Current,

Resistance,

and

Voltage

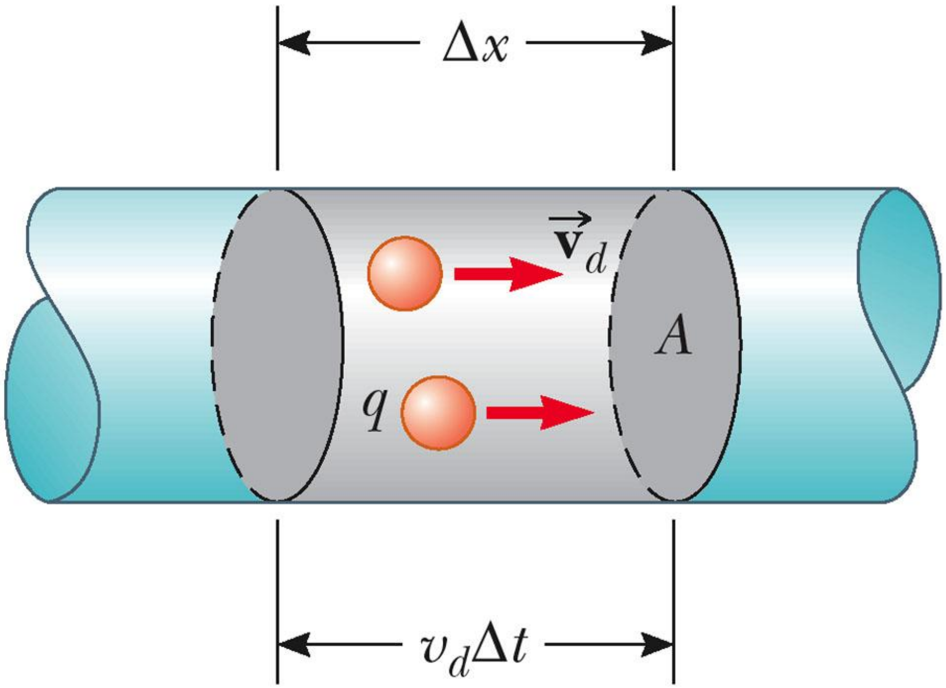
in a simple circuit

Part 2

Electric Current

Whenever electric charges of like signs move, an *electric current* is said to exist.

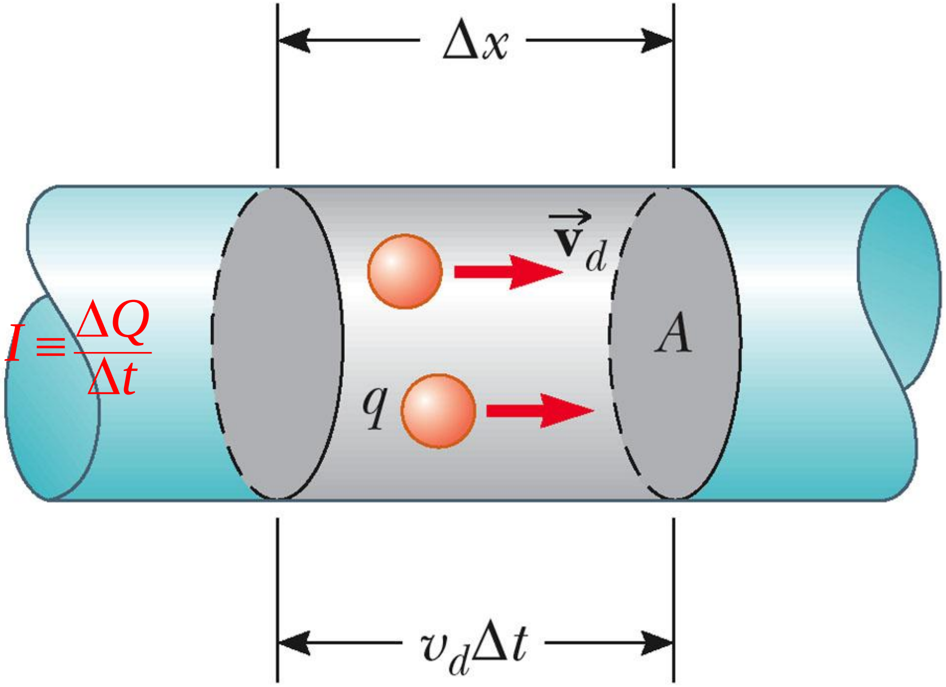
Look at the charges flowing perpendicularly to a surface of cross-sectional area *A*.



(This motion is due to the presence of a uniform electric field along the length of the conductor.)

The current is the rate at which the charge flows through this surface.

$$I \equiv \frac{\Delta Q}{\Delta t}$$



The SI unit of current is the *ampere* (A).

1 A = 1 C/s

The direction of the current is the direction positive charge would flow.

This is known as *conventional current direction*.

In a common conductor, such as copper, the current is due to the motion of the negatively charged electrons.

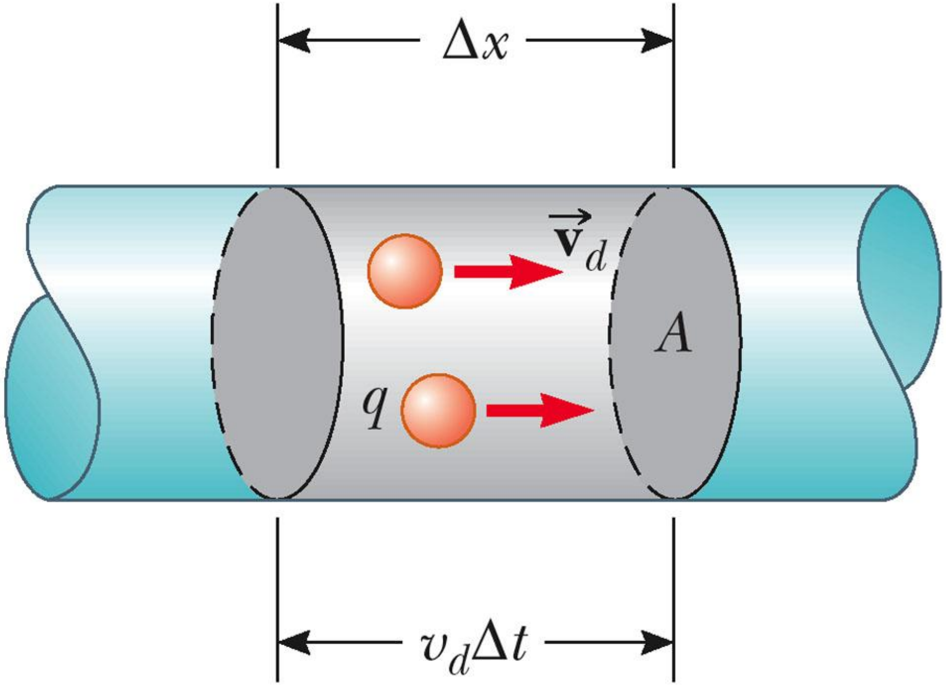
It is common to refer to a moving charge as a mobile *charge carrier*.

A charge carrier can be positive or negative

Current and Drift Speed

n **is the number of charge carriers per unit volume.**

nAΔx **is the total number of charge carriers.**



Current and Drift Speed

The total charge is the number of carriers times the charge per carrier, q.

$$\Delta Q = (nA\Delta x)\, q$$

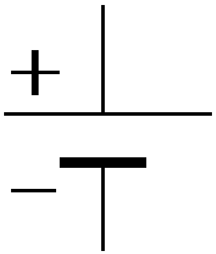
The drift speed, υ_d , is the speed at which the carriers move.

$$\upsilon_d = \Delta x/\Delta t$$

Rewritten: $\Delta Q = (nA\upsilon_d\Delta t)q$

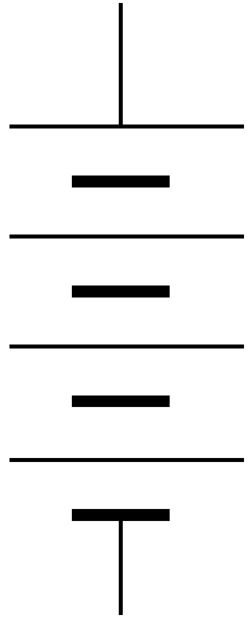
Finally, current, $I = \Delta Q/\Delta t = nq\upsilon_d A$

Circuit Elements



Chemical cell
e.g., "D" cell

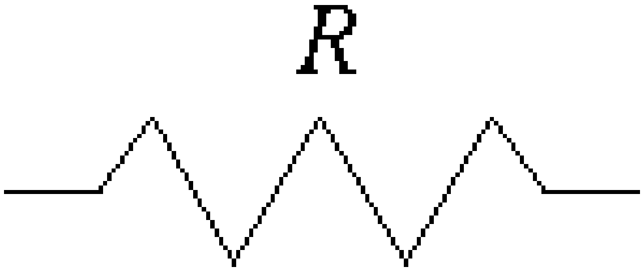
Potential difference
across terminals ~ 1.5 V



"Battery" of cells.

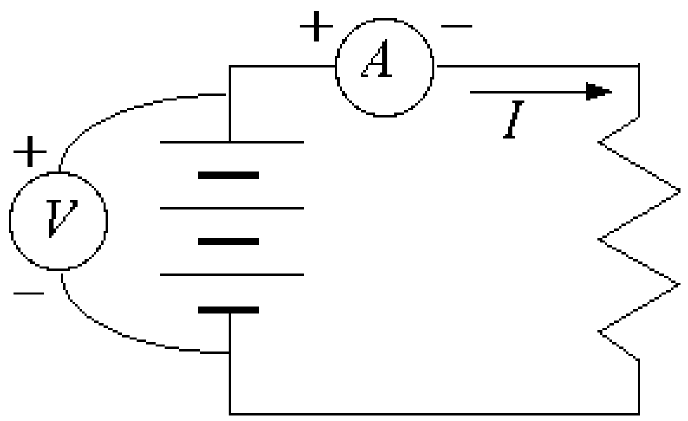
Resistor

Symbolic representation in a circuit diagram



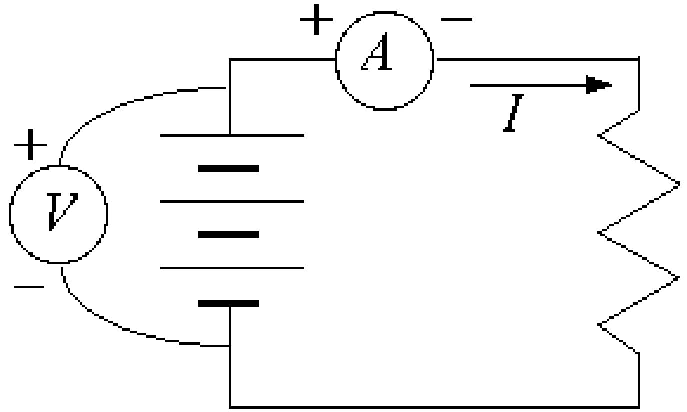
Connect a battery to a resistor.
Note location and polarity of meters.

Arrow indicates direction of conventional current.



For the resistor in this circuit (if temperature is ~ constant), current is proportional to the potential difference across the resistor.

$I \propto \Delta V$ **or** $\Delta V = IR$



This is *Ohm's law* in its simplest form.

The proportionality factor *R* is the <u>resistance</u>.
The unit for resistance is the ohm (Ω).

Resistance (*R*) depends upon

- the length *l* of the conductor,

- the cross sectional area *A*,

- and the resistivity ρ of the conductor.

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

The <u>unit</u> for resistivity is Ω-m.

The reciprocal of resistance is conductance (G). The unit is Ω^{-1}.

$$G = \frac{1}{R}$$

The reciprocal of resisitivity is conductivity (σ). The unit is $\Omega\text{-m}^{-1}$.

$$\sigma = \frac{1}{\rho}$$

Temperature Variation of Resistivity

For most metals, resistivity increases with increasing temperature.

With a higher temperature, the metal’s constituent atoms vibrate with increasing amplitude.

The electrons find it more difficult to pass through the atoms.

For most metals, resistivity increases approximately linearly with temperature over a limited temperature range.

$$\rho = \rho_o \left[1 + \alpha \left(T - T_o \right) \right]$$

ρ **is the resistivity at some temperature** T**.**

ρ_o **is the resistivity at some reference temperature** T_o**.**

T_o **is usually taken to be 20° C**

α **is the** ***temperature coefficient of resistivity*****.**

Temperature Variation of *Resistance*

Since the resistance of a conductor with uniform cross sectional area is proportional to the resistivity, you can find the effect of temperature on resistance:

$$R = R_o\left[1+\alpha\ T-T_o\ \right]$$

Electrical Energy in a Circuit

In a circuit, as a charge moves through the battery, the electrical potential energy of the system is increased by $\Delta Q \Delta V$.

The chemical potential energy of the battery decreases by the same amount.

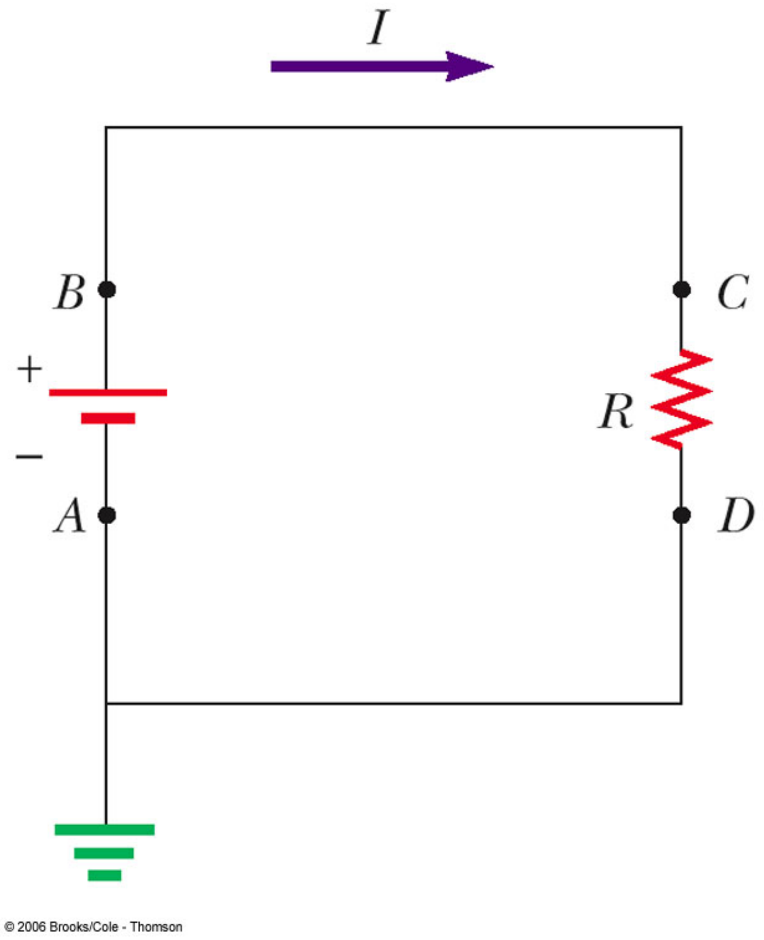
As charge carriers move through a resistor, there is a potential energy loss as the charge carriers collide with atoms in the resistor.

The temperature of the resistor will increase.

Energy Transfer in a Circuit

Imagine a quantity of positive charge, Δ*Q*, moving around the circuit along path *A-B-C-D-A* .

(If *R* is a metal resistor the actual charge movement is electron movement along path *A-D-C-B-A*.)

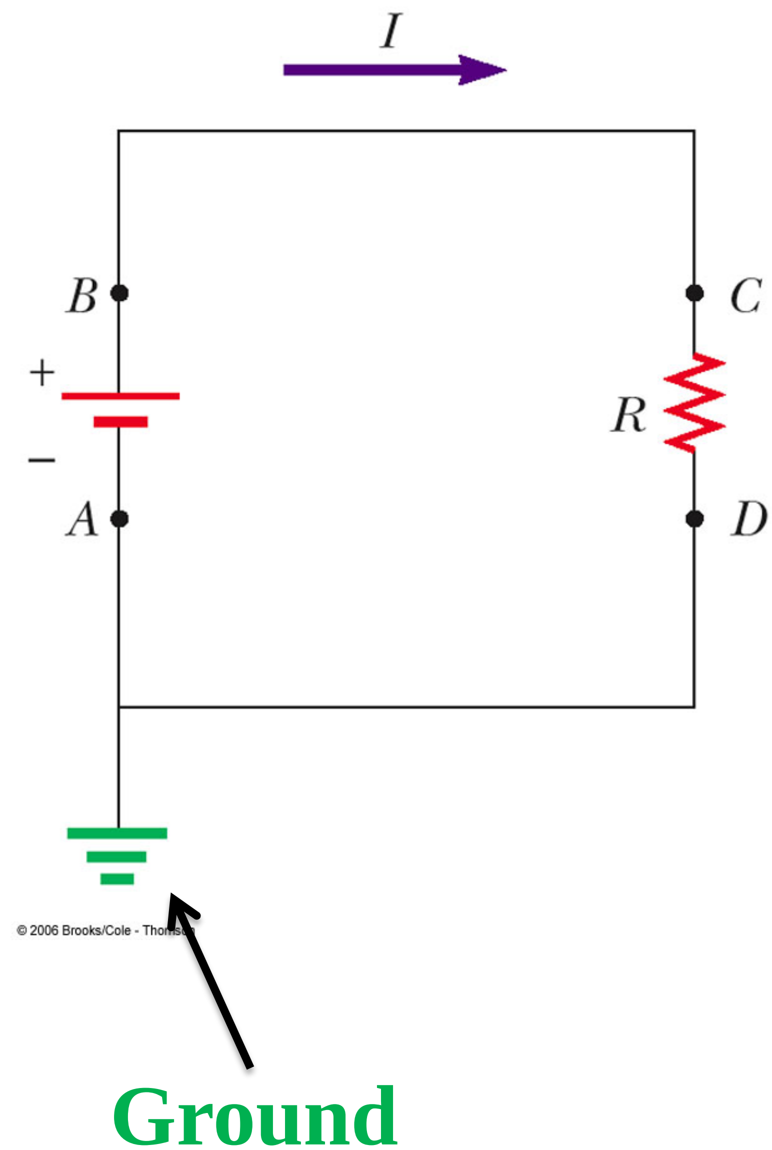


Point A is the reference point.

- **It is "grounded" and its potential is taken to be zero.**

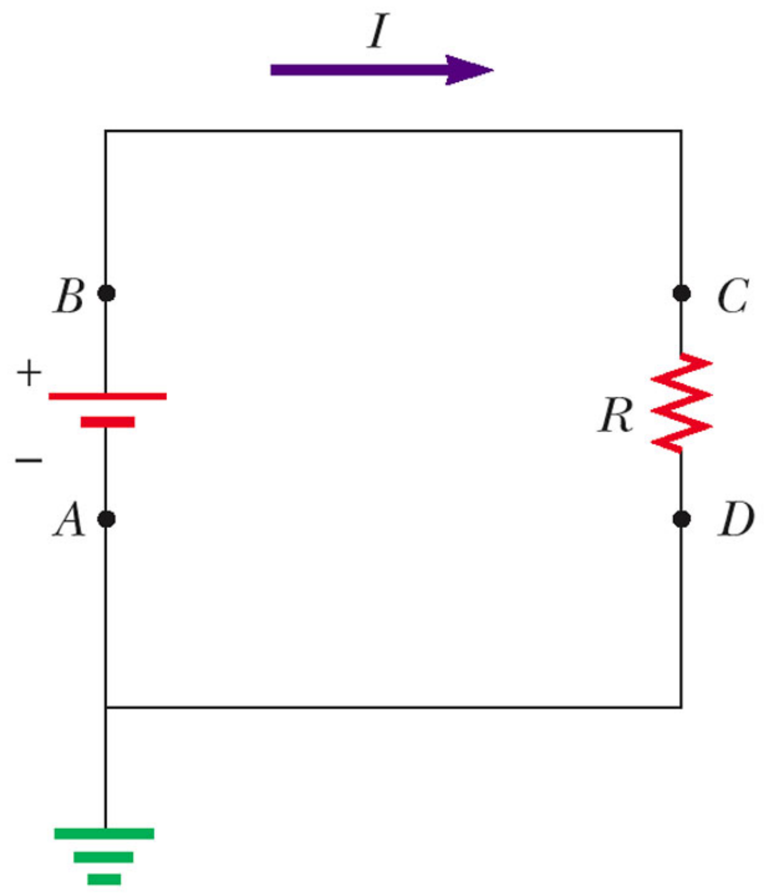
As the charge moves through the battery from A to B, the potential energy of the system increases by $\Delta Q \Delta V$

- **The chemical energy of the battery decreases by the same amount.**



Energy is transferred to internal energy of the resistor.

When the charge returns to *A*, the *net result* is that some chemical energy of the battery has been delivered to the resistor and caused its temperature to rise.



Power

Power **is the rate at which energy is delivered to a circuit, or the rate at which energy is dissipated in a circuit.**

$$\mathcal{P} = \frac{\Delta Q}{\Delta t} \Delta V = I \Delta V$$

Alternative expressions for power (using Ohm's law):

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

Units

The SI unit of power is the watt (W)

I must be in amperes, R in ohms and ΔV in Volts.

The unit of energy used by electric companies is the *kilowatt-hour.*

This is defined in terms of the unit of power and the amount of time it is supplied.

1 kWh = 3.60×10^6 J