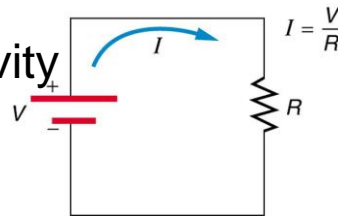


PHY132 Introduction to Physics II  
Class 15 – **Outline:**

- 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



Helen Meyertholen  
was born Mar. 1, 2014

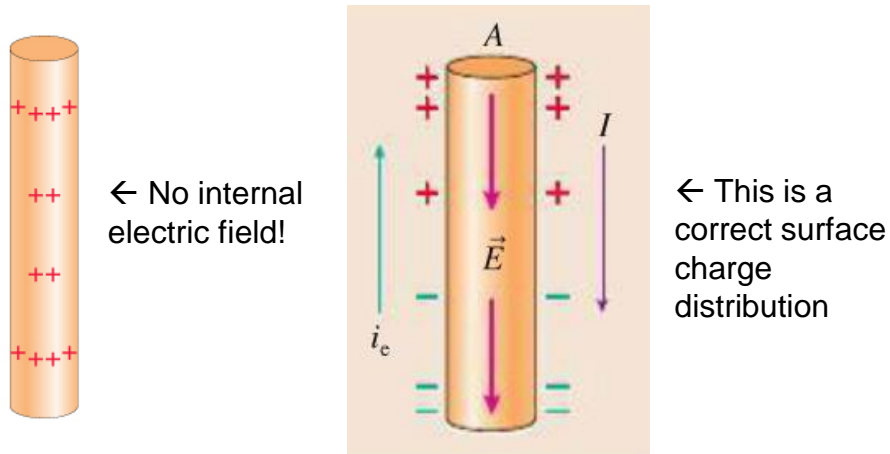


**Class 15 Preclass Quiz on MasteringPhysics**

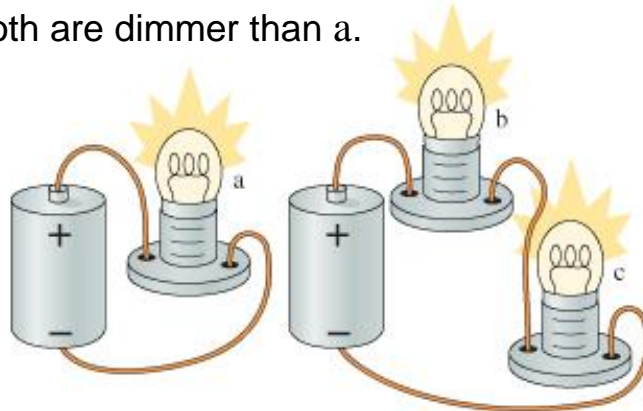
- The electron drift speed in a wire is exceedingly slow—typically only a fraction of a millimeter per second. Yet when you turn on a flashlight switch, the light comes on almost instantly. Resolve this apparent paradox.
- Best student answer courtesy of Jaisie:
- *“Light can come on almost instantly because the components of the circuit in the flashlight already contain electrons. When the flashlight switch is turned on, the electric field created push on the electrons that are already in the circuit to progress through the circuit almost instantaneously. As a result, electrons will enter the lightbulb of the flashlight almost instantly, causing the light to come on almost instantly.”*

## Class 15 Preclass Quiz on MasteringPhysics

- 72% got: The surface charge distribution for a current-carrying wire shown is **not** possible.



- 80% got: a is brightest. b and c have the same brightness; both are dimmer than a.



- Best student answer courtesy of Xiaotang:
- “for a, the total voltage of the battery is for bulb a alone. however, for b and c, they are sharing voltage, then they are not as bright as a. since all bulbs are the same, b and c have the same brightness”*

## Class 15 Preclass Quiz – Student Comments...

- *“Why a lightbulb does NOT use up current in a circuit?”*
- **Harlow answer:** Current is the motion of electric charge. If there was a different amount of current going into the bulb as going out of the bulb, it would quickly get a static charge build-up! It is the **voltage** that is used up in a lightbulb, not the current.
- *“What is the difference between resistivity and resistance?”*
- **Harlow answer:** Resistance is for a particular **object** (resistor). Resistivity is for a particular **material**. Also, the units are different.

## Class 15 Preclass Quiz – Student Comments...

- *“What is the difference between an electron current and current?”*
- **Harlow answer:** Current is what we always use in calculations involving Ohm’s law, series and parallel circuits, etc. It is measured in amps = coulombs/second. “Electron current” is the number of electrons that pass a certain surface per second. It’s used more conceptually in this course.
- *“4. What does it mean that “the direction of current is DEFINED to be the direction in which positive charges seem to move”?”*
- **Harlow answer:** Even if the charge carriers happen to be negative (which they are in a metal) we still define “current” as being the flow of positive charge.

## Class 15 Preclass Quiz – Student Comments...

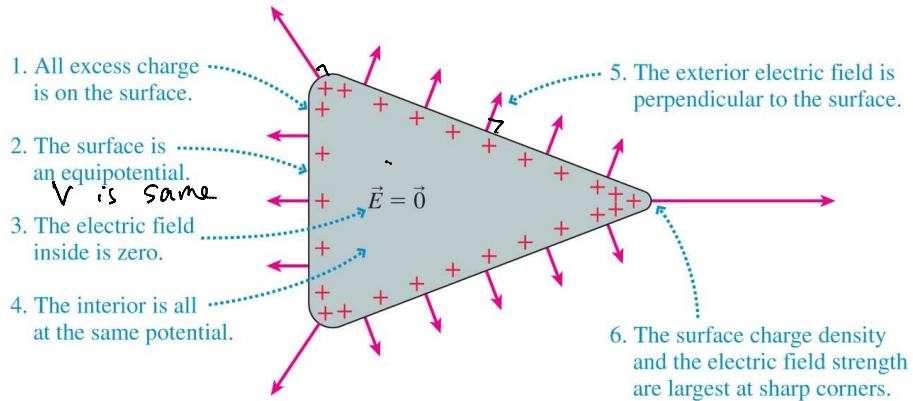
- *“what affects the “brightness” of a bulb, is it V, I, R or a combination of said factors?”*
- **Harlow answer:** Actually it's **power:**  $P = IV$ . More on this next class!

## Class 15 Preclass Quiz – Student Comments...

- Did you have any questions concerning the reading or pre-class video?
- *“Not currently but maybe when I'm a little more amped I will.”*

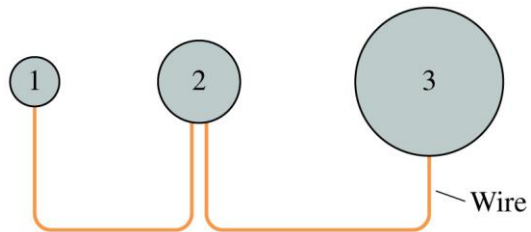
Charge in a conductor tends to flow very quickly until it comes into equilibrium...

FIGURE 30.19 Electric properties of a conductor in electrostatic equilibrium.



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?**

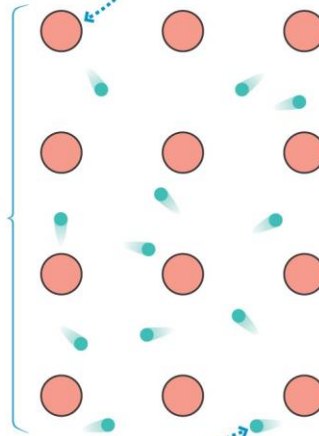


- $V_1 = V_2 = V_3$  and  $E_1 > E_2 > E_3$
- $V_1 > V_2 > V_3$  and  $E_1 = E_2 = E_3$
- $V_1 = V_2 = V_3$  and  $E_1 = E_2 = E_3$
- $V_1 > V_2 > V_3$  and  $E_1 > E_2 > E_3$
- $V_3 > V_2 > V_1$  and  $E_1 = E_2 = E_3$

# Inside an electrical conductor:

Ions (the metal atoms minus one valence electron) occupy fixed positions in the lattice.

The metal as a whole is electrically neutral.

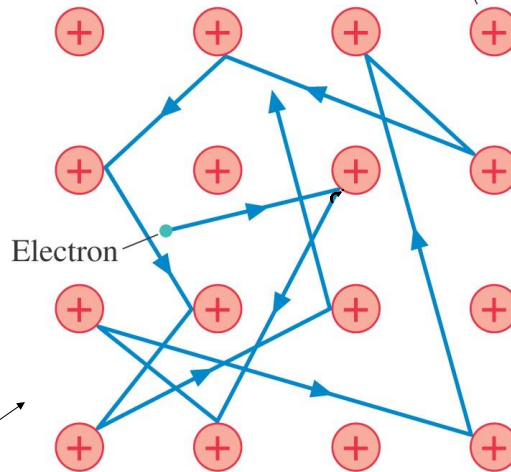


The conduction electrons (one per atom) are free to move around. They are bound to the solid as a whole, not to any particular atom.

# Inside an electrical conductor:

(a) No electric field

Ions in the lattice of the metal

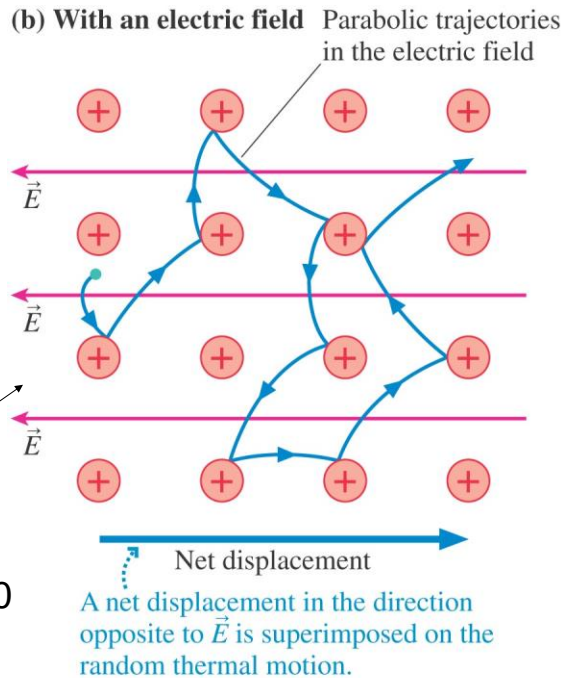


The overall average or "Drift" velocity is zero!

The electron has frequent collisions with ions, but it undergoes no net displacement.

## Inside an electrical conductor:

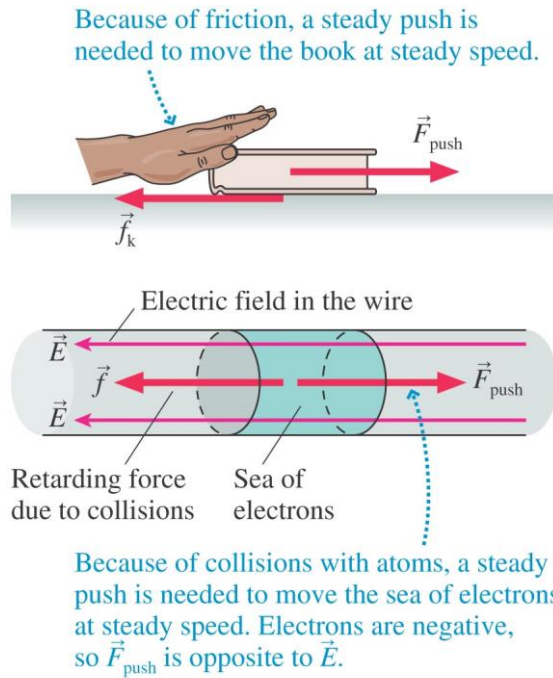
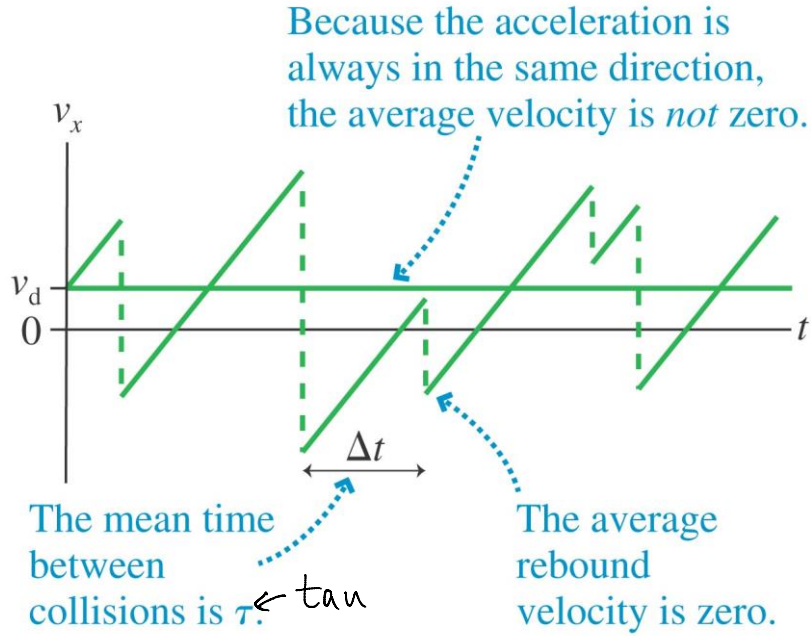
The overall average or "Drift" velocity is opposite to the electric field, about 10 to 100 cm/hour



### 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.





## 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  $\tau$  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:

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

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<sup>2</sup>.

units check:

$$n_e = \left[ \frac{1}{\text{m}^3} \right] \text{ (electrons per volume)}$$

$$e = [C]$$

$$v_d = \left[ \frac{\text{m}}{\text{s}} \right]$$

$$J = \left[ \frac{1}{\text{m}^3} \right] [C] \left[ \frac{\text{m}}{\text{s}} \right] = \frac{C}{\text{s m}^2} = \frac{A}{\text{m}^2}$$

## 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.

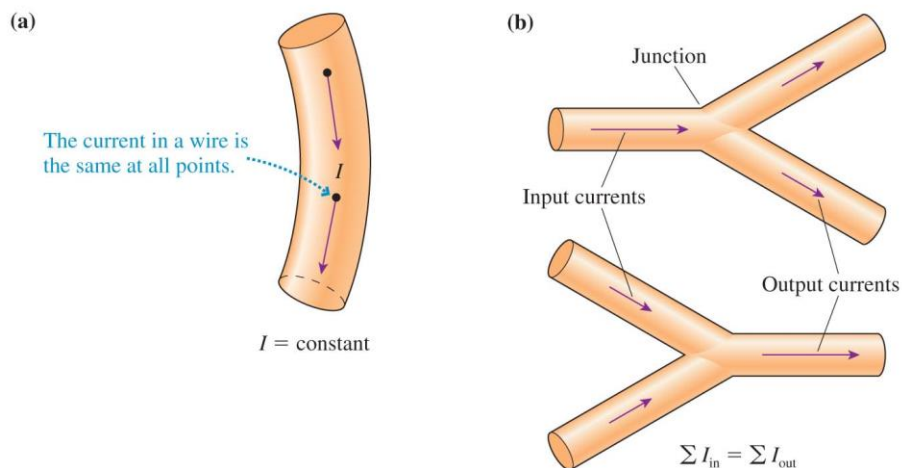
For a *junction*, the law of conservation of current requires that

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

where the  $\Sigma$  symbol means summation.

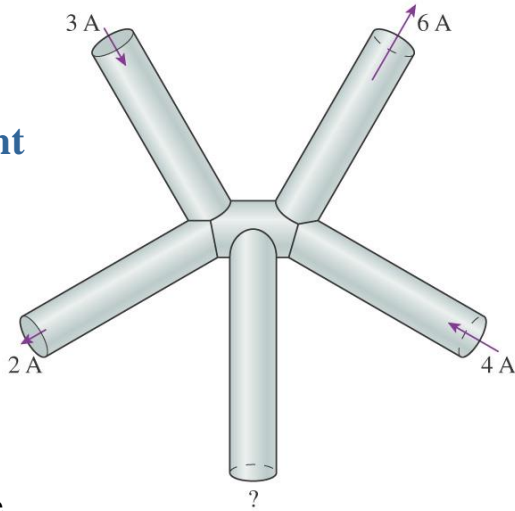
This basic conservation statement – that the sum of the currents into a junction equals the sum of the currents leaving – is called **Kirchhoff's junction law**.

**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:

$$J = \sigma E$$

← like Ohm's law for current density.

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

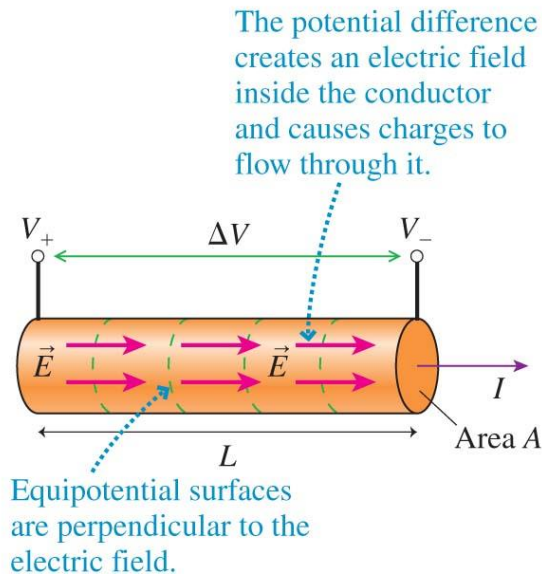
\*Nickel-chromium alloy used for heating wires.

## 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  $\text{YBa}_2\text{Cu}_3\text{O}_7$ ), which can superconduct at temperatures below 125 Kelvin ( $-150 \text{ C}$ ).
- 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  $\Delta V$ .



## Resistance and Ohm's Law

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

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

$R =$  resistance  $\Omega$

$\rho =$  resistivity  $\Omega \cdot m$

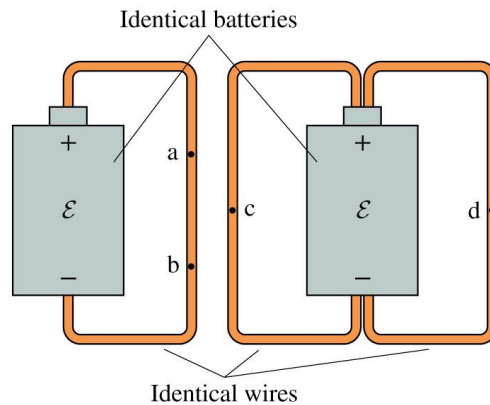
The SI unit of resistance is the ohm.  $1 \text{ ohm} = 1 \Omega = 1 \text{ V/A}$ .

The current through a conductor is determined by the potential difference  $\Delta V$  along its length:

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

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.**



$$\mathcal{E} = \mathcal{E}'$$

- 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.  $I_a > I_b > I_c = I_d$

## Andrew will be back Wednesday

- Please read Chapter 31, first three sections.
- Kirchoff's Laws and the Basic Circuit
- Energy and Electric Power (this is what you pay for from Toronto Hydro!)
- Note: Problem Set 7 is not for marks; it is just practice for the test which is one week from tomorrow.

