Physics 1B

Lecture 17A

"Success is the ability to go from one failure
to another with no loss of enthusiasm."
--Winston Churchill

Capacitors

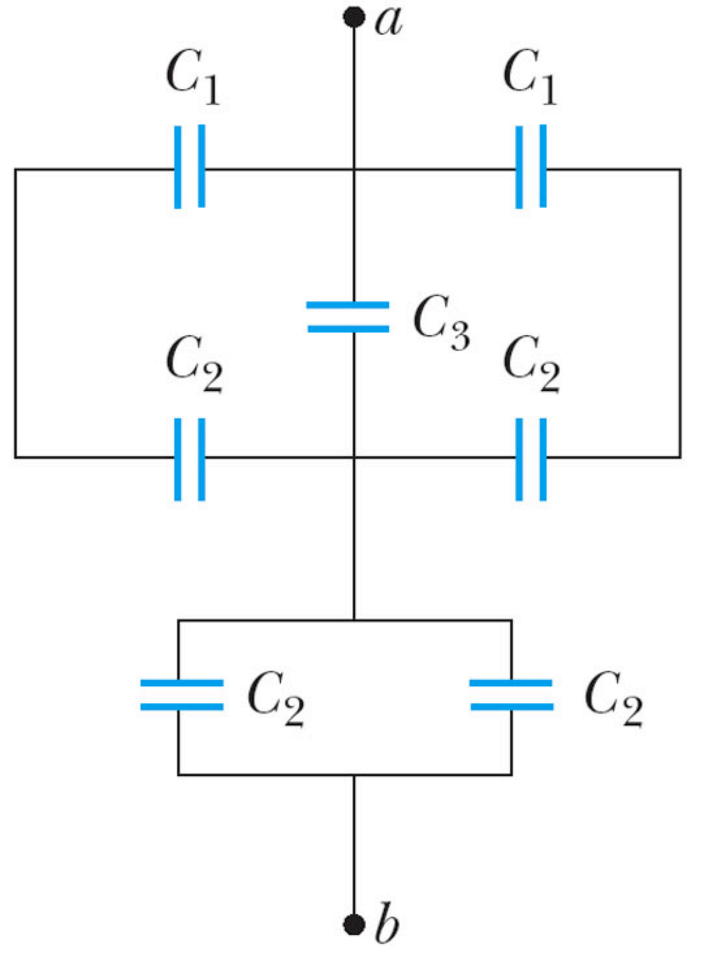
- Capacitors are usually used in circuits.
- A circuit is a collection of objects usually containing a source of electrical energy (like a battery).
- This energy source is connected to elements (like capacitors) that convert the electrical energy to other forms.
- We usually create a circuit diagram to represent all of the elements at work in the real circuit.

Capacitors

- Remember when you have multiple capacitors in a circuit that:
- Capacitors in parallel all have the same potential differences.
- The equivalent capacitance of the parallel capacitors also will have the same potential difference.
- Capacitors in series all have the same charge.
- The equivalent capacitor of the series capacitors also will have the same charge.

Capacitance

- Example
- Find the equivalent capacitance between points a and b in the group of capacitors connected in series as shown in the figure to the right (take C_1=5.00μF, C_2=10.0μF, and C_3=2.00μF).



- Answer
- Reduce the circuit by equivalent capacitance.
- Start with the C_1 and C_2 in series on the top.

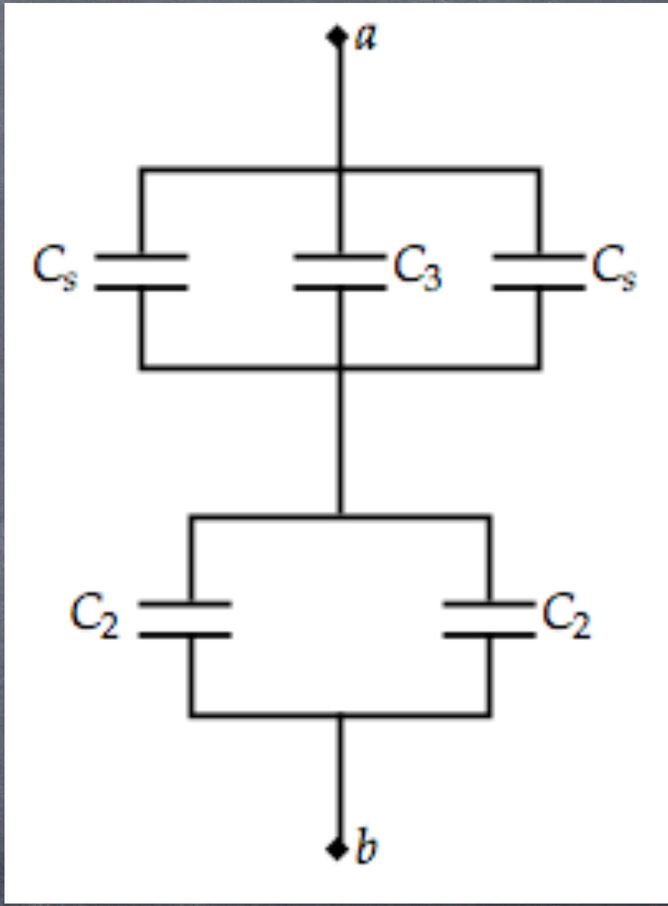
Capacitance

- Answer
- Combine the two top capacitors that are in series (left and right are the same) to form an equivalent C_S:

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{5\mu\text{F}} + \frac{1}{10\mu\text{F}}$$

$$\frac{1}{C_S} = \frac{2}{10\mu\text{F}} + \frac{1}{10\mu\text{F}} = \frac{3}{10\mu\text{F}}$$

$$C_S = \frac{10\mu\text{F}}{3} = 3.33\mu\text{F}$$



- Next, combine the top three that are in parallel:

$$C_{\text{P1}} = C_S + C_3 + C_S$$

$$C_{\text{P1}} = 3.33\mu\text{F} + 2.00\mu\text{F} + 3.33\mu\text{F} = 8.66\mu\text{F}$$

Capacitance

- Answer

- Next, combine the bottom two that are in parallel:

$$C_{P2} = C_2 + C_2$$

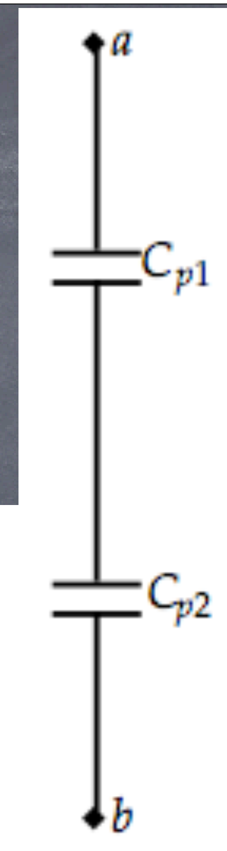
$$C_{P2} = 10.0\,\mu\text{F} + 10.0\,\mu\text{F} = 20.0\,\mu\text{F}$$

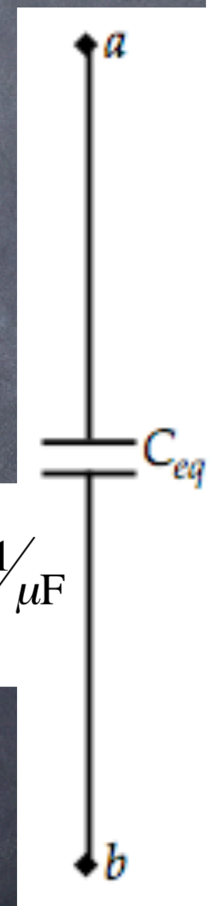
- Finally, combine the remaining two capacitors that are in series:

$$\frac{1}{C_{eq}} = \frac{1}{C_{P1}} + \frac{1}{C_{P2}} = \frac{1}{8.66\,\mu\text{F}} + \frac{1}{20\,\mu\text{F}}$$

$$\frac{1}{C_{eq}} = (0.1155)\,{}^{1}\!/_{\mu\text{F}} + (0.0500)\,{}^{1}\!/_{\mu\text{F}} = (0.1655)\,{}^{1}\!/_{\mu\text{F}}$$

$$C_{eq} = 6.04\,\mu\text{F}$$





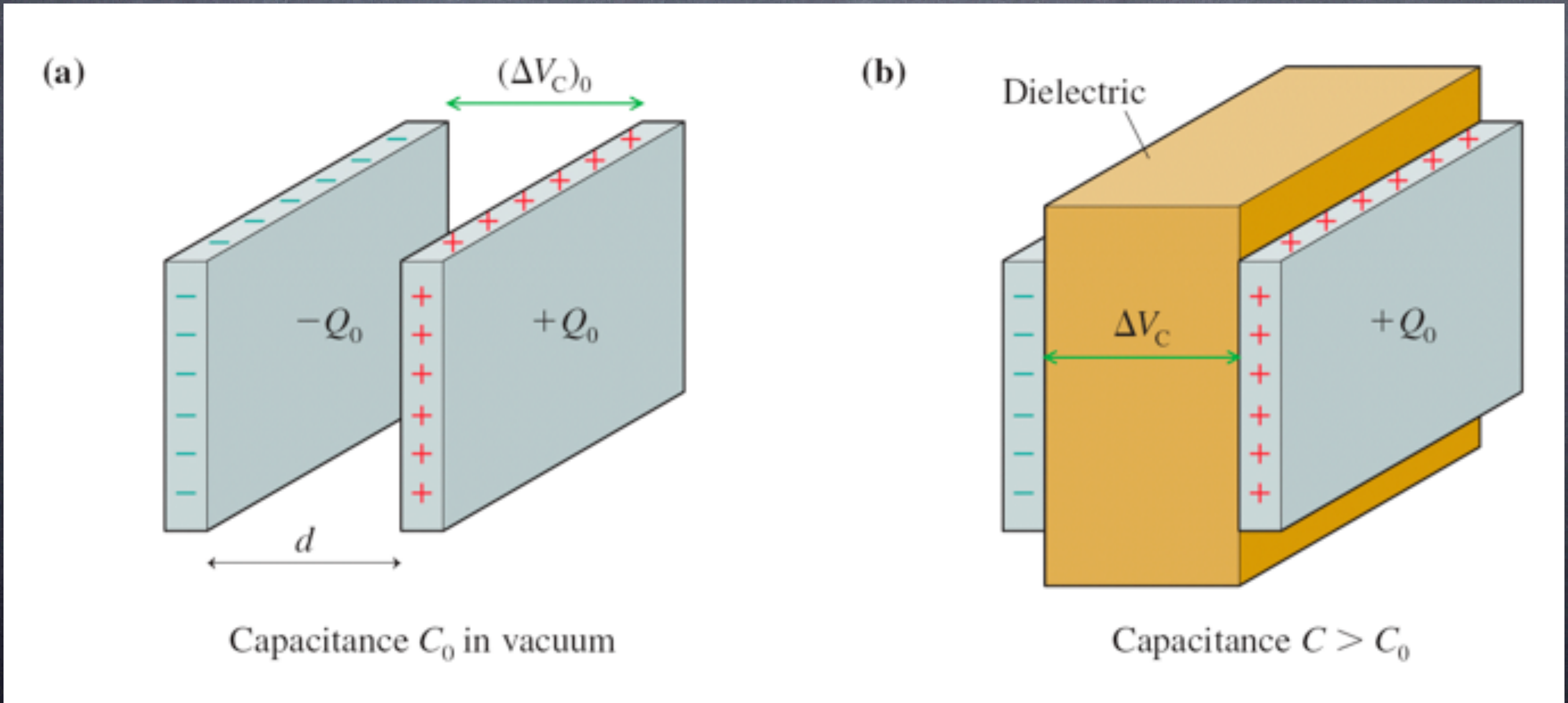
Dielectrics

- The problem with capacitors is that they need to have huge dimensions to carry a significant amount of charge.
- Cost of material and manufacturing become a problem.
- The solution is to substitute an electrically insulating material between the parallel-plates instead of air or a vacuum.
- This is known as a dielectric.
- When inserted into the capacitor the dielectric will increase the overall capacitance.

Dielectrics

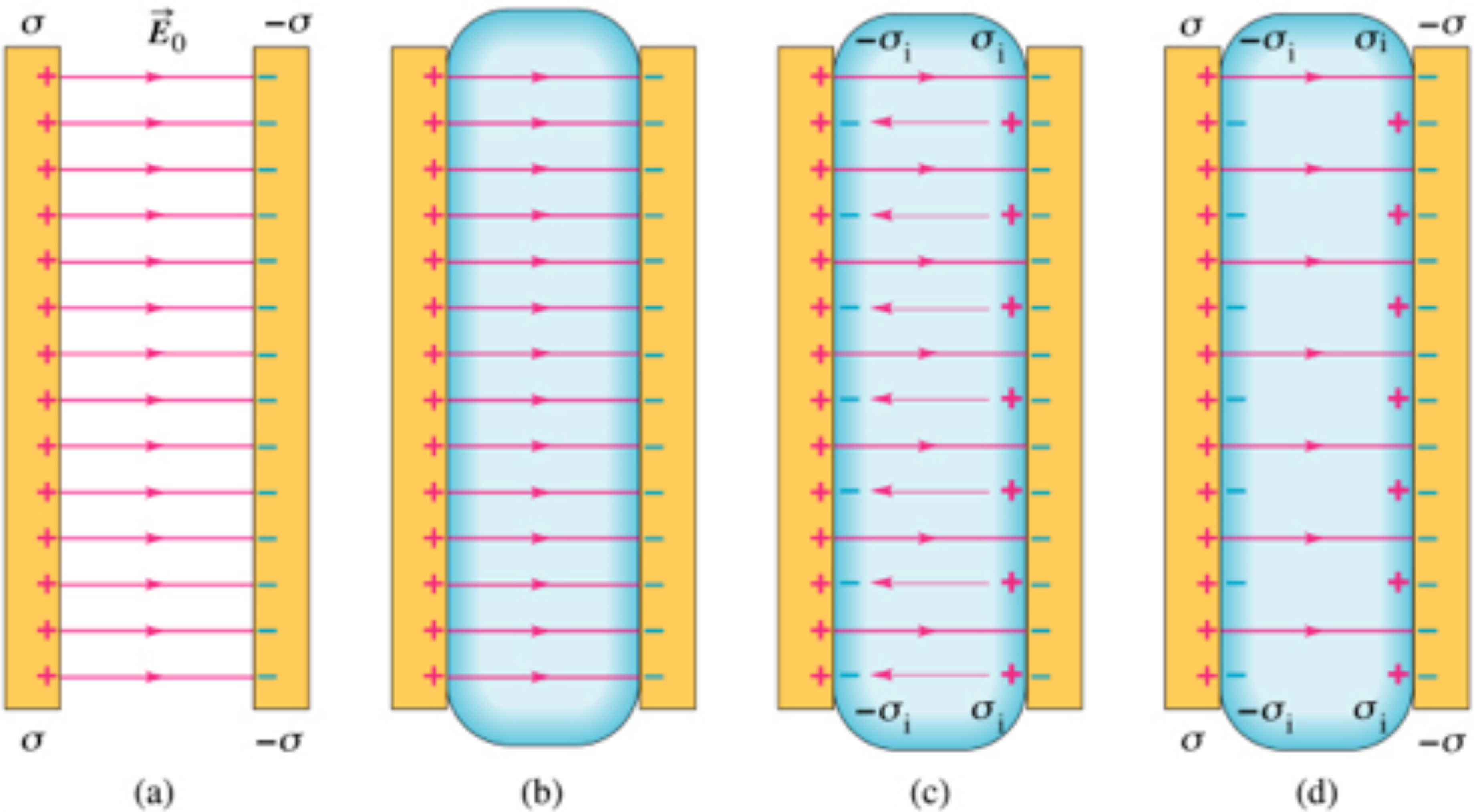
- The dielectric constant, κ, is the ratio of the new capacitance to the capacitance in a vacuum:

$$\kappa = \frac{C_{dielectric}}{C_{vacuum}}$$



Dielectrics

- Easily polarized materials have larger dielectric constants than materials not easily polarized.



Dielectrics

- Filling a capacitor with a dielectric increases the capacitance by a factor equal to the dielectric constant.
- The capacitance for a parallel-plate capacitor changes to:

$$C = \kappa \varepsilon_o \frac{A}{d}$$

  - Common dielectric values:
  - $K_{vacuum} = 1$
  - $K_{air} = 1.0006$
  - $K_{glass} \approx 7$
- Note that the dielectric constant is a unitless variable.

Energy of a Capacitor

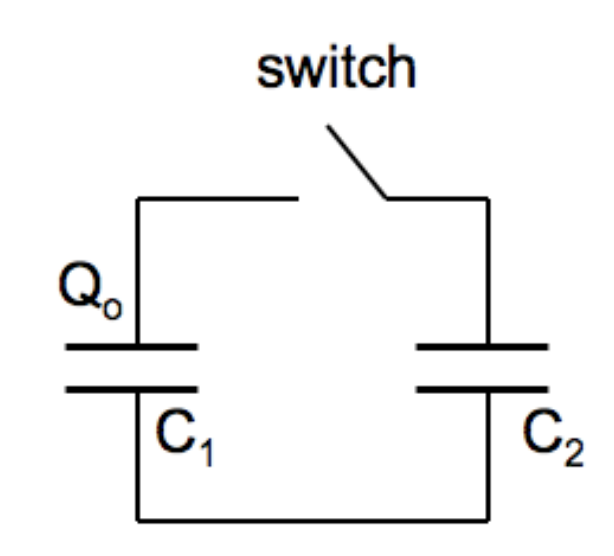
- For any given plate separation, there is a maximum electric field that can be produced in the dielectric before it breaks down and begins to conduct.
- This maximum electric field is called the dielectric strength (measured in N/C).
- The energy stored in a capacitor will be:

$$\text{Energy stored} = \tfrac{1}{2}Q(\Delta V) = \tfrac{1}{2}C(\Delta V)^2 = \frac{Q}{2C}$$

- The main use of a capacitor is to store and then discharge energy.

Capacitance

- Example
- A 3.55μF capacitor (C_1) is charged to a potential difference ΔV_o = 6.30V, using a battery. the charging battery is then removed, and the capacitor is connected to an uncharged 8.95μF capacitor (C_2). After the switch is closed, charge flows from C_1 to C_2 until an equilibrium is established with both capacitors at the same potential difference, ΔV_f. What energy is stored in the two capacitors after the switch has been closed?



- Answer
- Usually no coordinate system needs to be defined for a capacitor (start with the original charge amount Q_o.)

Capacitance

- <u>Answer</u>
- The original charge, Q_o, shared by the two capacitors is:

$$Q_o = Q_1 + Q_2$$

- Next, turn to the definition of capacitance: $C = \dfrac{Q}{\Delta V}$

- Substituting back into our charge equation gives us:

$$C_1(\Delta V_o) = C_1(\Delta V_1) + C_2(\Delta V_2)$$

- But we know the final potential difference is the same between the two capacitors:

$$\Delta V_1 = \Delta V_2 = \Delta V_f$$

$$C_1(\Delta V_o) = C_1(\Delta V_f) + C_2(\Delta V_f) = (C_1 + C_2)\Delta V_f$$

Capacitance

- Answer
- Solving for ΔV_f gives us:

$$\Delta V_f = \frac{C_1(\Delta V_o)}{(C_1 + C_2)}$$

$$\Delta V_f = \frac{3.55\mu\text{F}(6.30\text{V})}{(3.55\mu\text{F} + 8.95\mu\text{F})} = 1.79\text{V}$$

- Putting this common potential difference into the energy equation gives us:

$$E_{Tot} = E_1 + E_2$$

$$E_{Tot} = \tfrac{1}{2}C_1(\Delta V_f)^2 + \tfrac{1}{2}C_2(\Delta V_f)^2$$

$$E_{Tot} = \tfrac{1}{2}(C_1 + C_2)(\Delta V_f)^2$$

$$E_{Tot} = \tfrac{1}{2}(3.55\mu\text{F} + 8.95\mu\text{F})(1.79\text{V})^2 = 20.0\mu\text{J}$$

Current

- Up until now, we have dealt with electrostatics (i.e. charges that do not move).

- We now define electric current, I, to be the rate at which electric charge passes through a surface or volume.

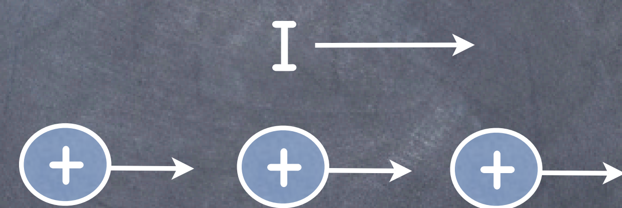
$$I \equiv \frac{\Delta Q}{\Delta t}$$

- The SI unit for current is the Ampere.

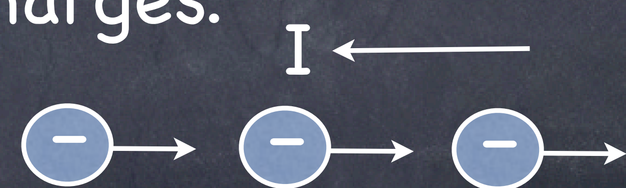
$$[\text{Ampere}] = \frac{[\text{Coulomb}]}{[\text{second}]}$$

Current

- What causes electric current to flow?
- An electric potential difference, usually created by some sort of battery. The battery uses chemical energy to create ΔV.
- Current is defined as positive charges moving in a certain direction.



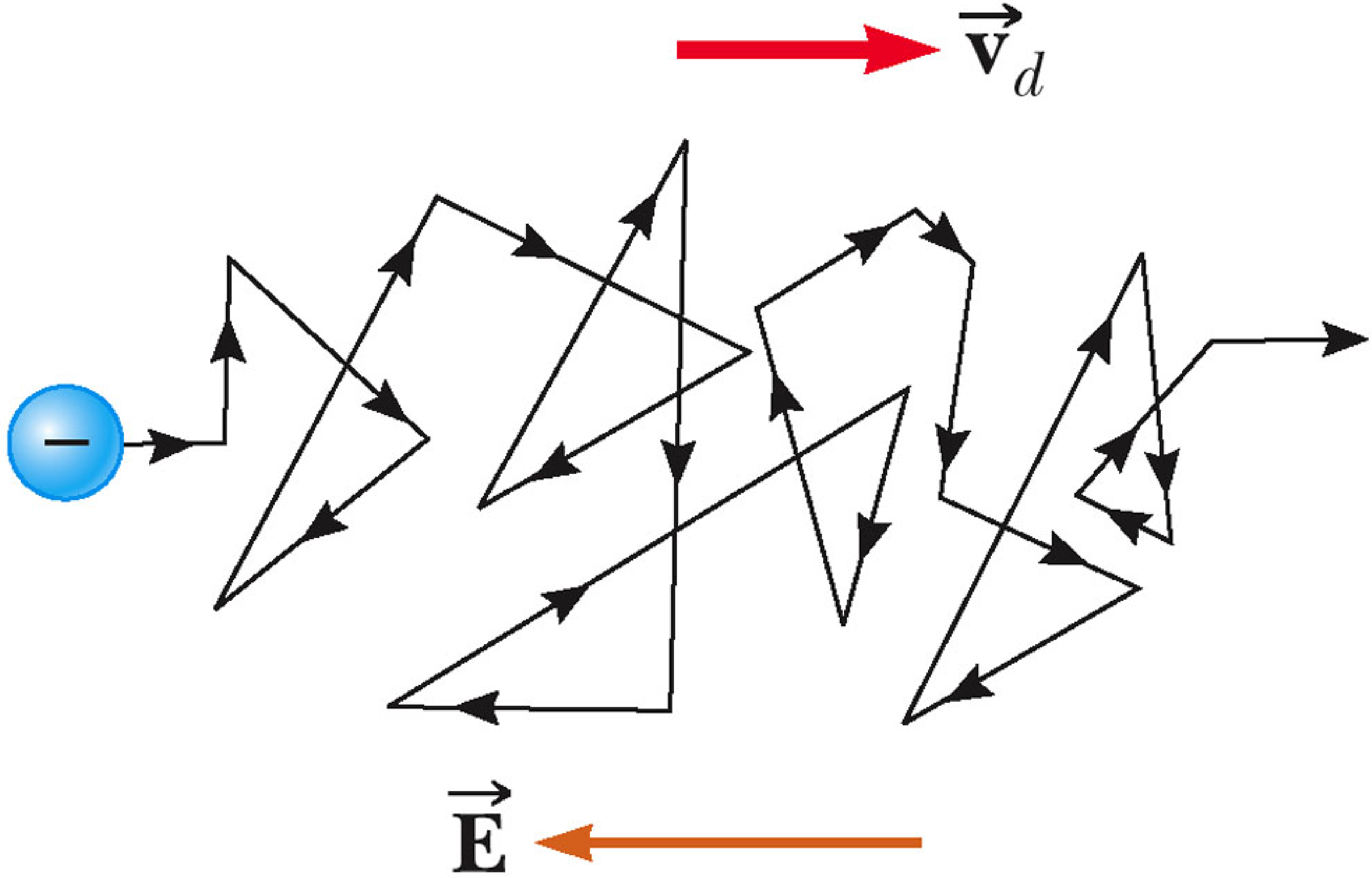
- If negative charges are actually moving, then current is defined as moving opposite to the motion of the negative charges.



Current

- What physically flows through wires: positive charges or negative charges?
- It is the tiny electrons that move in the wire. They move more easily than the massive protons.
- But due to historical reasons, we use positive current when performing calculations.
- How fast do electrons move in a wire under current flow?
- Not fast at all, electrons move about 0.5mm/s in a conducting wire.

Current



Current

- If electrons move so slowly, then why do lights turn on exactly when I hit the switch?
- The electron at the switch isn't the one that will give energy to the lights.
- When you turn on a light switch you are establishing an electric field that moves all the free electrons in the wire circuit.
- You need a closed loop with the wire. An open loop means no electric field and no current flow. This is known as an open circuit.

For Next Time (FNT)

- Finish reading Chapter 17
- Keep working on the homework for Chapter 16