Chapter 23 Revision problem

While we are waiting, please try problem 14 –

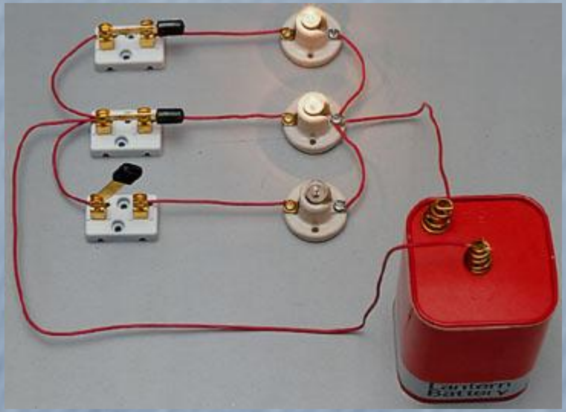
"You have a collection of six 1kOhm resistors…."

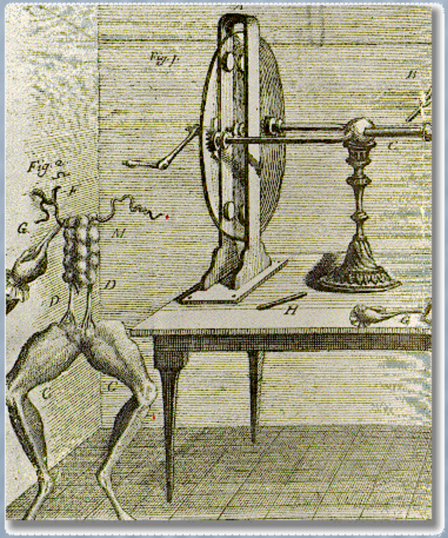
Electric Circuits

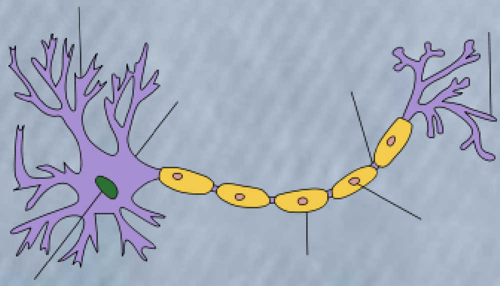
- Elements of a circuit
- Circuit topology
- Kirchhoff's law for voltage and current
- Series and parallel circuit
- Household circuits
- RC circuits
- Nervous system and electricity

Circuits

- Combine batteries, resistors, capacitors to make something useful
- First circuits to drive something – biophysics
- Neurons are circuits in the central nervous system

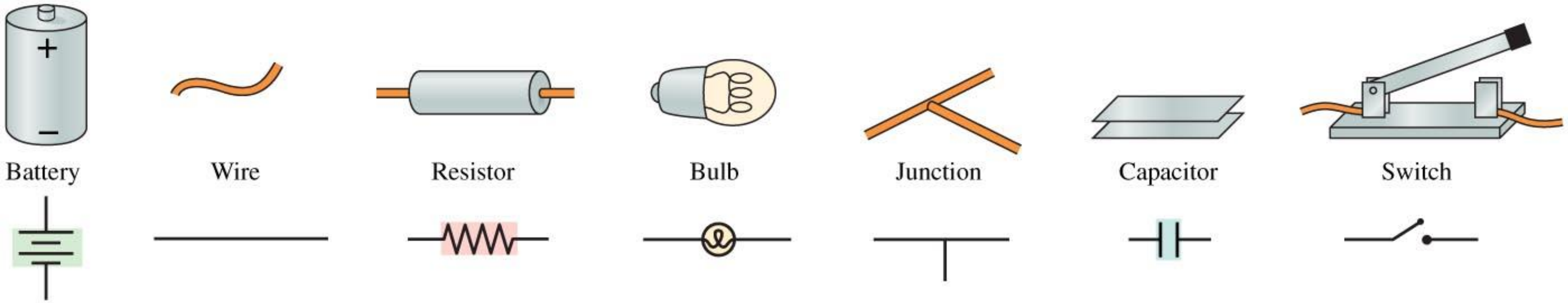






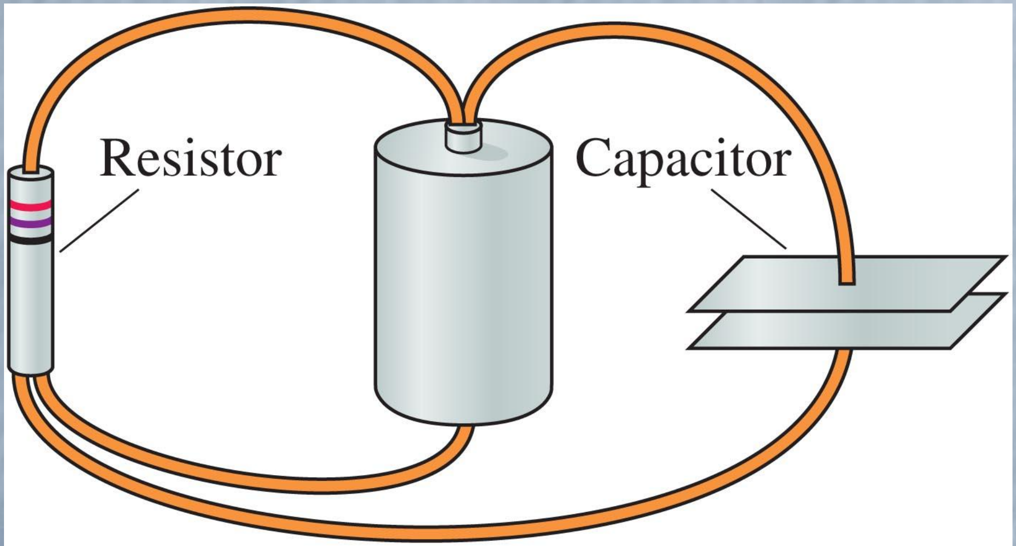
Elements of a circuit

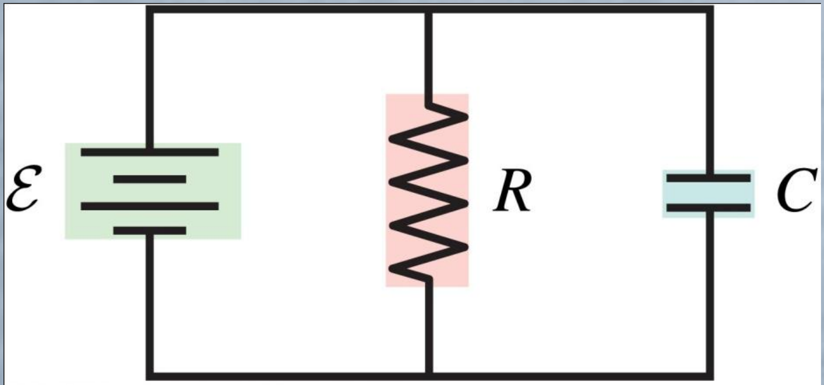
- We will use the following pictograms or symbols
- IEEE and ANSI standard
- All “ideal” components



Circuit Diagram

Convert from pictorial representation to standard symbols

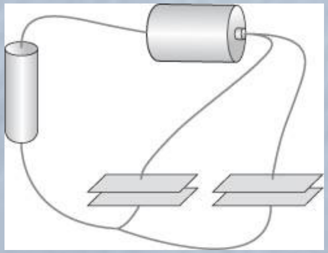




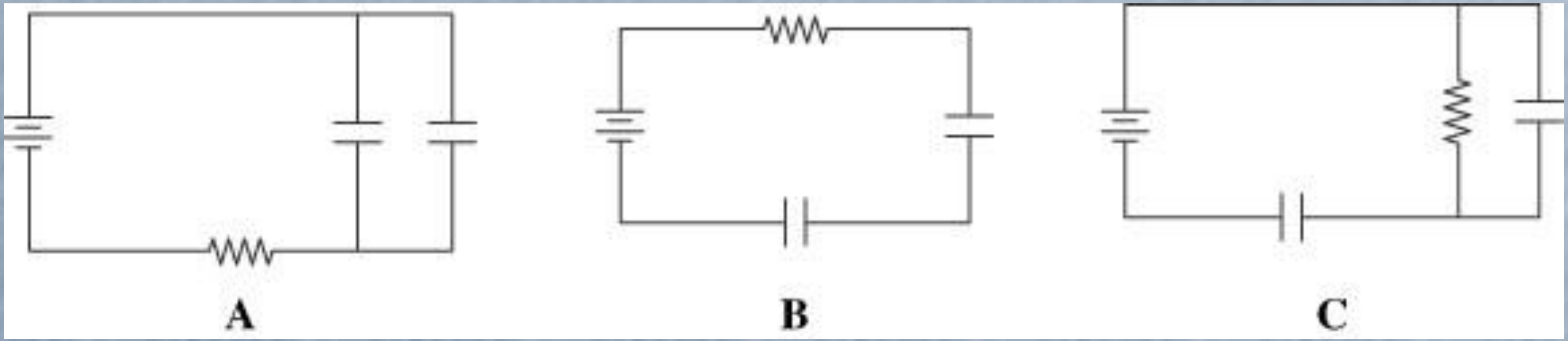
Circuit Topology

- Circuits follow simple laws of topology – you can stretch the wires, but you must preserve the number and order of vertices, and order of components
- Its normal to re-draw a circuit to make it easier to calculate physical quantities like current and potential difference

The following circuit has a battery, two capacitors and a resistor.

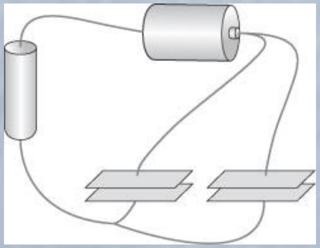


Which of the following circuit diagrams is the best representation of the above circuit?

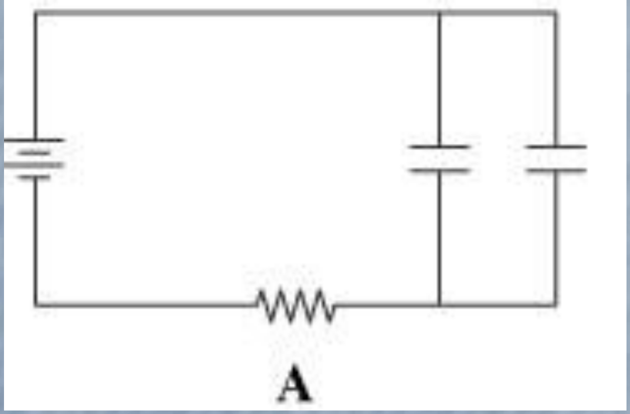


Answer

The following circuit has a battery, two capacitors and a resistor.



Which of the following circuit diagrams is the best representation of the above circuit?

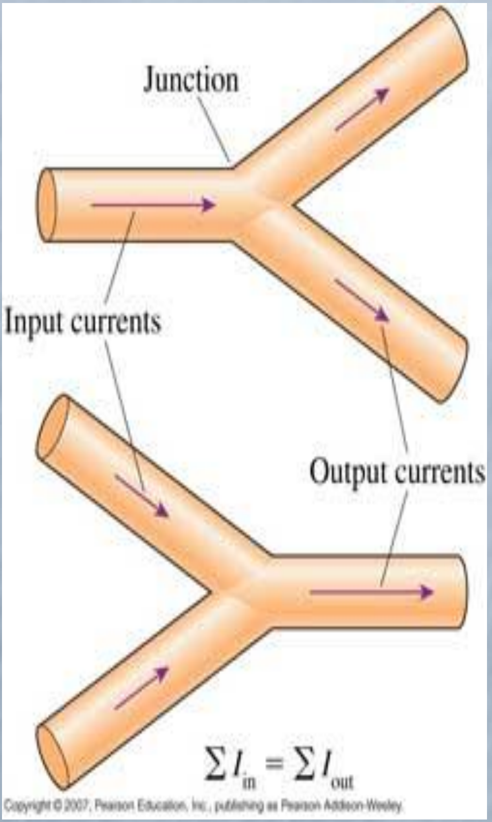


Kirchhoff revisited

We saw from the last chapter that

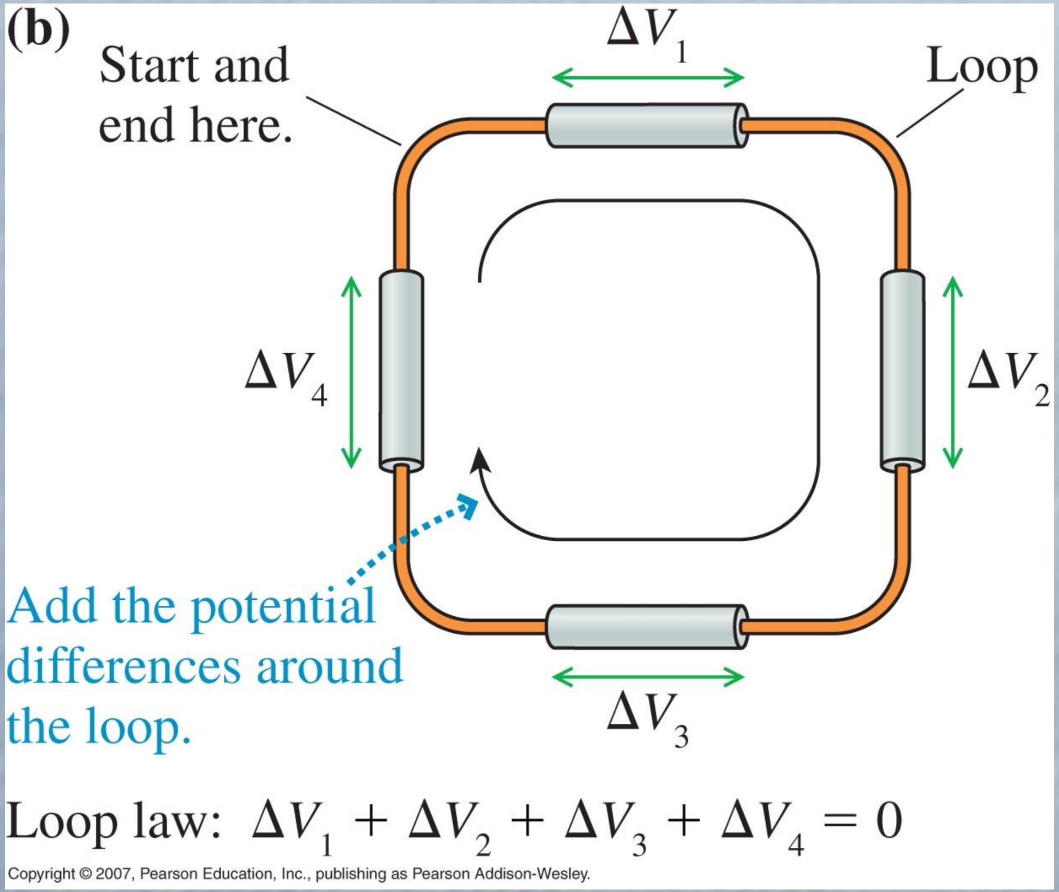
$$\sum I_{in} = \sum I_{out}$$

The sum of the currents into a junction is the same as the current flowing out.



Kirchhoff's loop law of electric potential

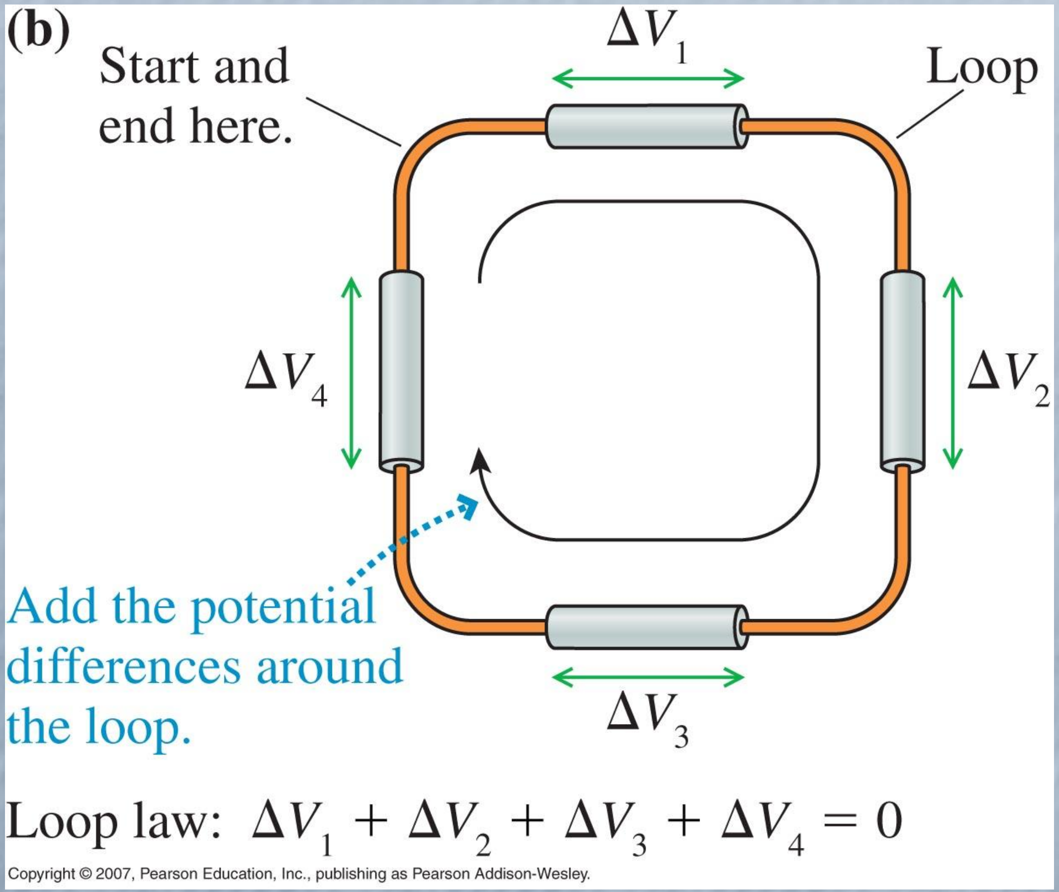
- The energy of an electron in a potential is U=qV
- Flowing around a circuit, the electron comes back to the same potential, so it cant gain or lose energy



Kirchhoff’s loop law of electric potential

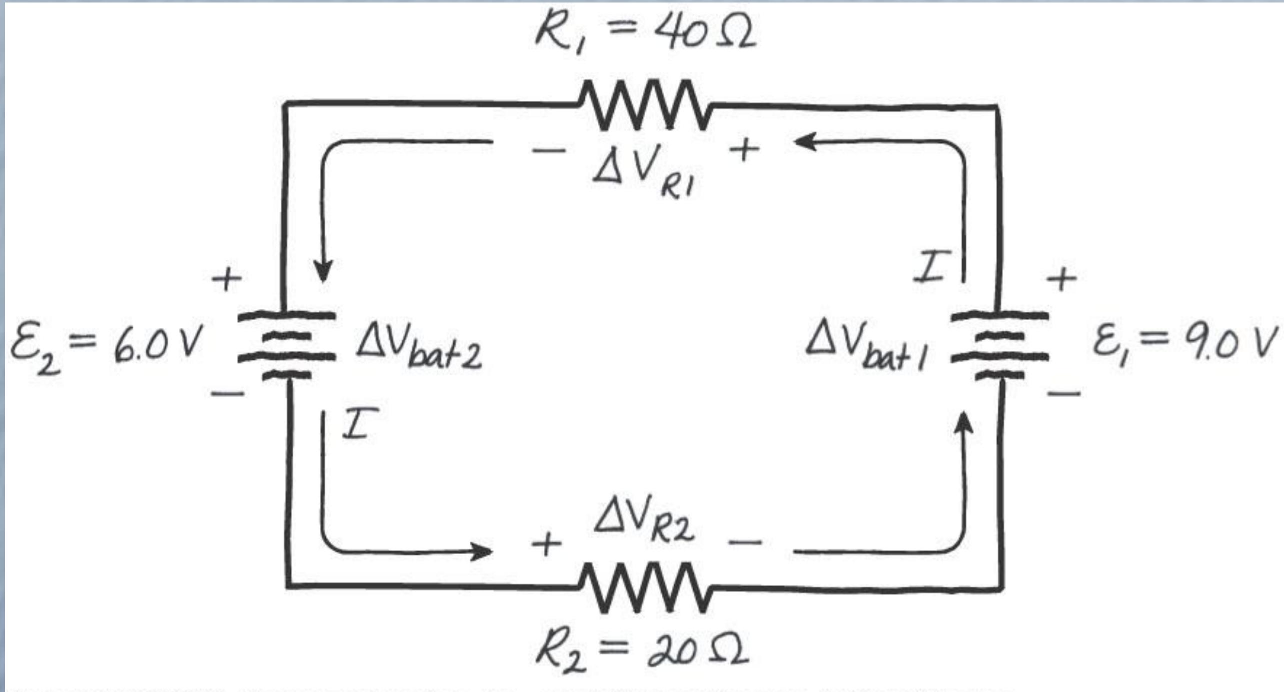
- The net change in the electric potential around any loop must be zero

$$\Delta V = \sum_i \Delta V_i = 0$$



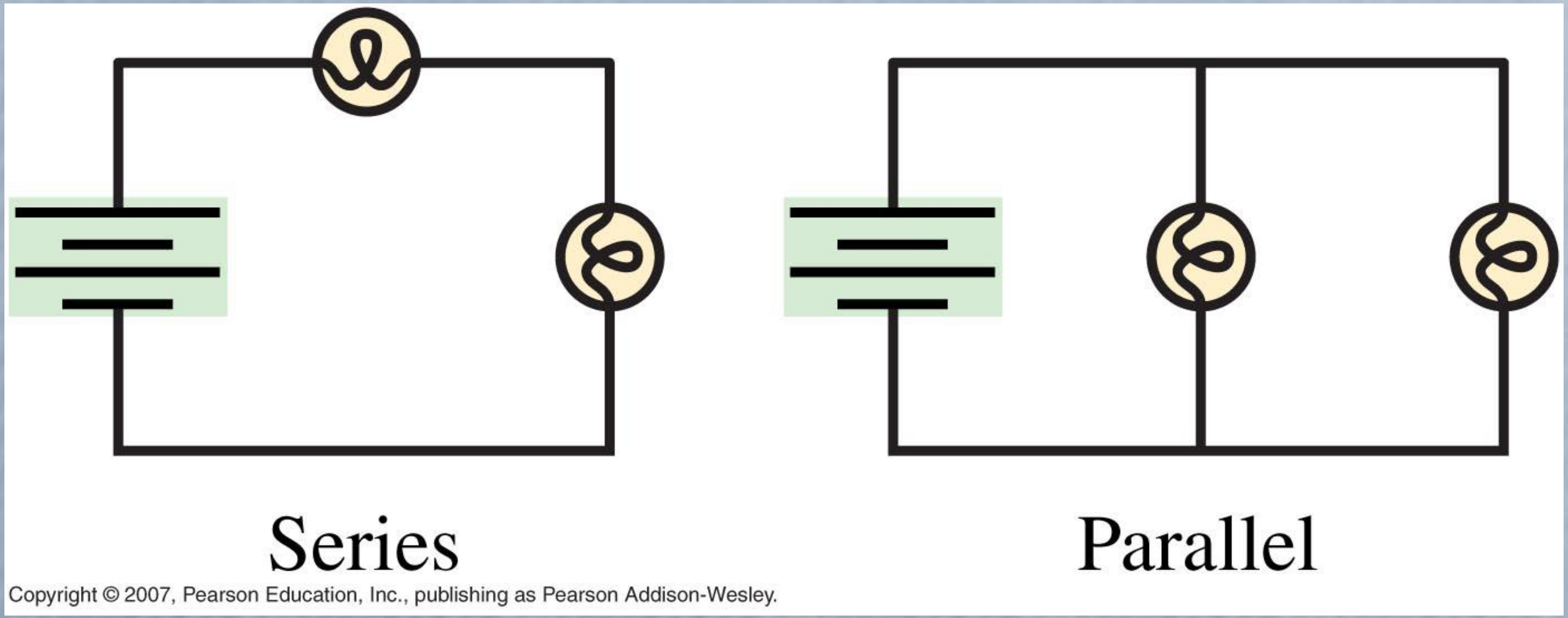
Multiple batteries in a circuit

- Sometimes you see multiple batteries in a circuit.
- The larger emf will drive current backwards through the battery with a smaller emf



Series and Parallel Circuits

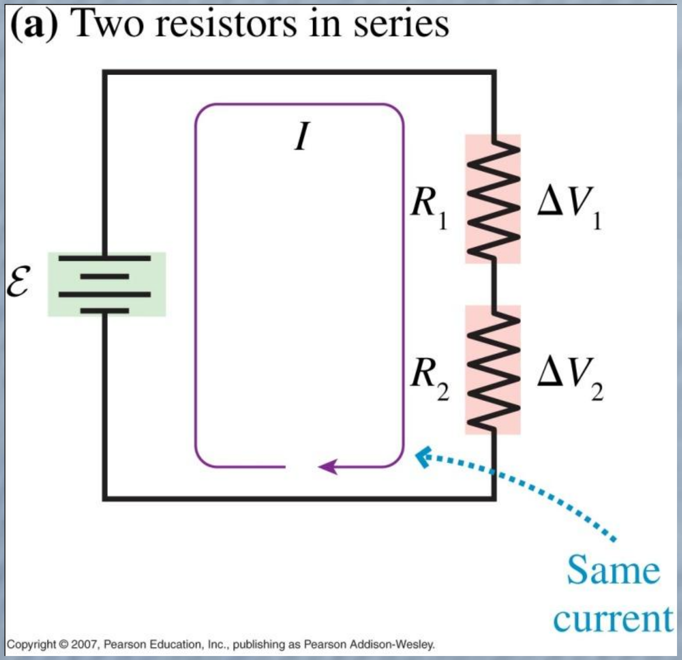
There are two types of circuit topology which are useful to identify when calculating current and potential differences

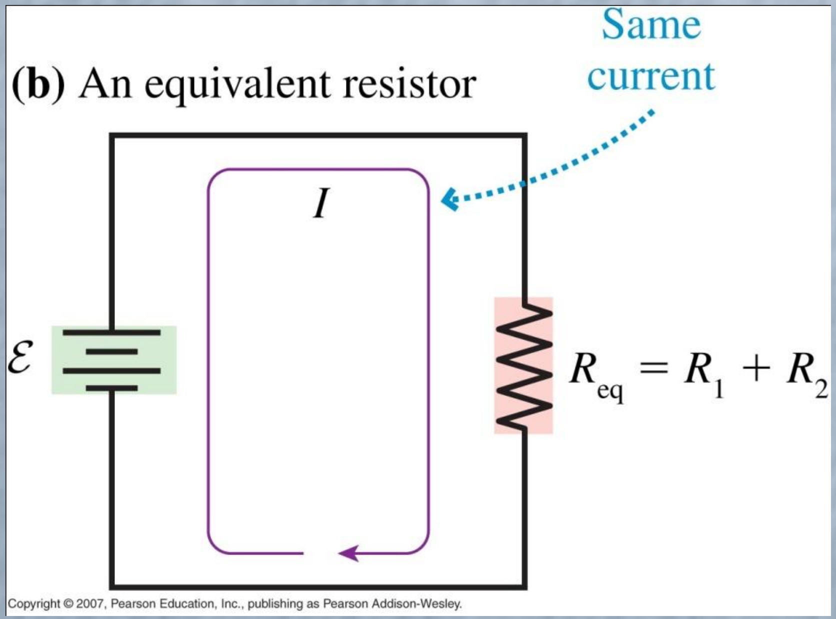


Series Circuits

Two resistors R_1 and R_2 in series have the same affect as a single resistance of R_{TOTAL}

$$R_{TOTAL} = R_1 + R_2$$

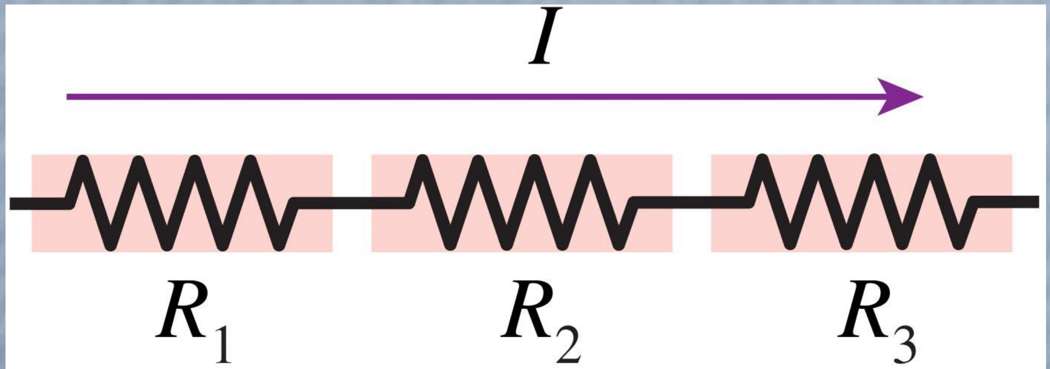




Series Circuits

In general, the total resistance of a chain of resistors R_{TOTAL} is the sum of the individual resistances

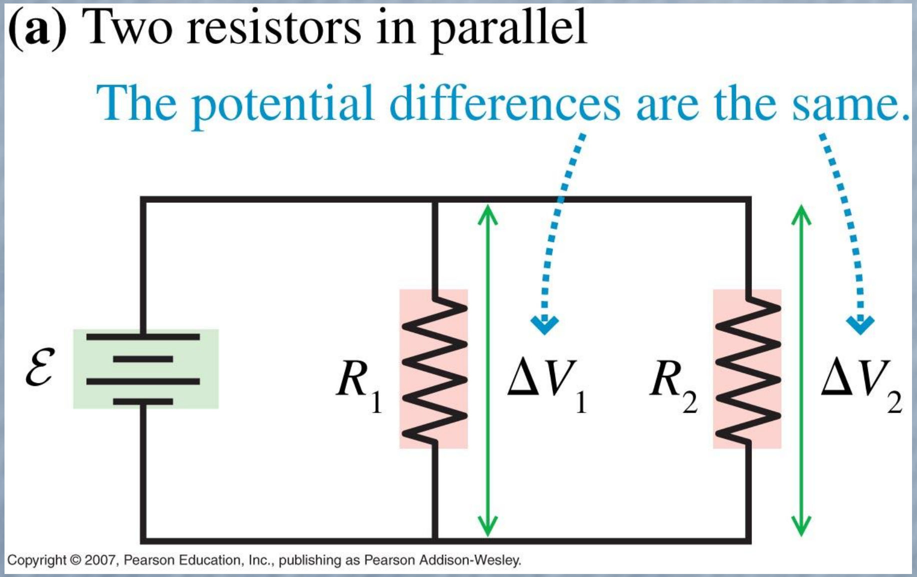
$$R_{TOTAL} = \sum_j R_j$$

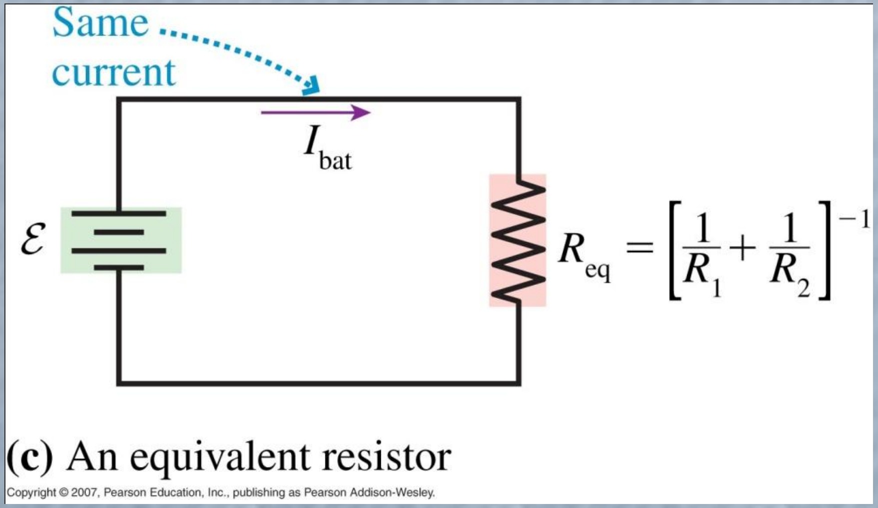


Parallel Circuits

Two resistors R_1 and R_2 in parallel have the same affect as a single resistance of R_{TOTAL}

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2}$$

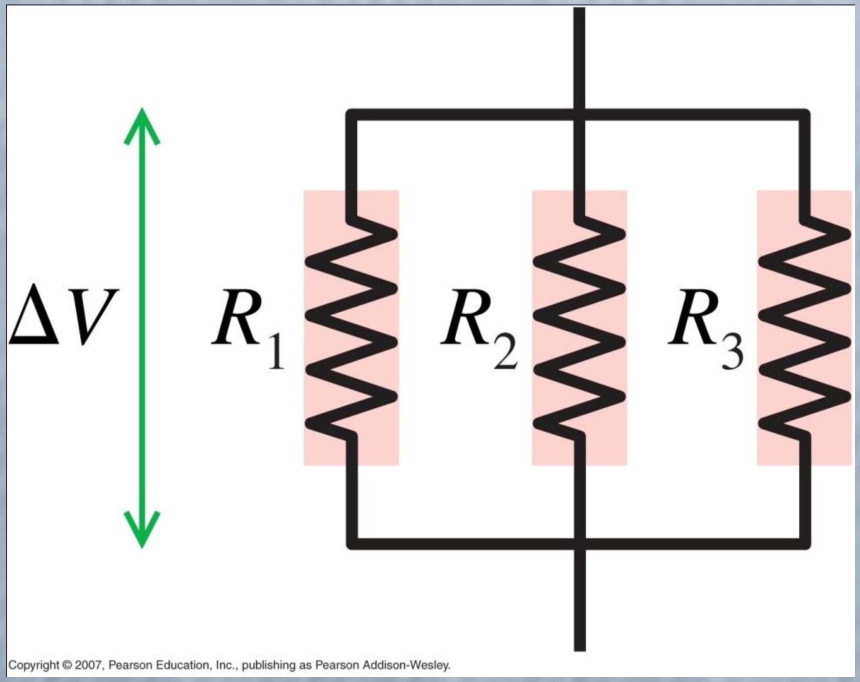




Parallel Circuits

In general, the total resistance of a chain of resistors R_{TOTAL} can be calculated from the sum of the reciprocals of the individual resistances

$$\frac{1}{R_{TOTAL}} = \sum_j \frac{1}{R_j}$$

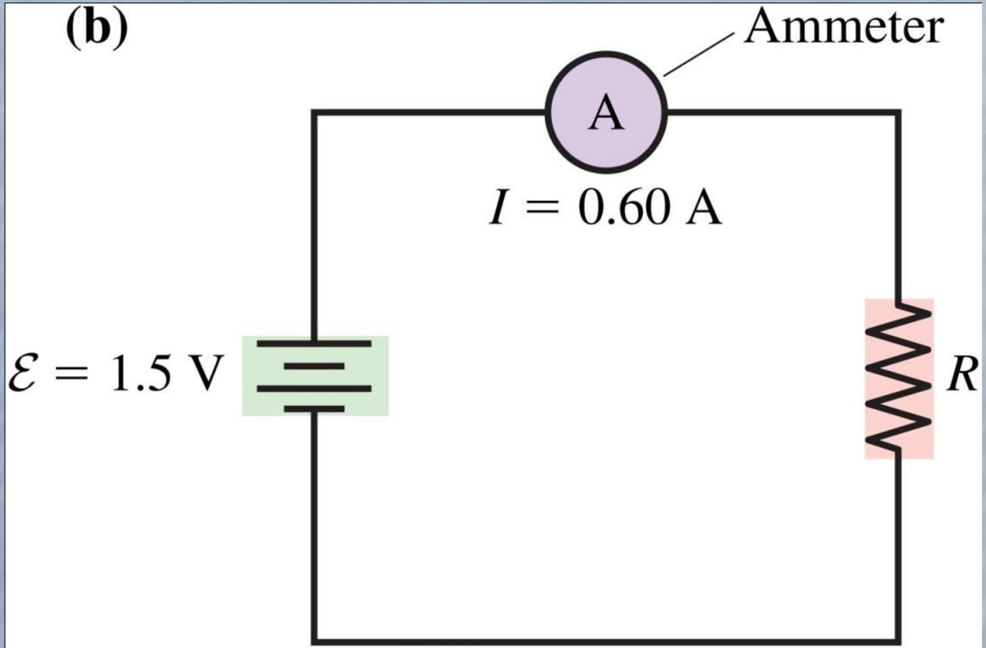


Measuring Voltage and Current

- We use “ideal” instruments for measuring currents – they measure the voltage or current without affecting the quantities we are measuring.
- This is quite close to today’s instruments.

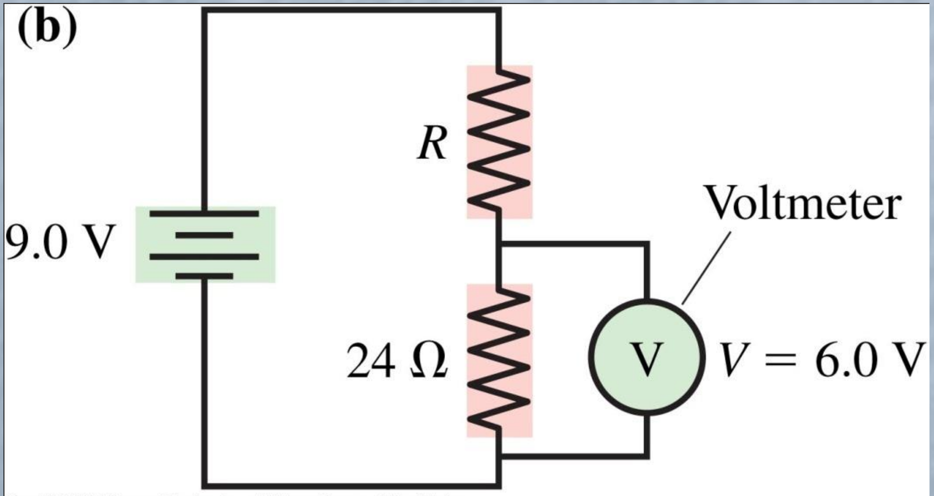
Ammeter

- Measures current
- Used in series
- Has zero resistance



Voltmeter

- Measures potential difference
- Used in parallel
- Has infinite resistance



Multimeters

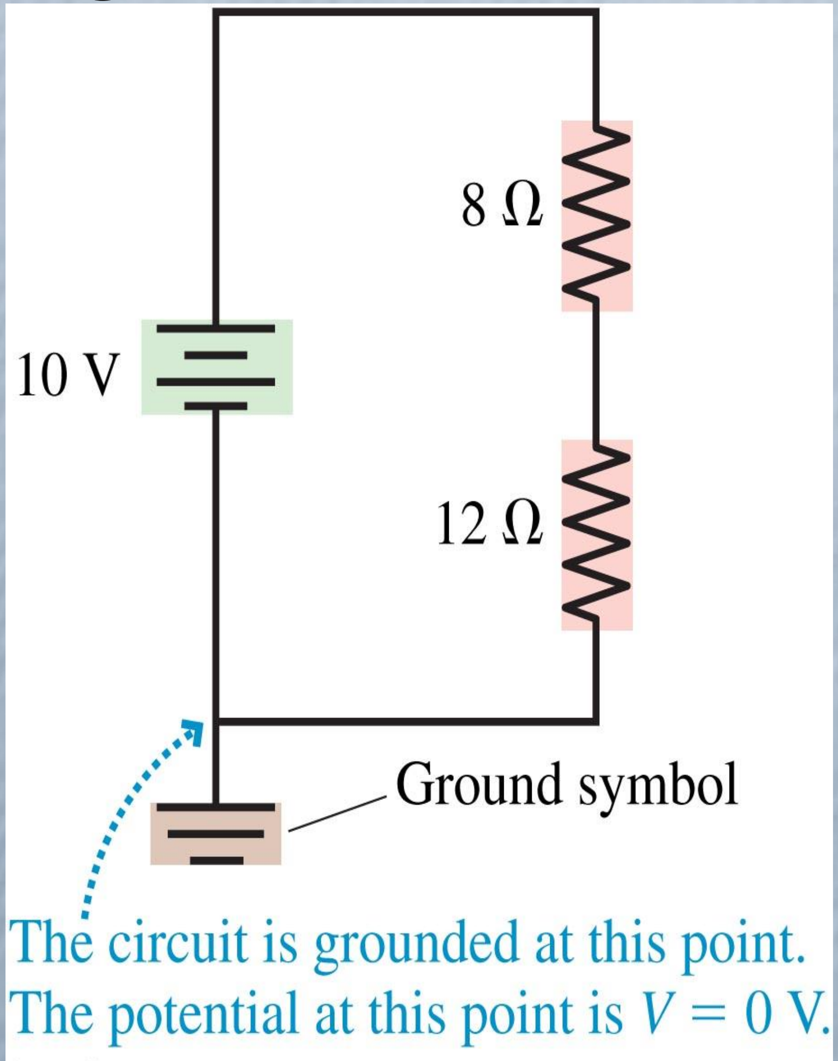
- We use multimeters which have an external power supply (battery) and semiconductor amplifiers
- Will also measure resistance

Household electricity

- Something we should all know about.
- DC (Direct Current) is generated by the emf in batteries - used in cars, boats, trailers.
- Household electricity is generated by electrical generators which work by producing AC (Alternating Current), but the principles are the same.

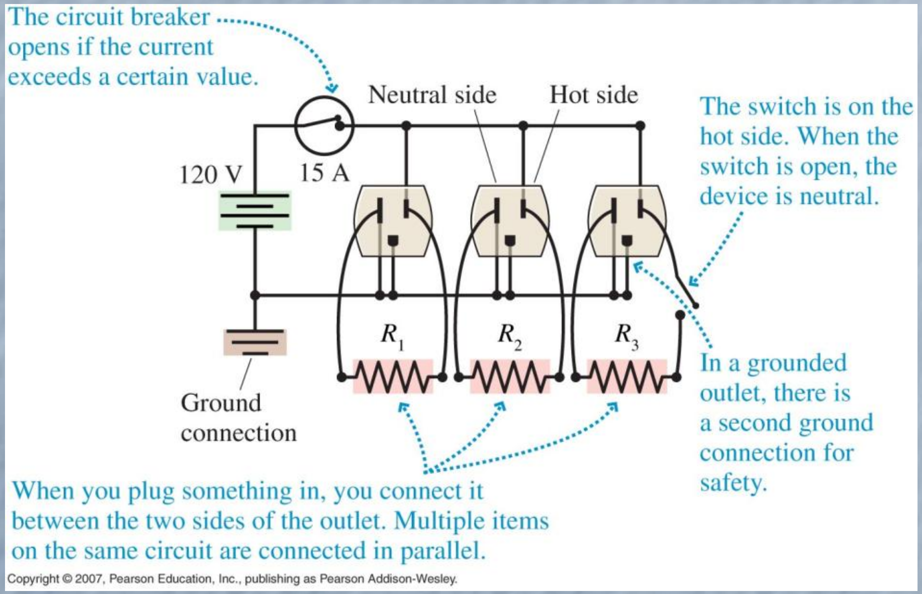
Grounding

- Grounding (or earthing) is setting one side of the circuit to the same potential as the Earth's surface
- This can make electrical items safer.
- Ground is carried by the larger prong on a 3-pin plug



Parallel or Serial ?

- All wall outlets are set to carry 120V potential
- This is done by using parallel circuits everywhere
- Fuses added to protect against large currents



Household energy units

- Different units are used for household electricity
- We pay for electricity monthly, so we need a bigger unit
- A space heater is rated at about 1kW, say we run it for 3 hours a day for a month
- Use kilowatt-hours
- 1 kW hour = 1000W*3600s = 3.6 MegaJoules

Capacitors in Parallel and Series

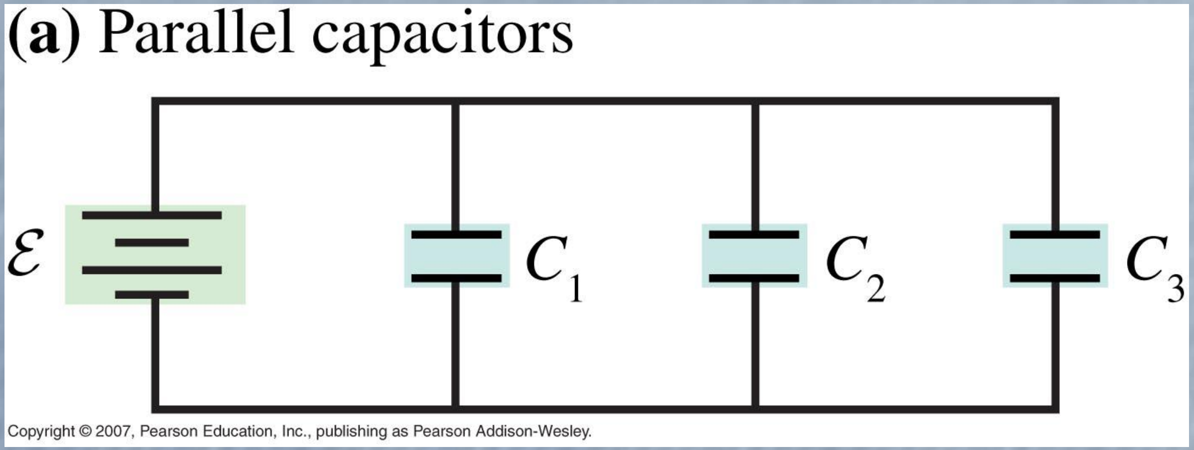
- Capacitors are used in parallel and series as well.
- They look almost, but not quite, exactly opposite of the resistance equations….

Capacitors in Parallel

To calculate total capacitance, need total charge stored

$$C_1 = \frac{Q_1}{V_1}, C_2 = \frac{Q_2}{V_2}, C_3 = \frac{Q_3}{V_3}$$

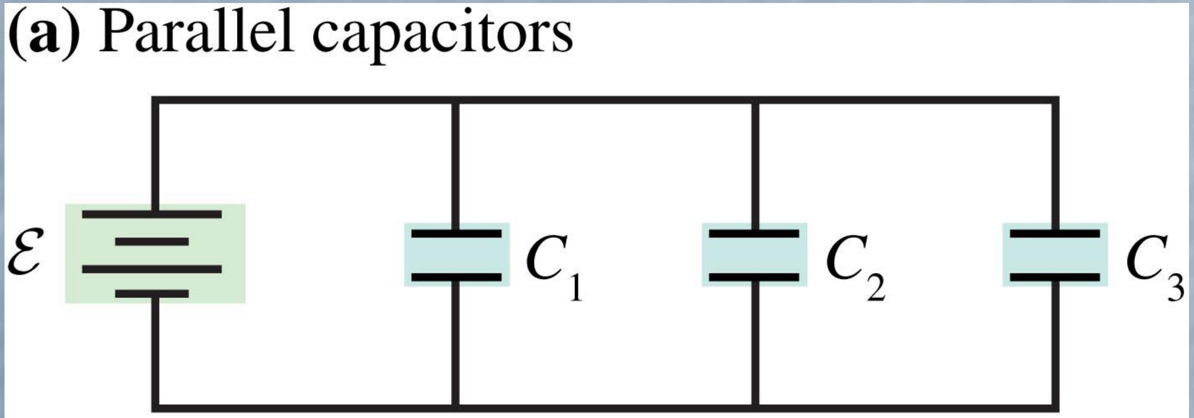
$$C_{total} = \frac{Q_1 + Q_2 + Q_3}{V} = C_1 + C_2 + C_3$$



Capacitors in Parallel

Capacitance in parallel add together

$$C_{TOTAL} = \sum_j C_j$$

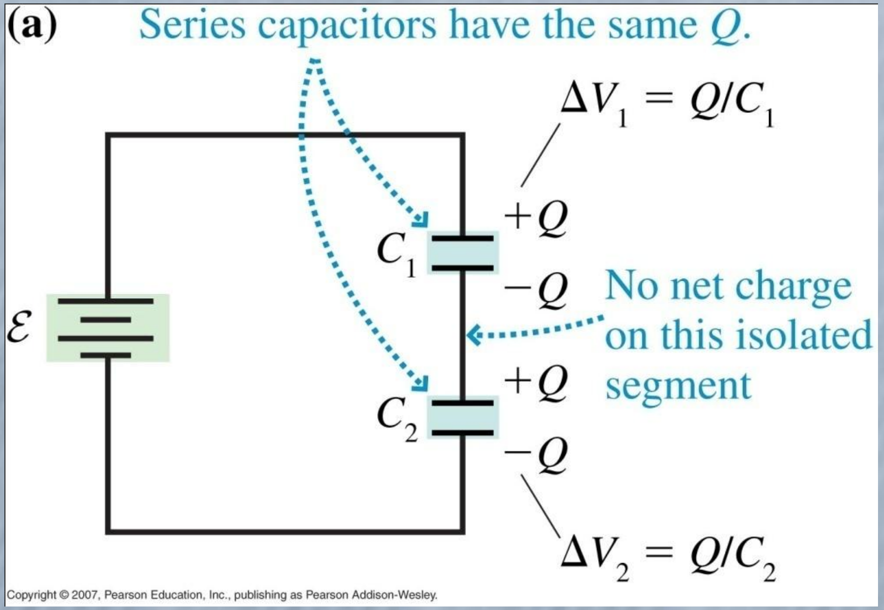


Capacitors in Series

- To calculate total capacitance, need total charge stored.
- Charge must be the same on the 2 capacitors

$$\frac{1}{C_1} = \frac{V_1}{Q_1}, \frac{1}{C_2} = \frac{V_2}{Q_2}$$

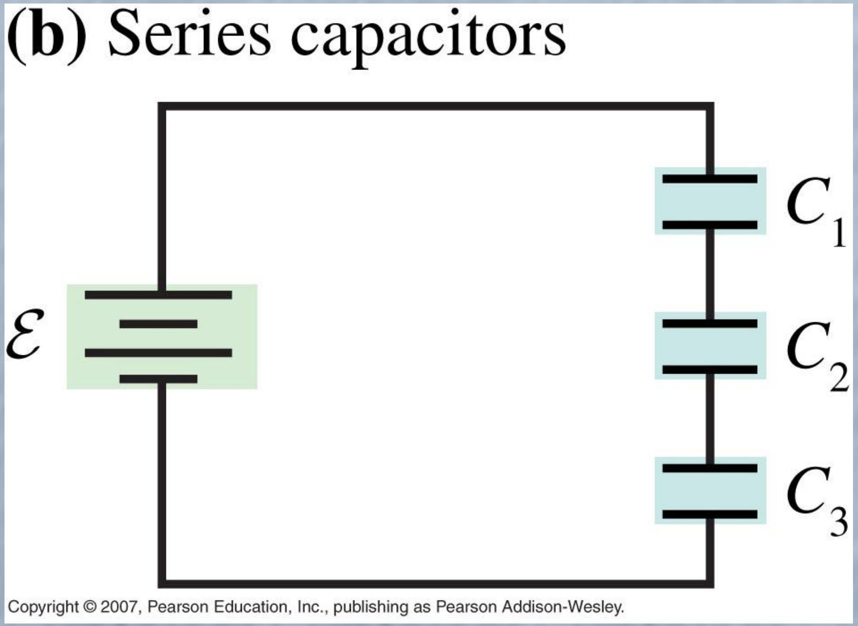
$$\frac{1}{C_{TOTAL}} = \frac{V_1 + V_2}{Q} = \frac{1}{C_1} + \frac{1}{C_2}$$



Capacitors in Series

- The total capacitance of capacitors in series can be calculated from the sum of the reciprocals
- Charge must be the same on the inside capacitors

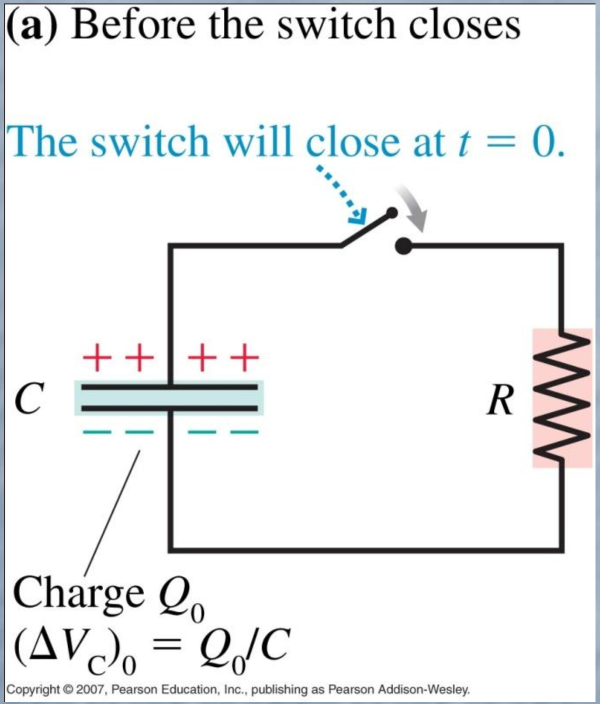
$$\frac{1}{C_{TOTAL}} = \sum_j \frac{1}{C_j}$$

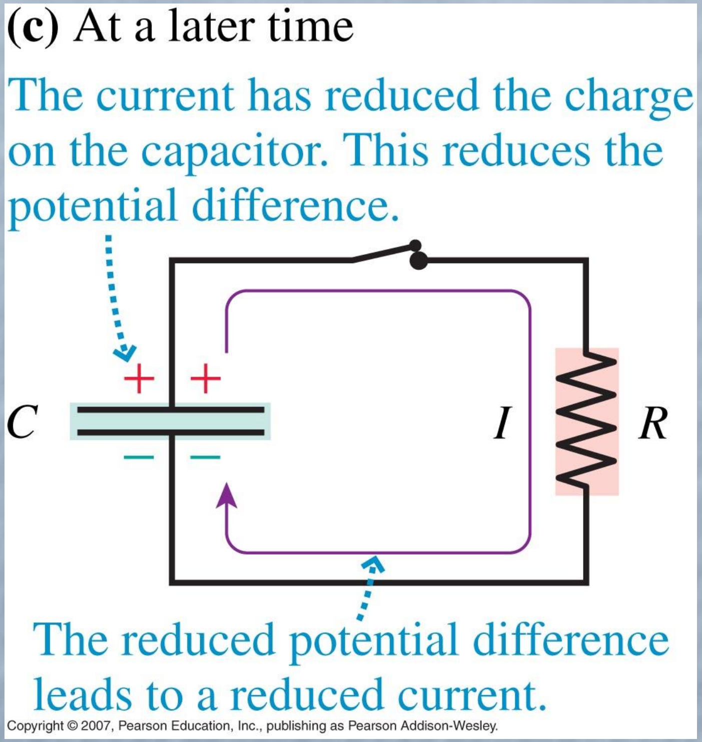


RC Circuits and Time

RC circuits are special circuits which have a characteristic clock built in.

The capacitor will gradually discharge





RC Circuits

We can show that the rate of change of charge is proportional to the remaining charge on the capacitor

$$V = \frac{Q}{C} = IR = R\frac{\Delta Q}{\Delta t}$$

$$Q = RC\frac{\Delta Q}{\Delta t}$$

RC Circuits

- Similarly, the rate of change of voltage is proportional to the voltage
- Rate of change of current is proportional to the current

$$V = RC\frac{\Delta V}{\Delta t}$$

$$I = RC\frac{\Delta I}{\Delta t}$$

RC Circuits

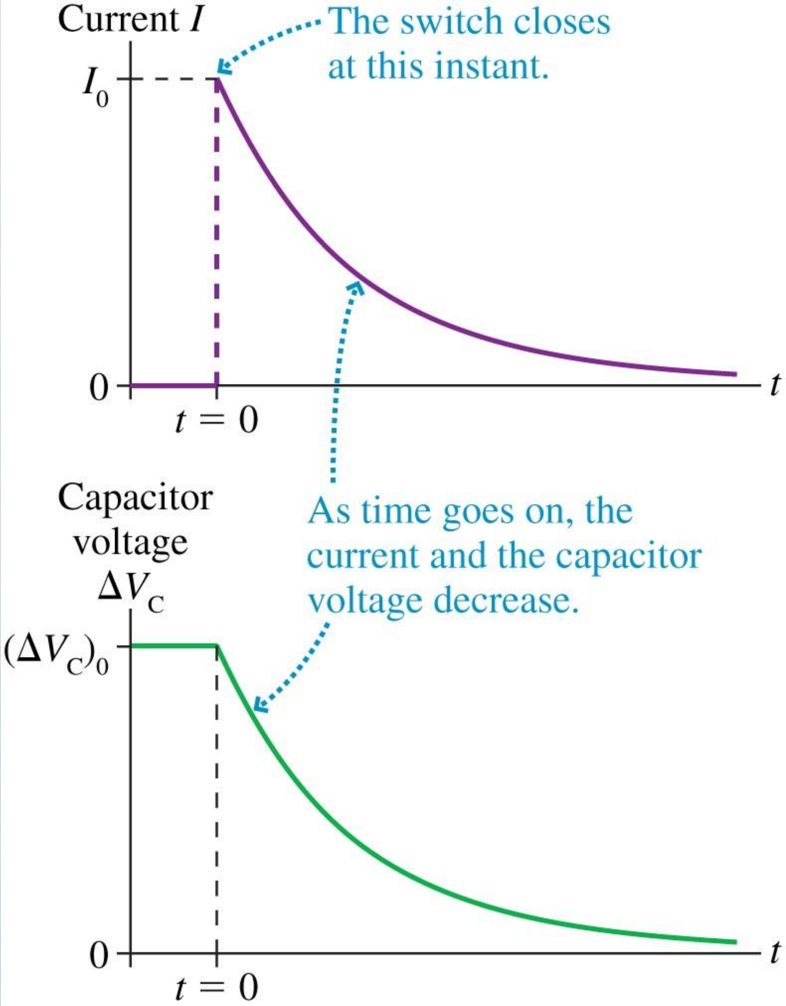
- It can be shown that the solutions to these equations is an exponential
- Where I_0 and V_0 are the initial values, and RC is the **time constant**

$$V(t) = V_0 e^{-t/RC} \qquad I(t) = I_0 e^{-t/RC}$$

Discharging a capacitor through a resistor

$$I(t) = I_0 e^{-t/RC}$$

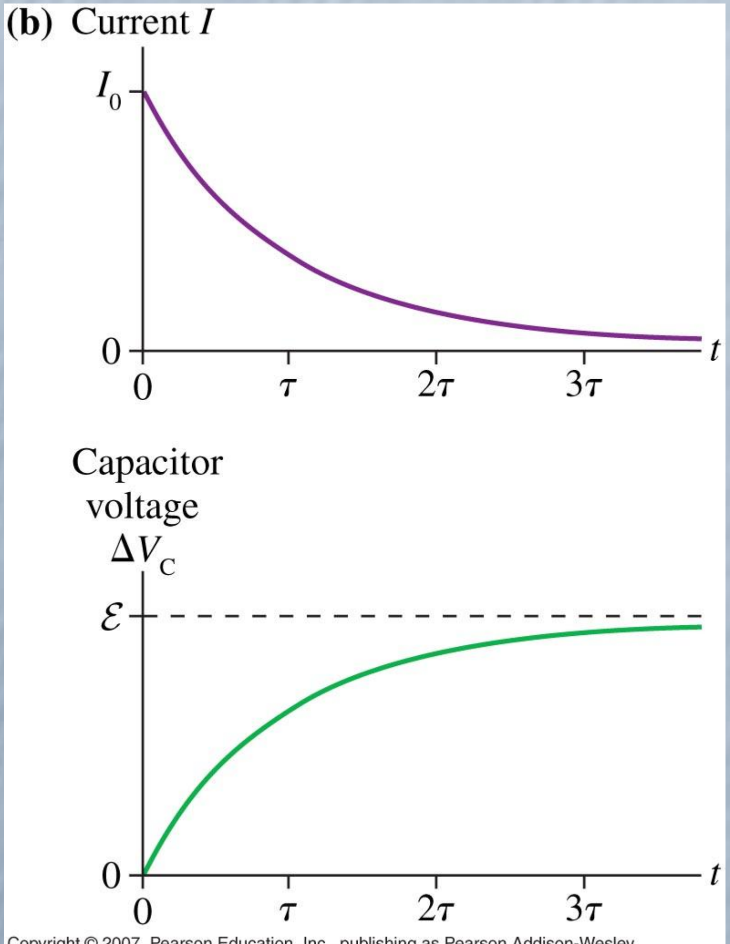
$$V(t) = V_0 e^{-t/RC}$$



Charging a capacitor through a resistor

$$I(t) = I_0 e^{-t/RC}$$

$$V(t) = V_{final}(1 - e^{-t/RC})$$



RC Circuits

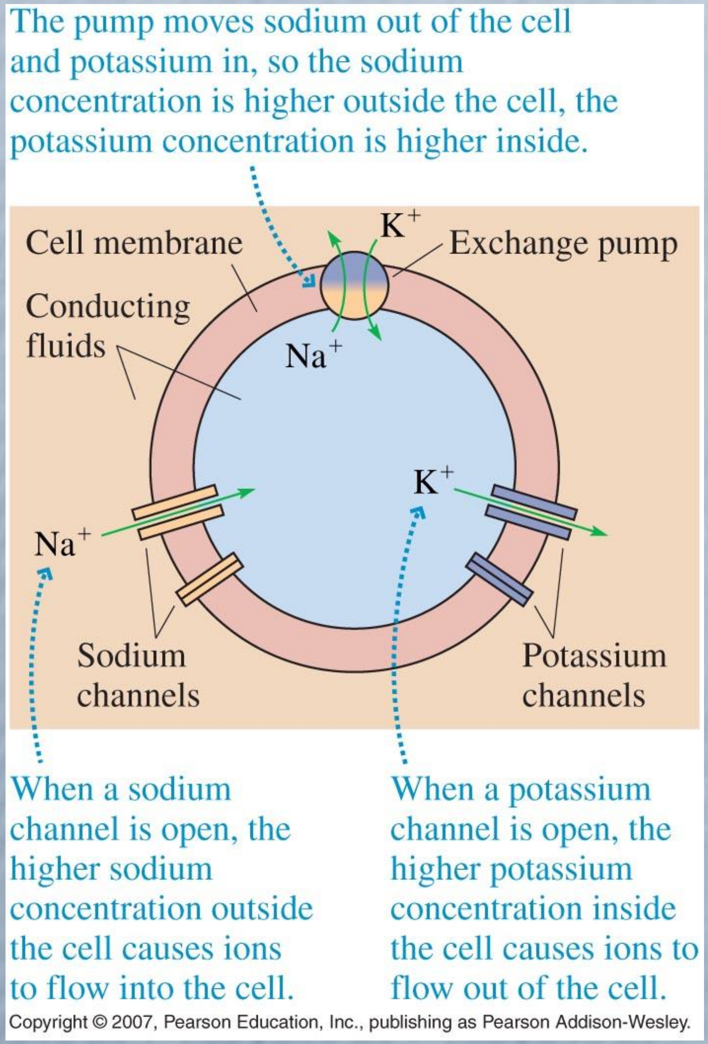
- Easy way to build a clock or oscillator
- Make a switch close or open when the potential across a capacitor reaches a certain voltage

Electrical Circuits and Biology

- Historically bioelectrics was one of the first uses of electric current to move something – up until then there was electrostatic and magnetic phenomena
- Volta and Galvani used electricity to move dead frogs legs.
- Cells can drive potassium and sodium ions through membranes with **ion** pumps – creating an emf

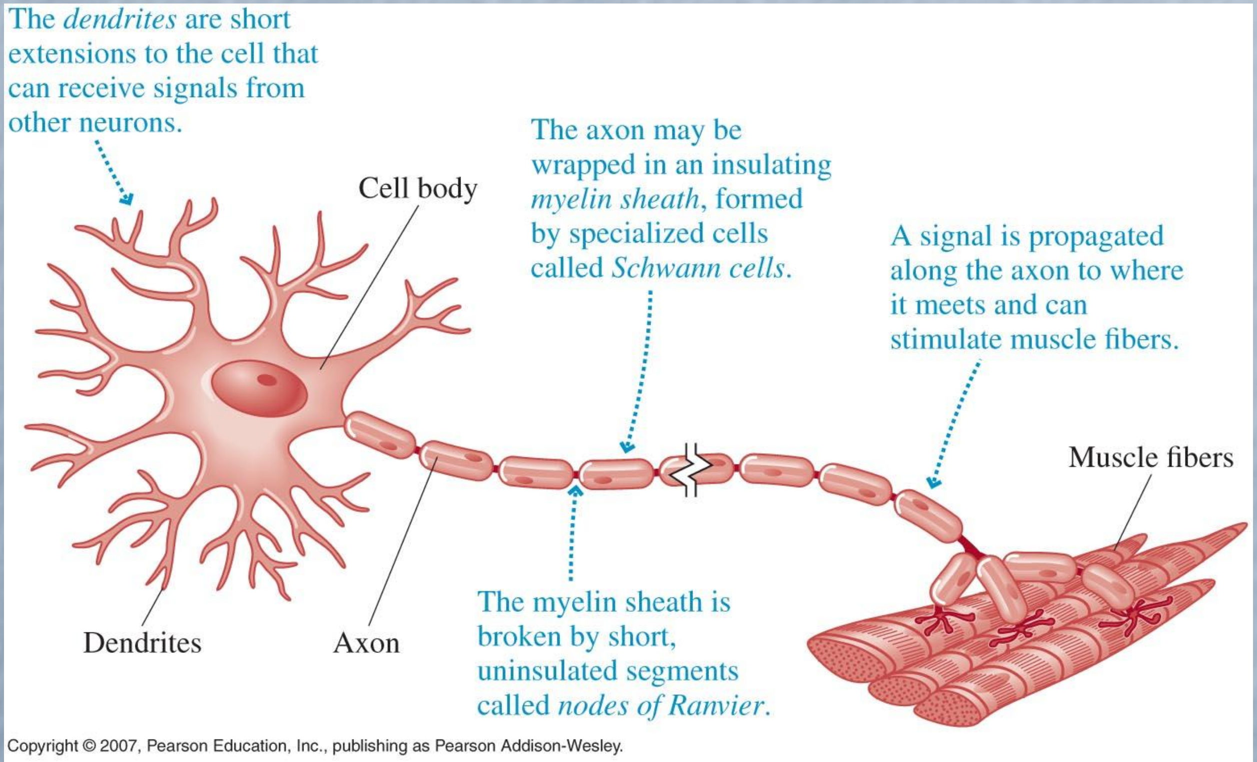
Ion pumps in a cell

- The cell attains a 70mV potential across the cell membrane 7nm thick
- This is an electric field of 10MV/m



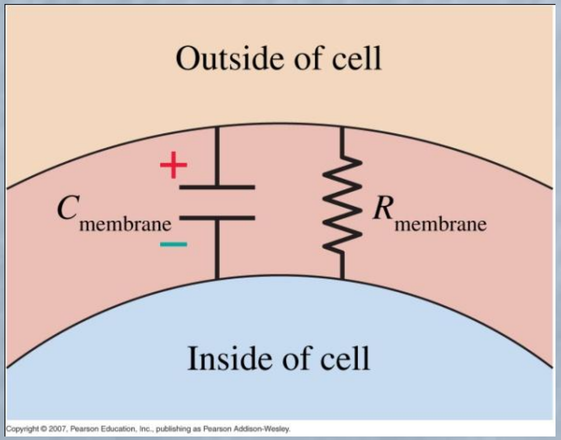
Neurons

Neuron cells collect inputs to the cell, sends down the axon and delivers a charge to other neurons or muscle fibers



RC time constants for a nerve

- Resistivity of a cell membrane: $36 \times 10^6\ \Omega m$
- Using the size of the cell, we get $R = 32 M\Omega$
- Dielectric constant for cell membrane is 9.0
- C= 89pF
- RC time constant is 3ms
- Very long time for 1 neuron



Summary

- Elements of a circuit
- Circuit topology
- Kirchhoff’s law for voltage and current
- Series and parallel circuit
- Household circuits
- RC circuits
- Nervous system and electricity

Homework problems

Chapter 23 Problems

45, 49, 52, 55, 59, 68, 69, 73