rate of energy exchange is called electric power, P.

$$P = \frac{W}{\Delta t} = \frac{\Delta q V}{\Delta t} = \left(\frac{\Delta q}{\Delta t}\right)V = IV$$



$$\textit{Since} \quad P = IV \quad \text{and} \quad R = \frac{V}{I}$$

$$P = IV = \frac{V^2}{R} = I^2 R$$

Joule heating of a resistor

Energy Consumption in the home:

We pay for the ***energy*** *(not power) we use per month.*
This is typically a lot of Joules so we pay for electricity
in large units that are called kiloWatt-Hours (kWh)

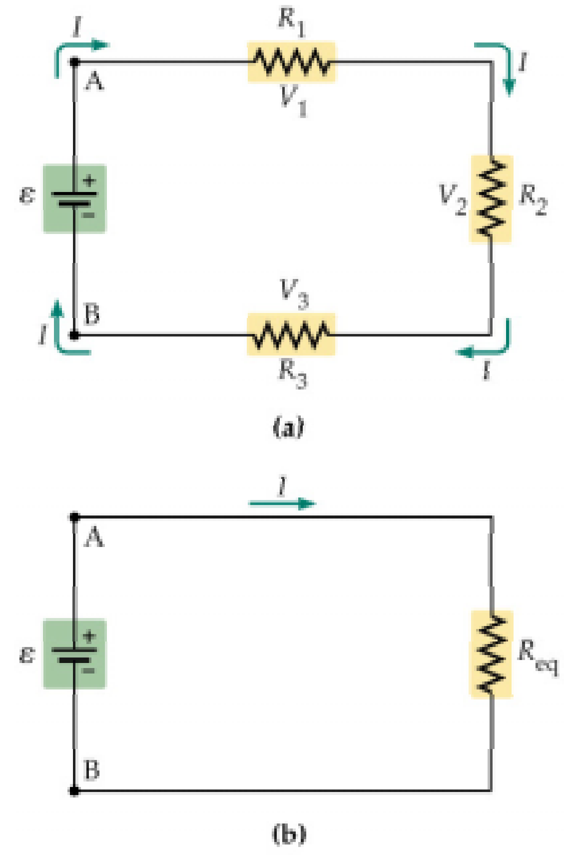
$$Power \quad \times \quad time \quad = \quad Energy$$

A kiloWatt-Hour (kWh) is a unit of energy.
It is the energy that ten 100 W light bulbs would consume in 1 hour.
1 kWh typically costs about 10 cents.

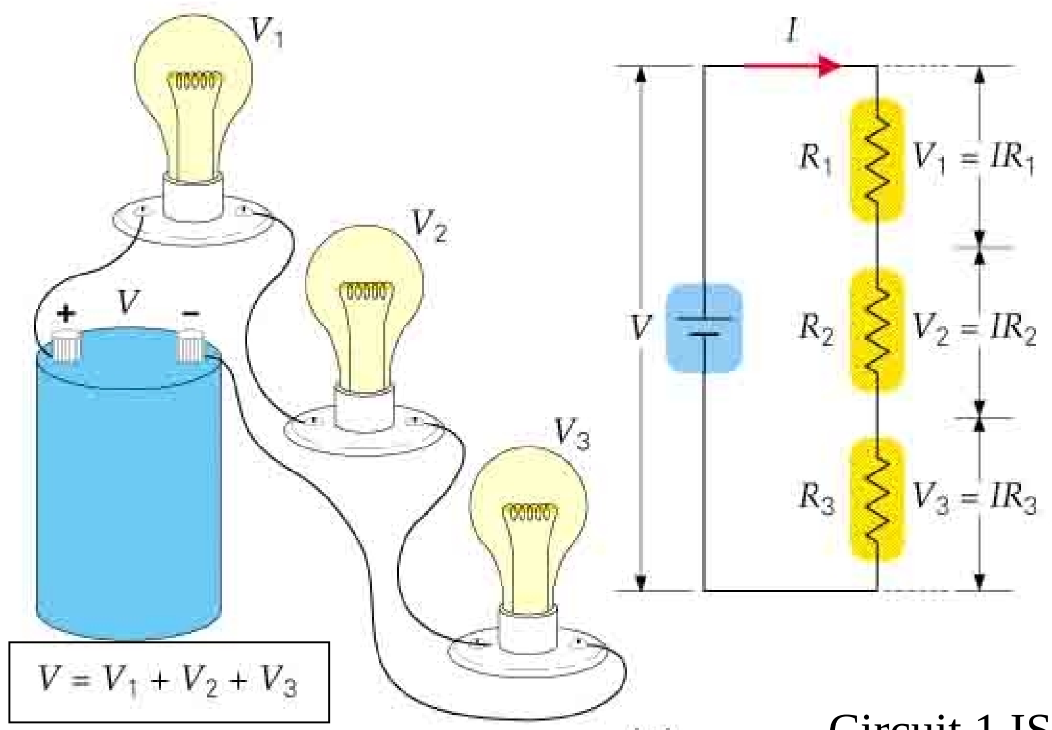
How much would it cost to run a 100 W bulb for 30 days if energy costs $0.10 per kWh?
($7.20)

Figure 21–6 Resistors in series

- (a) Three resistors, R_1, R_2, and R_3, connected in series. Note that the same current I flows through each resistor. (b) The equivalent resistance, $R_{eq} = R_1 + R_2 + R_3$ has the same current flowing through it as the current I in the original circuit.

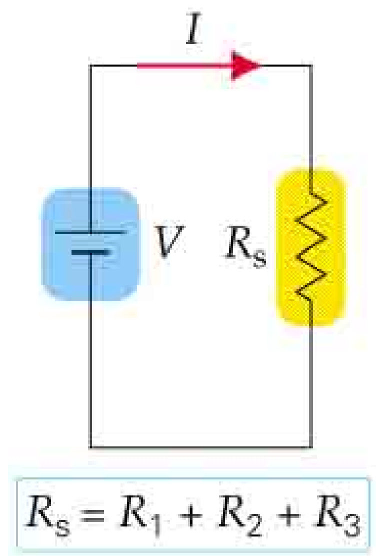


1



(a)

2

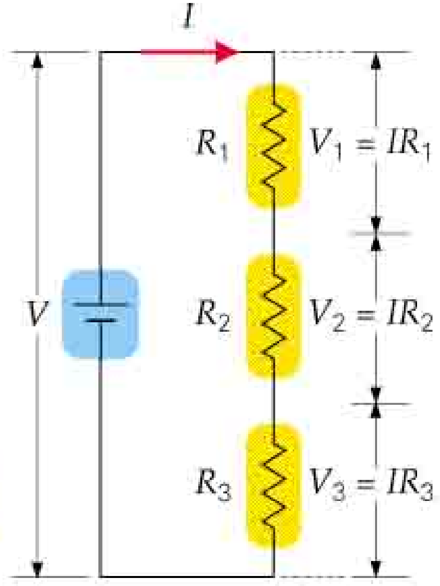


Circuit 1 IS EQUIVALENT to circuit 2.

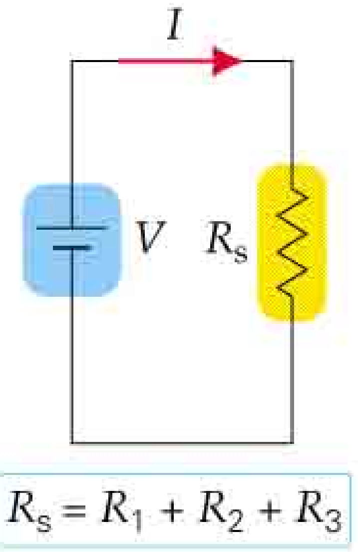
Resistors in series sum.

Note: if one resistor "blows up" then no current will flow to any of the resistor elements

In a series circuit the current is the same at each point in the circuit.



Circuits are EQUIVALENT



$V_1 = IR_1$

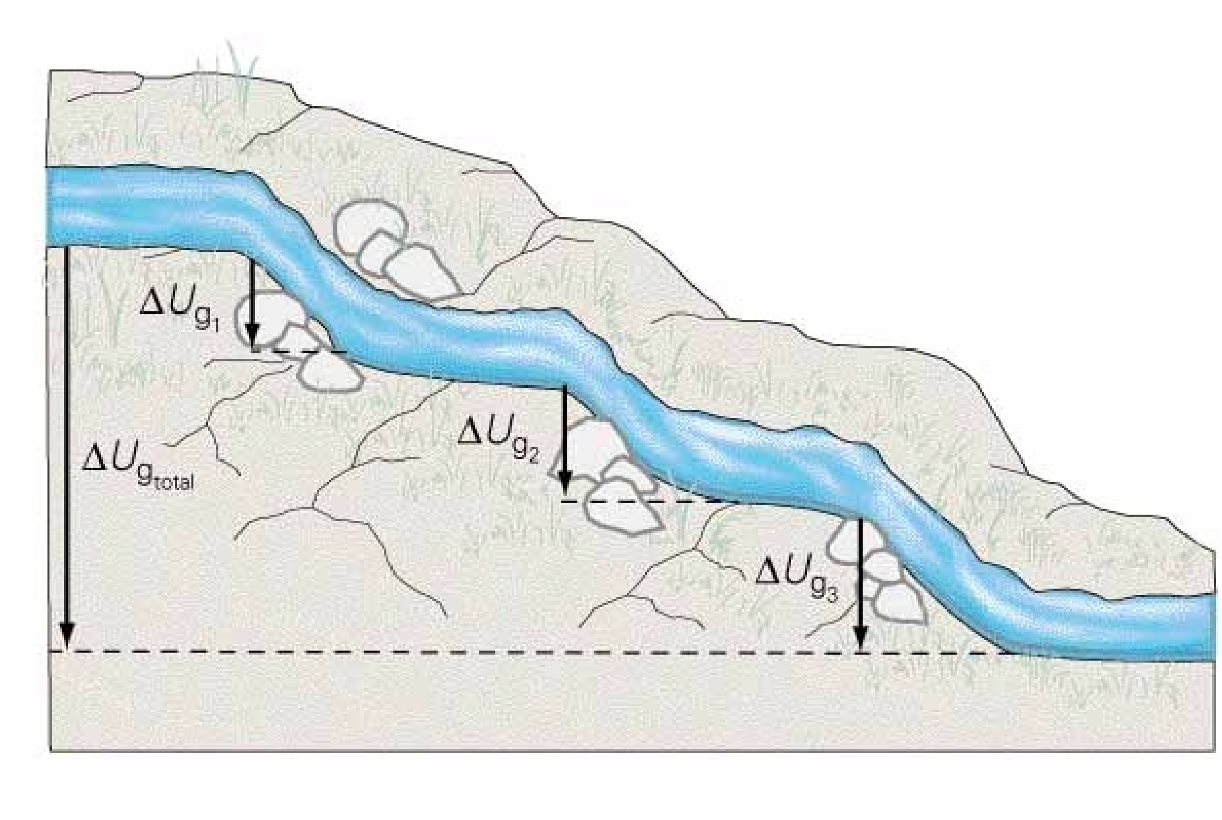
$V_2 = IR_2$

$V_3 = IR_3$

$$V = V_1 + V_2 + V_3$$
$$= I(R_1 + R_2 + R_3)$$

$$V = IR_s$$

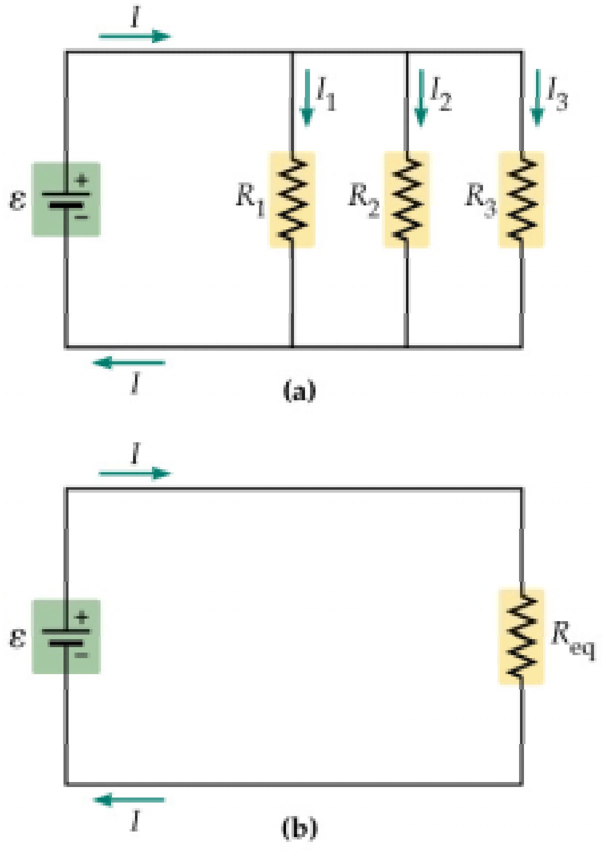
$$\boxed{R_s = (R_1 + R_2 + R_3)}$$

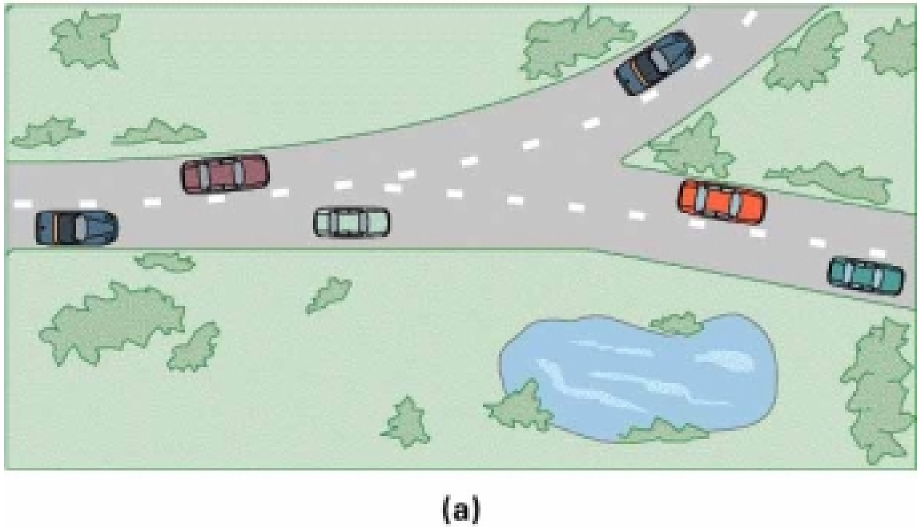


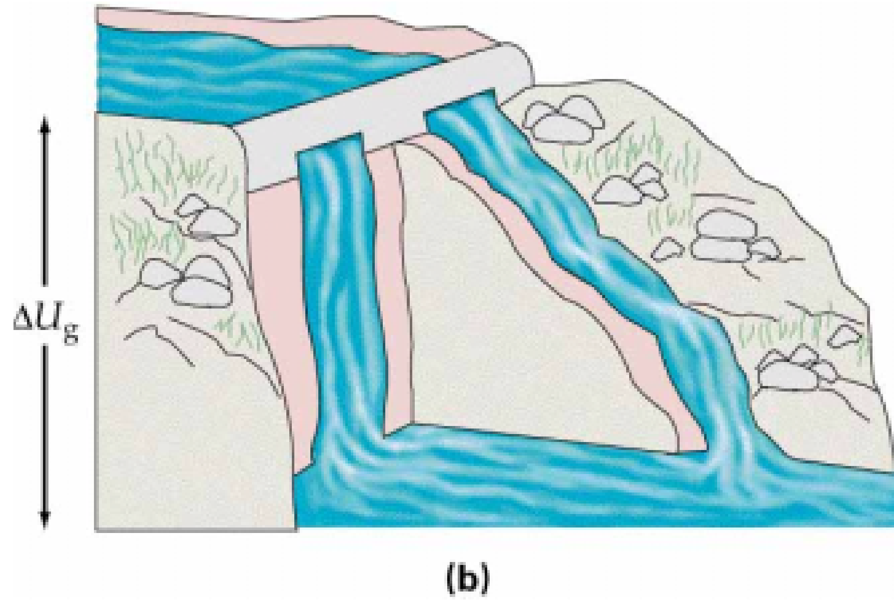
Gravitational equivalent of three resistors in series

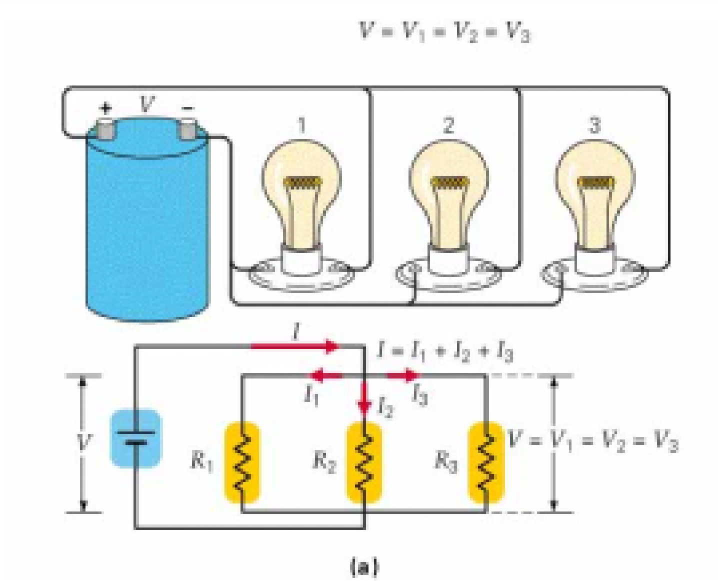
Figure 21–8 Resistors in parallel

- (a) Three resistors, R_1, R_2, and R_3, connected in parallel. Note that each resistor is connected across the same potential difference, E. (b) The equivalent resistance, $1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$ has the same current flowing through it as the total current I in the original circuit.





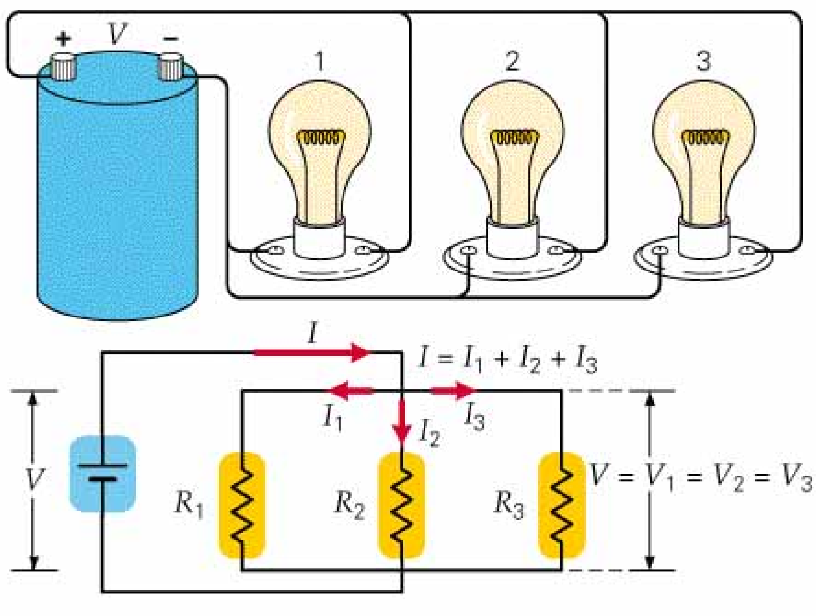




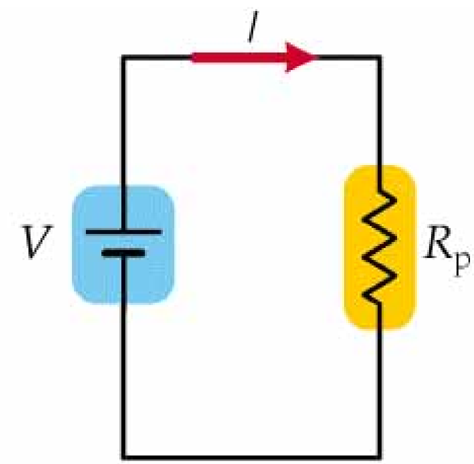
The same amount of energy is lost by the charges independent of which path is taken.

Current entering a junction
Equals current leaving a junction

Circuits are EQUIVALENT



(a)



$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

(b)

$V=V_1=V_2=V_3$

$=I_1R_1=I_2R_2=I_3R_3$

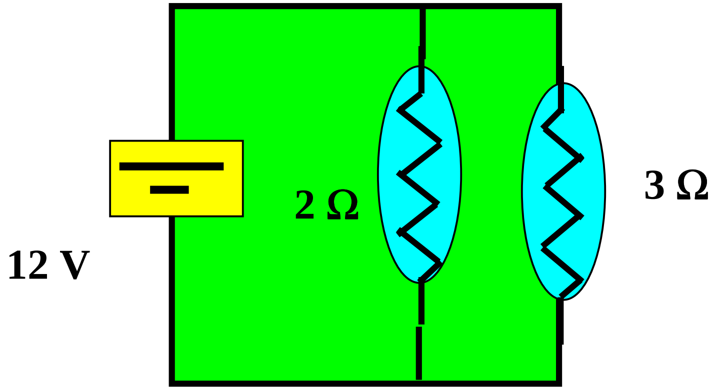
$I=I_1+I_2+I_3$

$I=V/R_1+V/R_2+V/R_3$

$I=V(1/R_1+1/R_2+1/R_3)$

$I=V/R_p$

Note: The equivalent parallel resistance, R_P, is ALWAYS less than any of the individual resistances.



The equivalent parallel resistance in the circuit is less than 2 Ω.

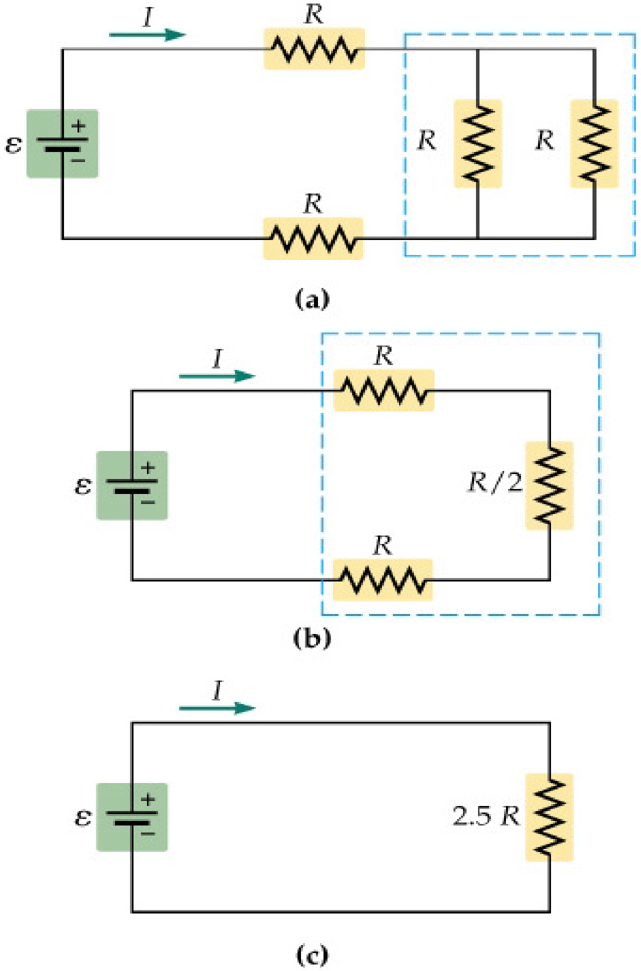
If a circuit contains only two resistances :

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{or} \quad R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{(3\Omega)(2\Omega)}{(3\Omega + 2\Omega)} = \frac{6\Omega}{5\Omega} = 1.2\Omega < 2\Omega$$

The smallest resistance is the most important one.

Figure 21–10 Analyzing a complex circuit of resistors

- (a) The two vertical resistors are in parallel with one another, hence they can be replaced with their equivalent resistance, R/2. (b) Now, the circuit consists of three resistors in series. The equivalent resistance of these three resistors is 2.5 R. (c) The original circuit reduced to a single equivalent resistance.



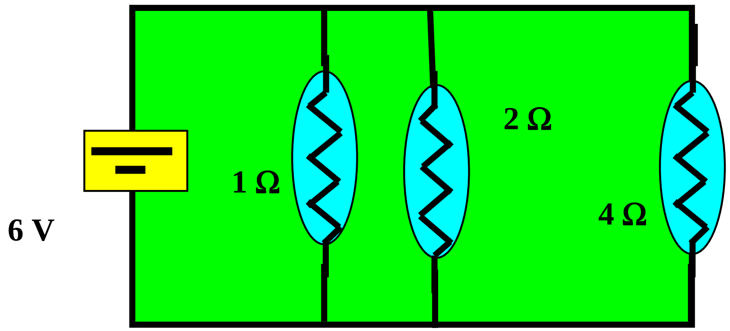
Three resistors of 1, 2 and 4 Ω are connected in parallel in a circuit with a 6 V battery.

A. What is the equivalent resistance?

B. What is the voltage across each resistor?

C. What is the power dissipated in the 4 Ω, the 1 Ω and the 2 Ω resistor?

D. What is the total power dissipated. Compare this to the power dissipated in the equivalent circuit.

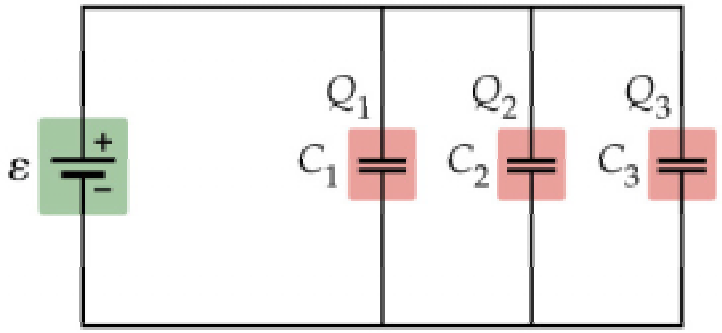


Two identical light bulbs are connected in series and then in parallel to a fixed voltage source. In which combination are the light bulbs brighter and by how much?

See conceptual checkpoint 21.3 on p691

Figure 21–16 Capacitors in parallel

- (a) Three capacitors, C_1, C_2, and C_3, connected in parallel. Note that each capacitor is connected across the same potential difference, E. (b) The equivalent capacitance, $C_{eq} = C_1 + C_2 + C_3$, has the same charge on its plates as the total charge on the three original capacitors.



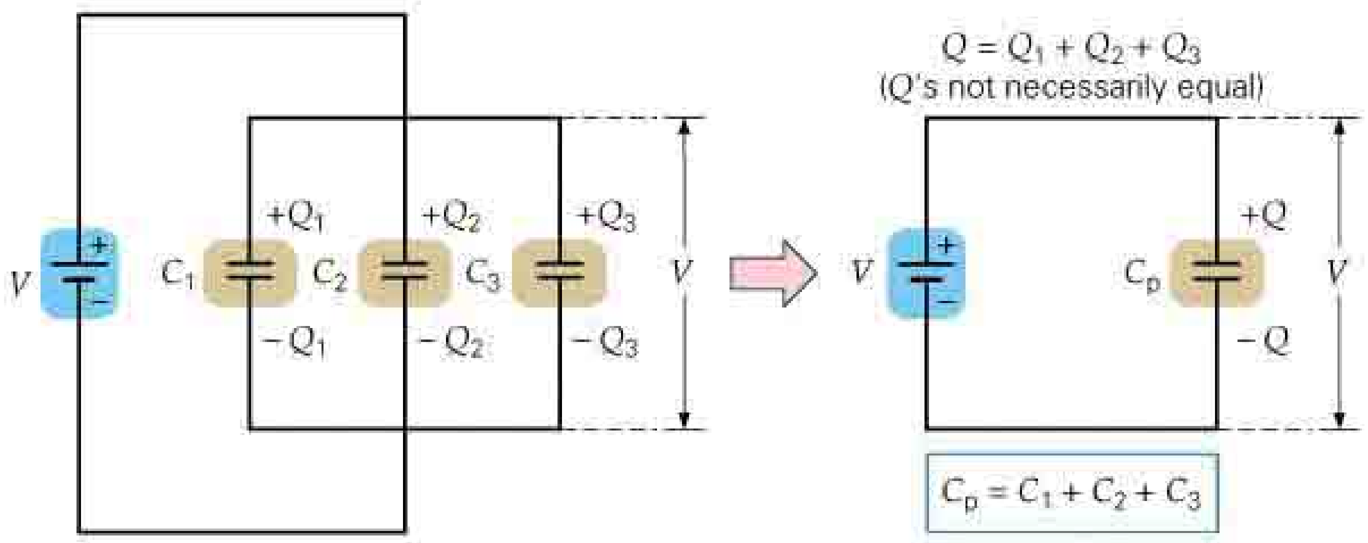
(a)

(b)

Capacitors in DC circuits

Capacitors in Parallel

Charge DOES NOT pass through a capacitor.
Current will only flow very briefly in the above circuit.
Each capacitor will have the same voltage.



(b) Capacitors in parallel

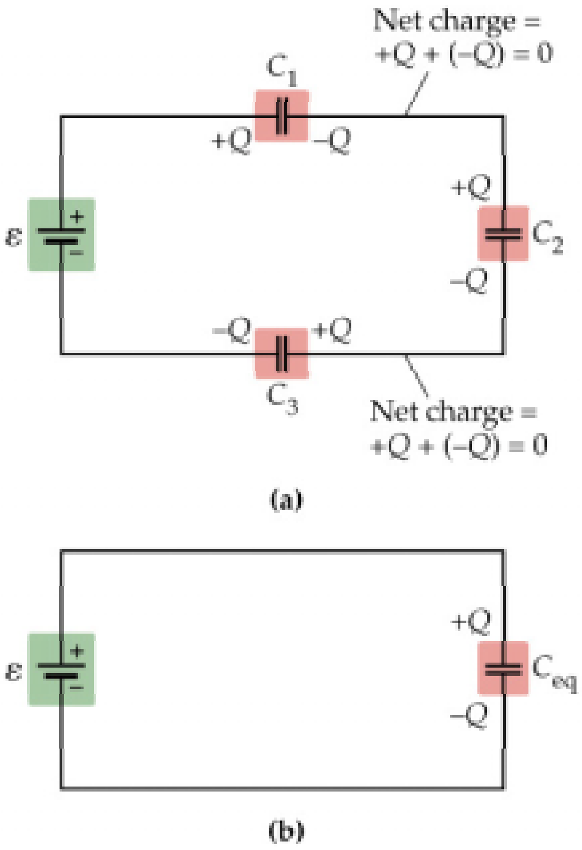
$$Q=Q_1+Q_2+Q_3$$
$$Q=\varepsilon C_1+\varepsilon C_2+\varepsilon C_3$$
$$Q=\varepsilon(C_1+C_2+C_3)$$

$$Q=\varepsilon C_p$$

$$\boxed{C_p=(C_1+C_2+C_3)}$$

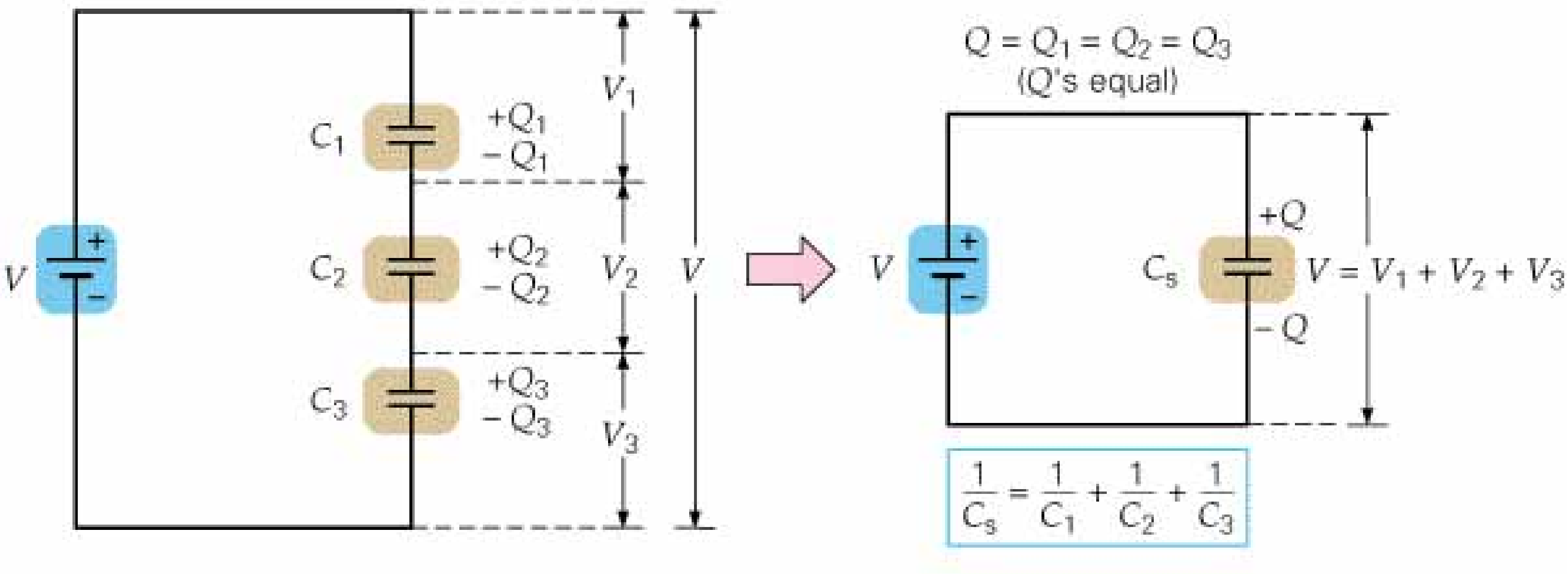
Figure 21–17 Capacitors in series

- (a) Three capacitors, C_1, C_2, and C_3, connected in series. Note that each capacitor has the same magnitude charge on its plates. (b) The equivalent capacitance, $1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3$, has the same charge as the original capacitors.



Capacitors in DC circuits
Capacitors in Series

Charge DOES NOT pass through a capacitor.
Current will only flow very briefly in the above circuit.
Each capacitor will have the same charge on it



(a) Capacitors in series

$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$

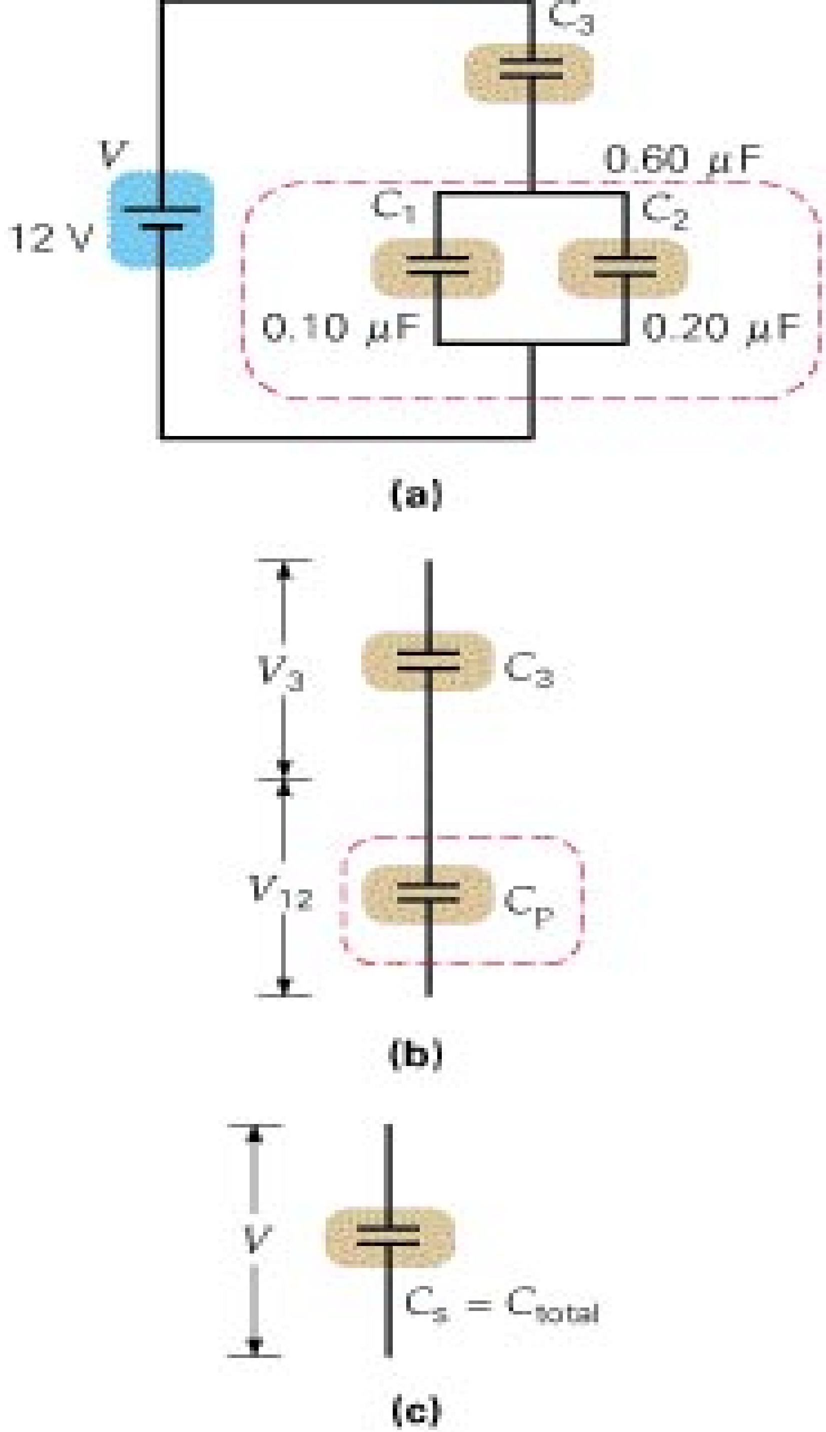
$\varepsilon = Q_1/C_1 + Q_2/C_2 + Q_3/C_3$

$\varepsilon = Q/C_s$

$Q = Q_1 = Q_2 = Q_3$

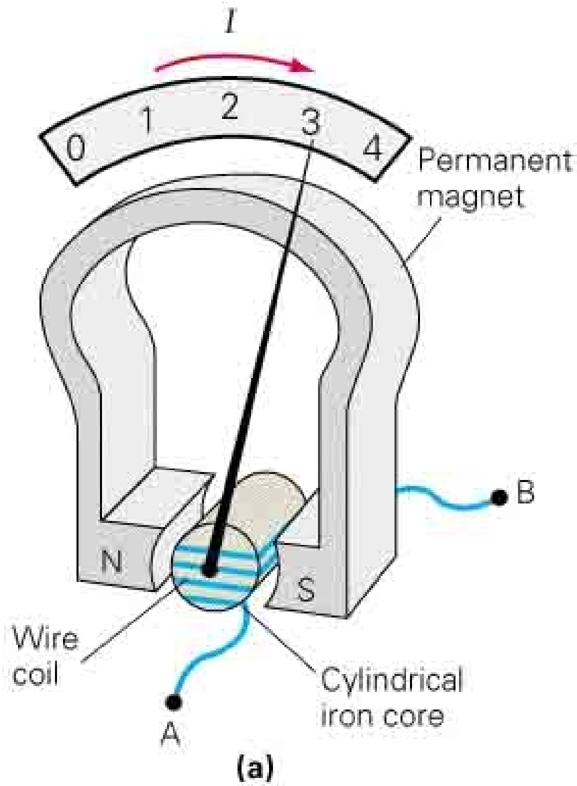
$\mathbf{1/C_s = 1/C_1 + 1/C_2 + 1/C_3}$

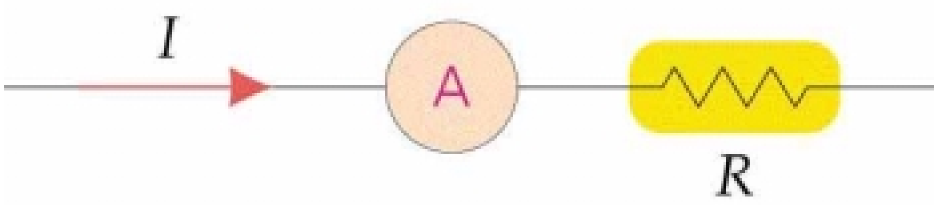
$\varepsilon = Q(1/C_1 + 1/C_2 + 1/C_3)$



Calculate C_{total}

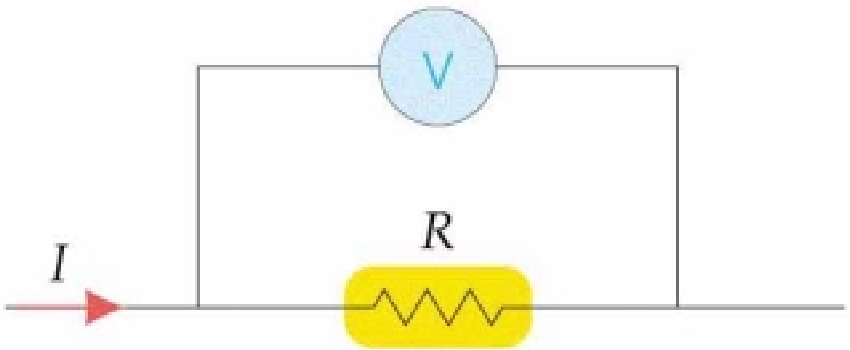
An ammeter.





(b)

A voltmeter

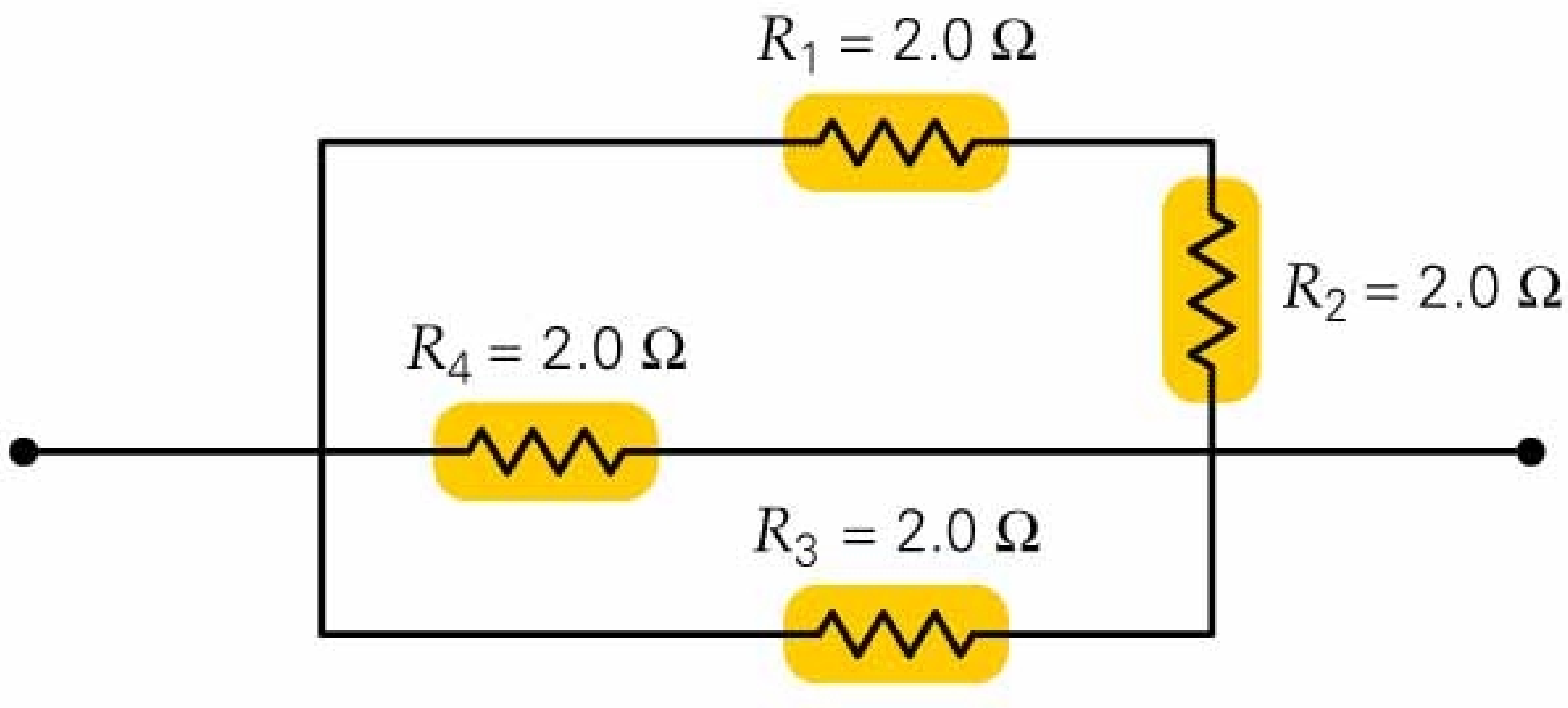


29. In your dorm room, you have two 100 W lights, a 150 W color TV, a 300 W refrigerator a 900 W hairdryer and a 200 W computer. If there is a 15 Amp circuit breaker in the 120 V power line, will the breaker trip?

$P = 2(100\ W) + 150\ W + 300\ W + 900\ W + 200\ W = 1750\ W.$

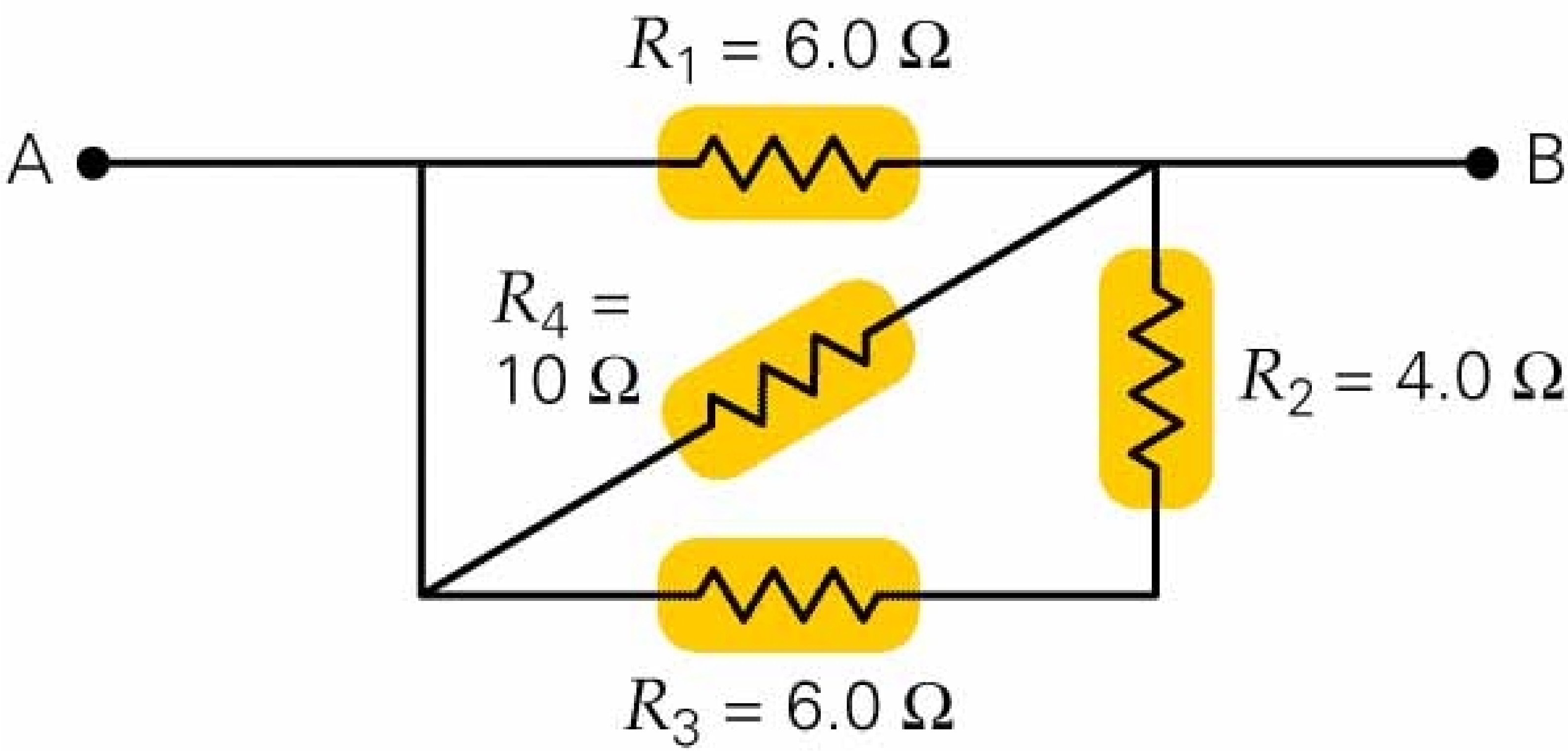
$I = P/V = 1750\ \mathrm{W} / 120\ \mathrm{V} = 14.6\ \mathrm{A} < 15\ \mathrm{A}.$ NO, the breaker will not trip.

Notice: The more devices you have connected the higher P is and the higher I is.



Problem 20: What is the equivalent resistance of the above resistors? (0.8 Ω)

Problem 30: Suppose that the resistors are connected to a 12 V battery.
What will be the current and voltage across each resistor and what will be the total power dissipated in the circuit?



Problem 21: What is the equivalent resistance between points A and B? (2.7 Ω)

Problem 32: A 6 V battery is connected between points A and B.
What will be the current in each how much power will be dissipated in each resistor. Compare the sum of the individual power dissipations to the total power dissipated in the circuit?