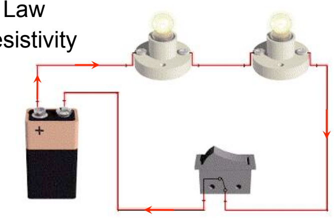
PHY132H1F Introduction to Physics II
Class 14 – **Outline:**

- Motion of charge carriers in a wire
- Electron density, mean time between collisions for electrons in a solid
- Electric current $I = dQ/dt$
- Kirchhoff's Junction Law
- Conductivity and Resistivity
- Resistance
- Ohm's Law



Quick Ch. 31 reading quiz..

The electron drift speed in a typical current-carrying metal wire is

A. about 10^{-4} m/s (less than 1 metre per hour)
B. about 1 m/s (slow walking speed)
C. about 10^4 m/s (greater than speed of sound)
D. 3×10^8 m/s (the speed of light)

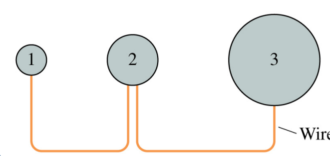
In Class Discussion Question

Why does the light in a room come on almost instantly when you flip a switch several meters away?

A. Electrons travel at the speed of light through the wire.
B. The wire between the switch and the bulb is already full of electrons. Starting the flow of electrons from the switch into the wire almost immediately causes electrons to flow from the other end of the wire into the lightbulb.
C. The switch sends a radio signal which is received by a receiver in the light which tells it to turn on.
D. Optical fibers connect the switch with the light, so the light travels from switch to the light at the speed of light in an optical fiber.

In class discussion question

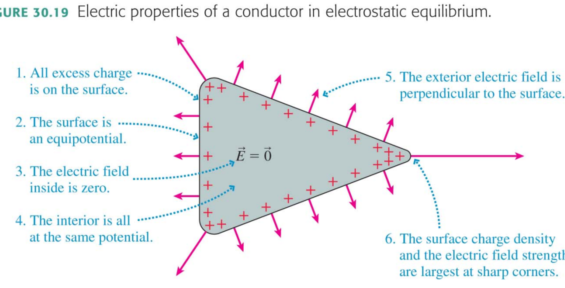
Three charged, metal spheres of different radii are connected by a thin metal wire. The potential and electric field at the surface of each sphere are *V* and *E*. Which of the following is true?



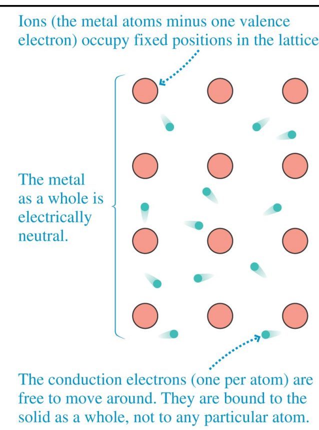
A. $V_1 = V_2 = V_3$ and $E_1 > E_2 > E_3$
B. $V_1 > V_2 > V_3$ and $E_1 = E_2 = E_3$
C. $V_1 = V_2 = V_3$ and $E_1 = E_2 = E_3$
D. $V_1 > V_2 > V_3$ and $E_1 > E_2 > E_3$
E. $V_3 > V_2 > V_1$ and $E_1 = E_2 = E_3$

Charge in a conductor tends to flow very quickly until it comes into equilibrium…

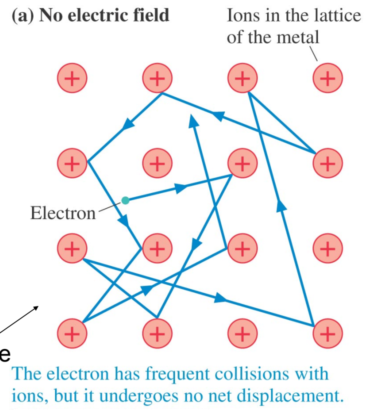
FIGURE 30.19 Electric properties of a conductor in electrostatic equilibrium.



Inside an electrical conductor:

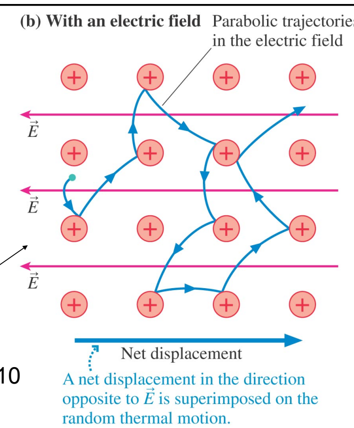


Inside an electrical conductor:

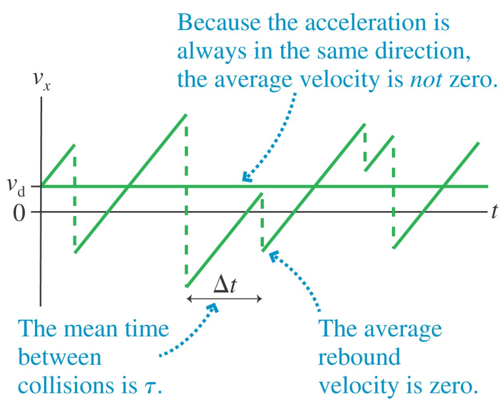


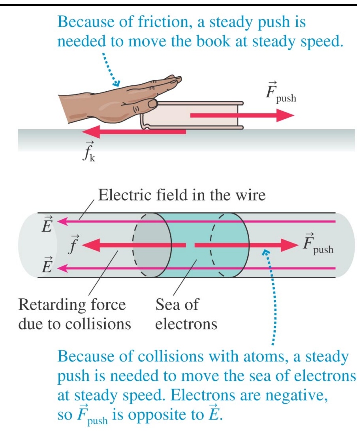
The overall average or "Drift" velocity is zero!

Inside an electrical conductor:



The overall average or "Drift" velocity is opposite to the electric field, about 10 to 100 cm/hour





Creating a Current

The average speed at which the electrons are pushed along by an electric field is

$$v_d = \frac{e\tau}{m}E$$

Where τ is the mean time between collisions, and m is the mass of the electron.

The electron current is then

$$i_e = \frac{n_e e\tau A}{m}E$$

Definition of Current

If Q is the total amount of charge that has moved past a point in a wire, we define the current I in the wire to be the rate of charge flow:

$$I \equiv \frac{dQ}{dt}$$ current is the *rate* at which charge flows

The SI unit for current is the coulomb per second, which is called the **ampere**. 1 ampere = 1 A = 1 C/s.

The Current Density in a Wire

The **current density** J in a wire is the current per square meter of cross section:

$$J = \text{current density} \equiv \frac{I}{A} = n_e e v_d$$

The current density has units of A/m^2.

Recall: Kirchhoff's Loop Law

For any path that starts and ends at the same point

$$\Delta V_{\text{loop}} = \sum_i (\Delta V)_i = 0$$

Stated in words, **the sum of all the potential differences encountered while moving around a loop or closed path is zero.**
This statement is known as **Kirchhoff's loop law.**

(The meaning is simply that **electric potential** is a property of *space*; it doesn't matter how you got there.)

Kirchhoff's Junction Law

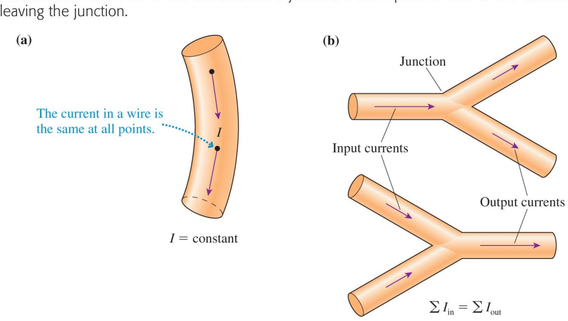
Law of conservation of current The current is the same at all points in a current-carrying wire.

For a *junction*, the law of conservation of current requires that

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

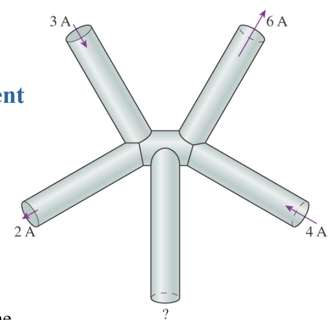
where the Σ symbol means summation.
This basic conservation statement – that the sum of the currents into a junction equals the sum of the currents leaving – is called **Kirchhoff's junction law**.

FIGURE 31.18 The sum of the currents into a junction must equal the sum of the currents leaving the junction.



In Class Discussion Question

What are the magnitude and the direction of the current in the fifth wire?



A. 15 A into the junction
B. 15 A out of the junction
C. 1 A into the junction
D. 1 A out of the junction
E. Not enough data to determine

Conductivity and Resistivity

The conductivity of a material is

$$\sigma = \text{conductivity} = \frac{n_e e^2 \tau}{m}$$

Conductivity, like density, characterizes a material as a whole.
The current density J is related to the electric field E by:

$$J = \sigma E$$

The resistivity tells us how reluctantly the electrons move in response to an electric field:

$$\rho = \text{resistivity} = \frac{1}{\sigma} = \frac{m}{n_e e^2 \tau}$$

TABLE 31.2 Resistivity and conductivity of conducting materials

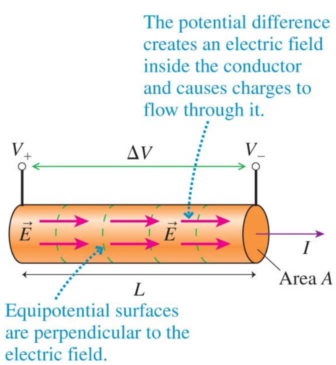
Material	Resistivity (Ω m)	Conductivity (Ω^{-1} m^{-1})
Aluminum	2.8×10^{-8}	3.5×10^{7}
Copper	1.7×10^{-8}	6.0×10^{7}
Gold	2.4×10^{-8}	4.1×10^{7}
Iron	9.7×10^{-8}	1.0×10^{7}
Silver	1.6×10^{-8}	6.2×10^{7}
Tungsten	5.6×10^{-8}	1.8×10^{7}
Nichrome*	1.5×10^{-6}	6.7×10^{5}
Carbon	3.5×10^{-5}	2.9×10^{4}

*Nickel-chromium alloy used for heating wires.

Superconductors

- In 1911, it was discovered that certain materials (ie lead and niobium) suddenly and dramatically lose *all* resistance to current when cooled below about 5 to 10 degrees above absolute zero. Resistivity = 0!
- In 1986, high-temperature superconductors were discovered (such as $YBa_2Cu_3O_7$), which can superconduct at temperatures below 125 Kelvin (−150 C).
- Superconductors also have a property of expelling magnetic fields; this makes them repel nearby permanent magnets, allowing them to float.

FIGURE 31.19 The current I is related to the potential difference ΔV.



Resistance and Ohm's Law

The resistance of a long, thin conductor of length L and cross=sectional area A is

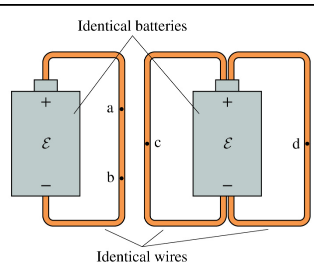
$$R = \frac{\rho L}{A}$$

The SI unit of resistance is the ohm. 1 ohm = 1 Ω = 1 V/A. The current through a conductor is determined by the potential difference ΔV along its length:

$$I = \frac{\Delta V}{R} \qquad \text{(Ohm's law)}$$

In Class Discussion Question

A wire connects the positive and negative terminals of a battery. Two identical wires connect the positive and negative terminals of an identical battery. Rank in order, from largest to smallest, the currents I_a to I_d at points a to d.



A. $I_c = I_d > I_a > I_b$
B. $I_a = I_b > I_c = I_d$
C. $I_c = I_d > I_a = I_b$
D. $I_a = I_b = I_c = I_d$
E. $I_a > I_b > I_c = I_d$

Before Next Class:

- Try all the suggested end-of-chapter problems for Chapter 31, posted on the Materials part of the web-site.
- Please read Chapter 32, sections 32.1 to 32.4 before Wednesday's class.

See you Wednesday!