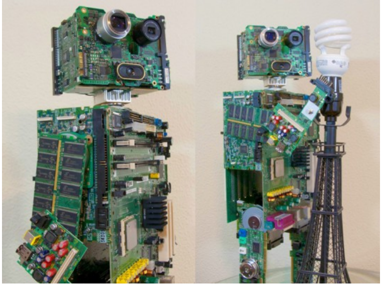
Current and Resistance



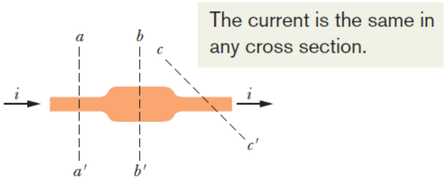
"Ampere was the Newton of electricity."
- *James C. Maxwell*

David J. Starling
Penn State Hazleton
PHYS 212

Electric Current

Current — the net charge (in coulombs) that passes through a fixed plane per unit of time (seconds).

$$i = \frac{\Delta q}{\Delta t} \text{ or } i = \frac{dq}{dt} \tag{1}$$

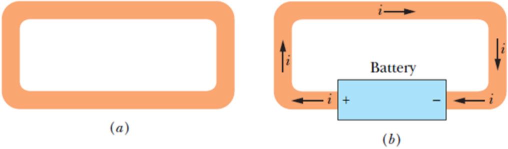


Another way to write this relationship is

$$q = \int dq = \int_0^t i dt'. \tag{2}$$

Electric Current

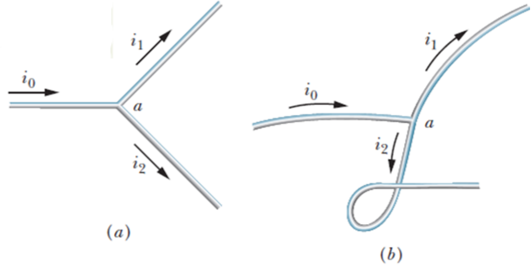
- The unit of current is the ampere (A)
- 1 A = 1 C/s = 1 coulomb per second
- Current can be thought of as a stream of moving positive charges



- In actuality, the electrons move the opposite way
- This is the *bulk motion*, and is actually very slow
- The microscopic motion is much faster
- Electrons bounce around randomly at $\approx$100 m/s

Electric Current

Charge is conserved, so *current* is conserved:

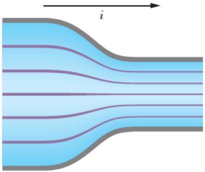


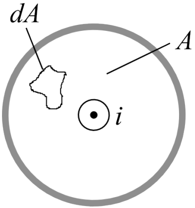
$$i_0 = i_1 + i_2 \tag{3}$$

- The orientation of the conductors is irrelevant

Electric Current

What if the size of the conductor changes?





- The current does not change (charge is conserved)
- Therefore, the *density* of current changes
- Current density: $J = i/A$ (A/m^2)
- Non-uniform current density:

$$i = \int J\, dA \tag{4}$$

Electric Current

Lecture Question 9.1

When lightning strikes, the current flows from the ground upward to the clouds above. What is the direction of the electric field of the lightning?

(a) upward

(b) downward

(c) perpendicular to the current at every point

(d) parallel to the ground

Resistance

Resistance slows down the motion of charge

(think: friction)

- Definition: $R = V/i$
- Apply a voltage V, get a current i
- Unit of R: 1 ohm $= 1\ \Omega = 1$ V/A
- Bigger R means we need bigger V for same i
- Bigger R means we get smaller i for same V

Resistance

Can we predict the resistance of a particular object?

- Let's define **resistivity** as $\rho = E/J$.
- We apply an elecric field, we get a current density
- Units: Ωm.
- Bigger ρ means smaller currents.
- This is a property of the *material*
- **Resistance** is a property of an *object*
- How are they related?

Resistance

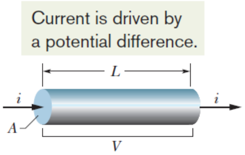


Fig. 26-9 A potential difference V is applied between the ends of a wire of length L and cross section A, establishing a current i.

Can we predict the resistance of this object?

- The resitance: $R = V/i$
- The voltage: $V = EL$
- The current density: $J = i/A$
- The *resistivity*:

$$\rho = \frac{E}{J} = \frac{V/L}{i/A} = \frac{V}{i}\frac{A}{L} = R\frac{A}{L} \tag{5}$$

Resistance

Or, solving for R,

$$R = \rho \frac{L}{A} \tag{6}$$

- We can find the resistance of a wire if we know its
  - **(a)** composition (i.e., ρ)
  - **(b)** length
  - **(c)** cross-sectional area
- Resistivity ρ is more general than resistance R

Resistance

Table 26-1

Resistivities of Some Materials at Room Temperature (20°C)

Material	Resistivity, ρ $(\Omega \cdot m)$	Temperature Coefficient of Resistivity, α (K^{-1})
	Typical Metals	
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	4.3×10^{-3}
Gold	2.35×10^{-8}	4.0×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Manganin[a]	4.82×10^{-8}	0.002×10^{-3}
Tungsten	5.25×10^{-8}	4.5×10^{-3}
Iron	9.68×10^{-8}	6.5×10^{-3}
Platinum	10.6×10^{-8}	3.9×10^{-3}
	Typical Semiconductors	
Silicon, pure	2.5×10^{3}	-70×10^{-3}
Silicon, *n*-type[b]	8.7×10^{-4}	
Silicon, *p*-type[c]	2.8×10^{-3}	
	Typical Insulators	
Glass	$10^{10} - 10^{14}$	
Fused quartz	$\sim 10^{16}$	

Lecture Question 9.2

When a potential difference is applied to a copper wire, a current of 1.5 A passes through the wire. If the wire was removed from the circuit and replaced with an identical copper wire but with twice the diameter, what current would flow through the new wire?

(a) 0.38 A

(b) 0.75 A

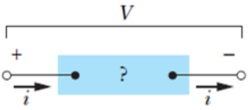
(c) 1.5 A

(d) 3.0 A

(e) 6.0 A

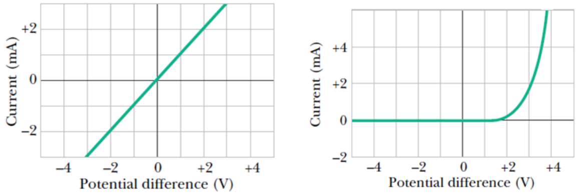
Ohm's Law

Ohm's Law is an assertion that the current through a device is *always* directly proportional to the potential difference applied to the device.



(a)

- Many devices behave this way.
- We often write this as $V = iR$



(b)

(c)

Ohm's Law

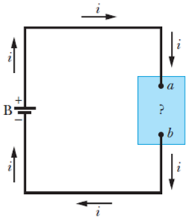
$$V = iR \tag{7}$$

Key Ideas:

- The resistance R tells us the current response of the system.
- Viewed another way, the resistance R tells us how much the potential drops as charge move through the system.

Power

Power is the rate of energy transfer



- When charge Δq moves through the circuit, its potential changes by V
- But $\Delta q = i\Delta t$
- So $\Delta U = (\Delta q)V = (i\Delta t)V$
- Or,

$$P = \frac{\Delta U}{\Delta t} = iV \tag{8}$$

Power

What is the power through a resistor?

- $P = iV$ in general
- Voltage drop across a resistor: $V = iR$
- Power dissipated by a resistor:

$$P = i^2 R = V^2/R \tag{9}$$

- Each version has R.
- The units of power are watts, W.

Semiconductors and Superconductors

Not all materials conduct charge in the same way

- Semiconductors have a very high resistivity
  - made of an insulator with small impurities
  - the process is called "doping"
- Superconductors have no resistivity
  - usually only work at low temps (about -450°F)
  - this is a quantum effect

Lecture Question 9.4

The insulated wiring in a house can safely carry a maximum current of 18 A. The electrical outlets in the house provide an alternating voltage of 120 V. A space heater when plugged into the outlet operates at an average power of 1500 W. How many space heaters can safely be plugged into a single electrical outlet and turned on for an extended period of time?

(a) zero

(b) one

(c) two

(d) three

(e) four