Physics 112

Chapter 16 Electric Potential Energy and Capacitance

You may ignore

- 16.8, 16.9, 16.10

Potential Energy

- The concept of potential energy is useful in the study of electricity.
- A potential energy function can be defined corresponding to the electric force.
- Electric potential can also be defined.
- The concept of potential relates to circuits.

Work Energy Theorem

- The change in the kinetic energy of an object equals the work done on the object
- For a conservative force (which the electric force is) the work done is -ΔPE

$$W_{done} = \Delta KE = -\Delta PE = PE_i - PE_f$$

- Let's use gravity as an example
  - Positive work denotes an increase in kinetic energy, negative work, a decrease
  - Does an object gain or loose kinetic energy when dropped/raised? The Electric potential works the same way (almost, two signs)

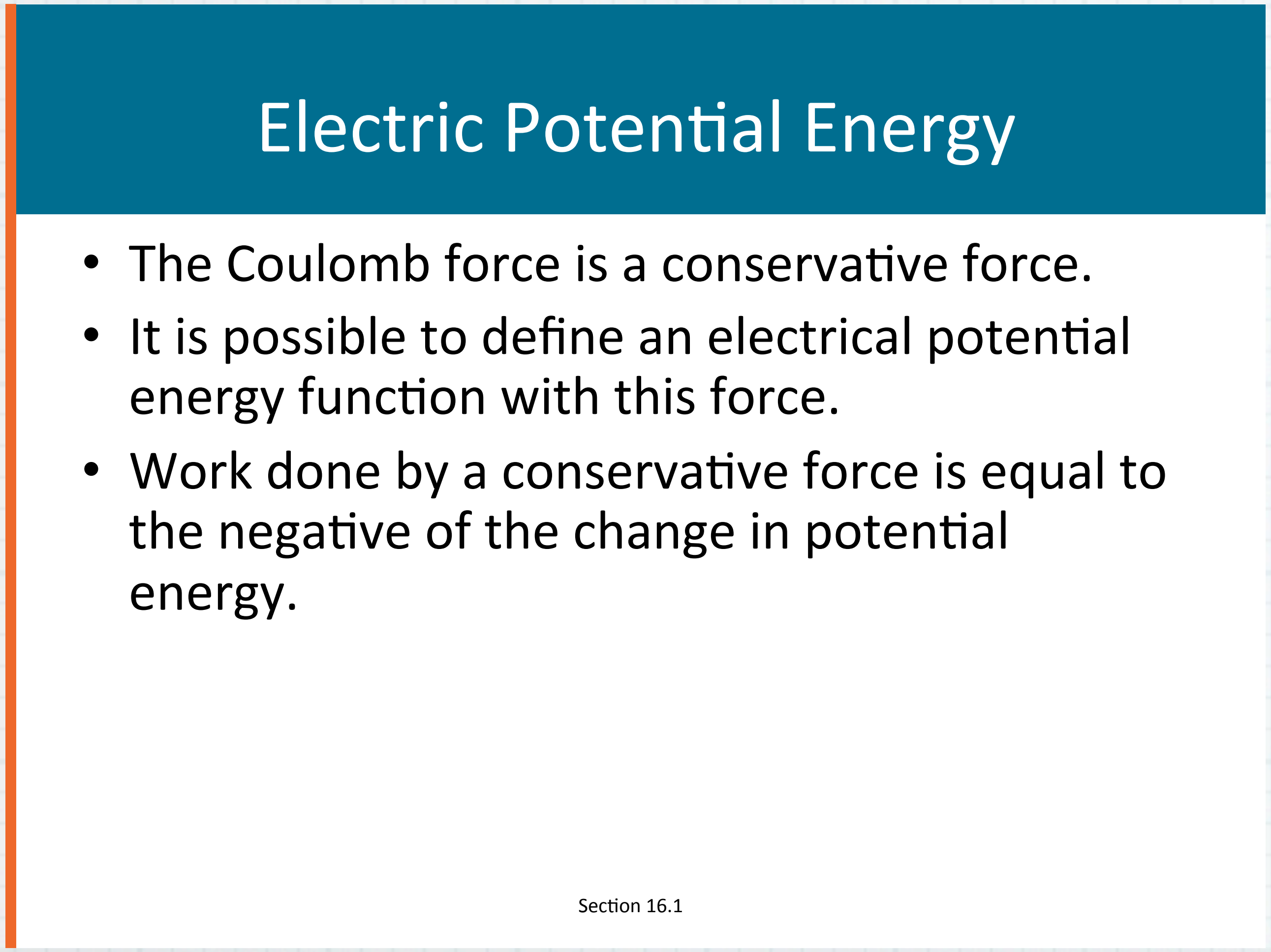
You either

- Put energy in to an object to move it against a potential or get energy out of the potential
- Think raising or dropping a weight, in which case do you have to do work against gravity?

The total energy

- In the case of conservative potentials is conserved or

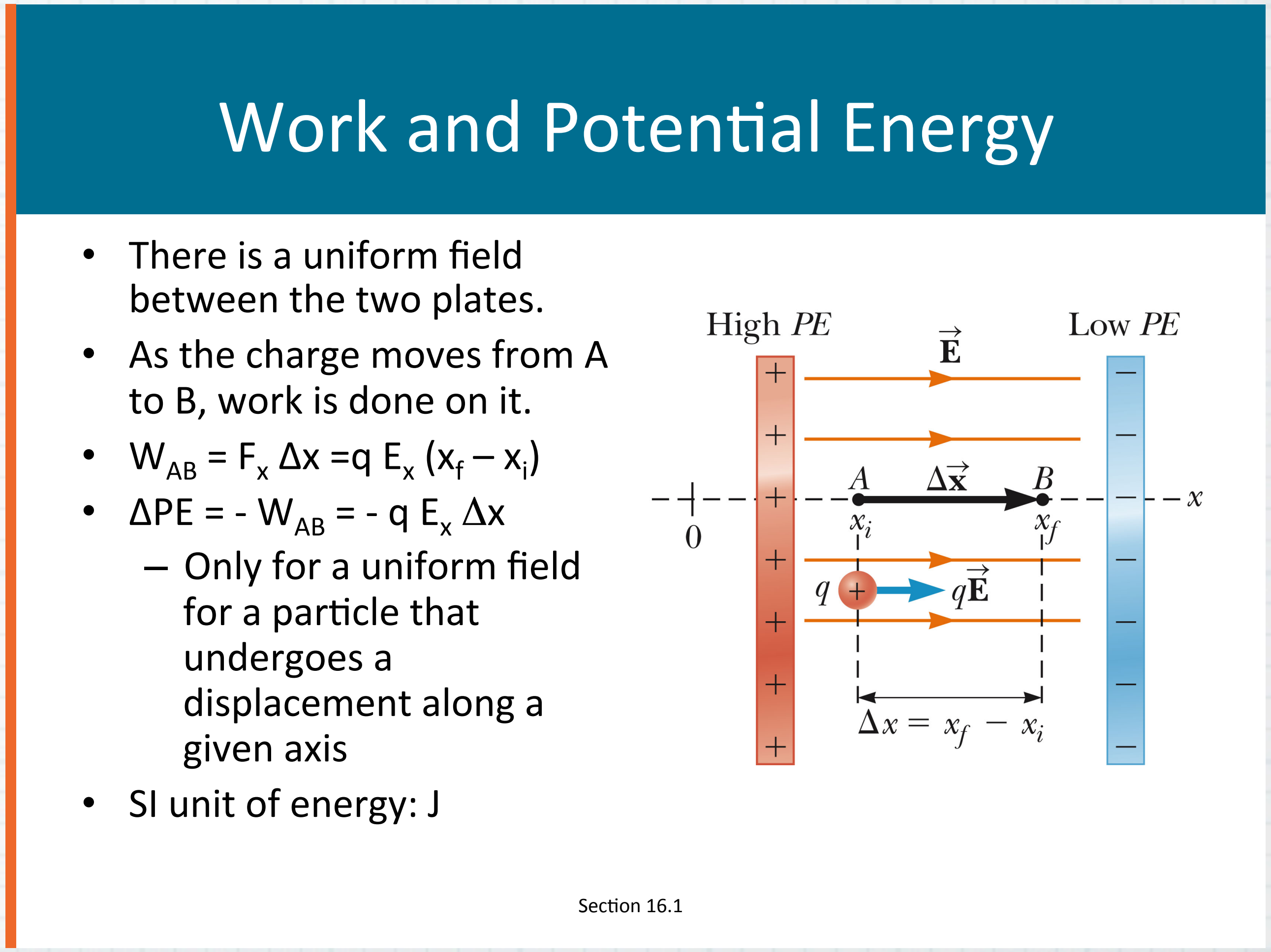
$$E_i = E_f \rightarrow \Delta KE + \Delta PE = 0$$



Electric Potential Energy

- The Coulomb force is a conservative force.
- It is possible to define an electrical potential energy function with this force.
- Work done by a conservative force is equal to the negative of the change in potential energy.

Section 16.1



Work and Potential Energy

- There is a uniform field between the two plates.
- As the charge moves from A to B, work is done on it.
- $W_{AB} = F_x \Delta x = q E_x (x_f - x_i)$
- $\Delta PE = - W_{AB} = - q E_x \Delta x$
  - Only for a uniform field for a particle that undergoes a displacement along a given axis
- SI unit of energy: J

Section 16.1

★ Let us take stock

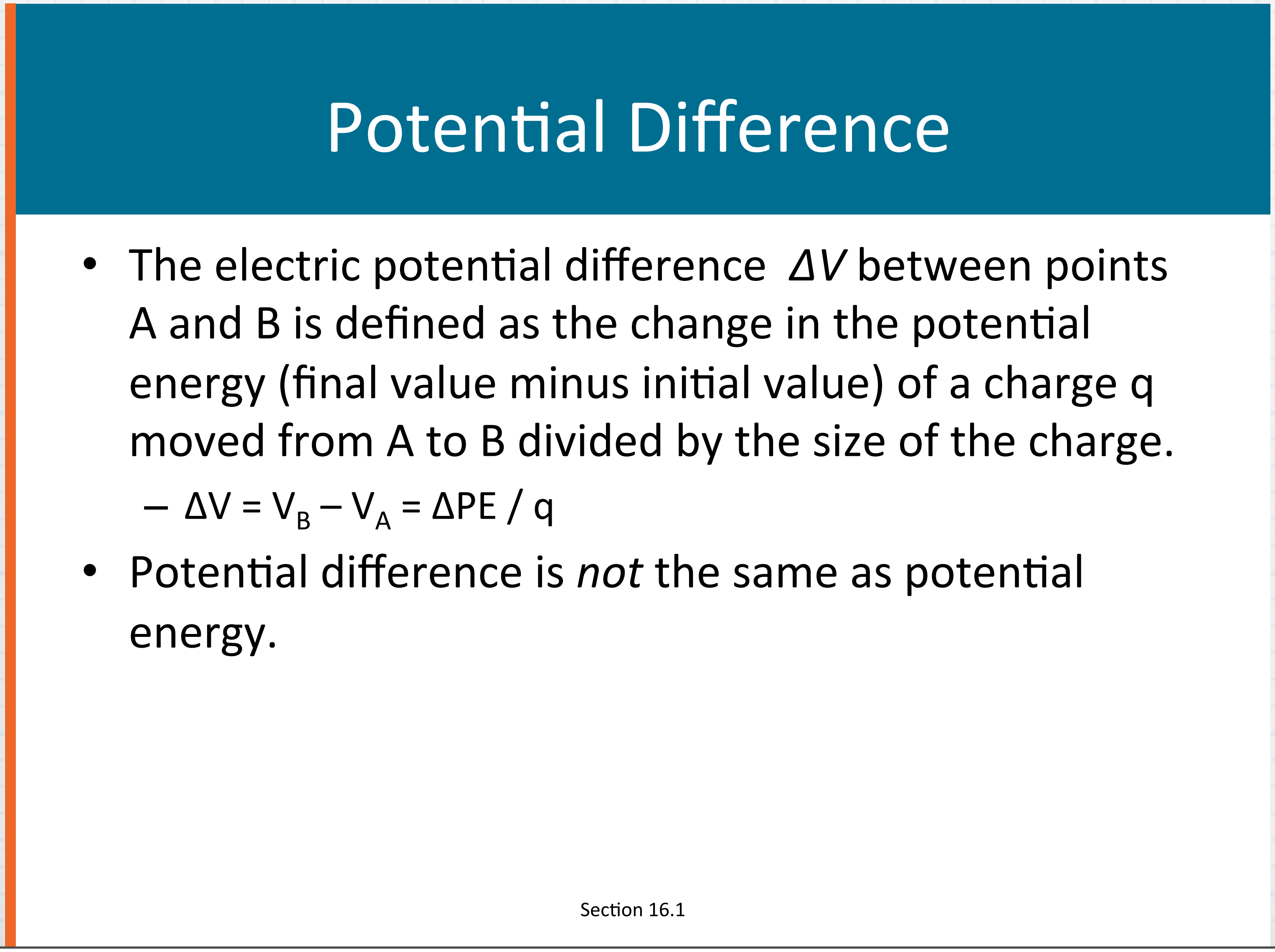
★ Regions of high to low potential energy point in the direction a positively charged particle would move

★ Drop a proton in a region of high potential and it moves towards regions of lower potential

- Positively charged particles move from high to low potential energy thus gaining kinetic energy from the electric field
- Negatively charged particles move from regions of low potential to high potential
- If this is reversed then work must be done AGAINST the potential
- If you want to move a positively charged object from low to high you must do work against the potential therefore the particle slows down
- If you want to move a positively charged object from low to high you must do work against the potential therefore the particle slows down
- If you want to move a negatively charged object from high to low potential work must again be done meaning the particle slows down

Electric Potential

- Not potential energy, but potential energy per unit charge, $\Delta V = \Delta PE / q$



Potential Difference

- The electric potential difference *ΔV* between points A and B is defined as the change in the potential energy (final value minus initial value) of a charge q moved from A to B divided by the size of the charge.
  - $\Delta V = V_B - V_A = \Delta PE / q$
- Potential difference is *not* the same as potential energy.

Potential Difference, Cont.

- Another way to relate the energy and the potential difference: $\Delta PE = q\,\Delta V$
- Both electric potential energy and potential difference are *scalar* quantities.
- Units of potential difference
  - $V = J/C$
- A special case occurs when there is a *uniform electric field.*
  - $\Delta V = -E_x\,\Delta x$
    - Gives more information about units: $N/C = V/m$

The Electron Volt

- The electron volt (eV) is defined as the kinetic energy that an electron gains when accelerated through a potential difference of 1 V.
  - Electrons in normal atoms have energies of 10's of eV.
  - Excited electrons have energies of 1000's of eV.
  - High energy gamma rays have energies of millions of eV.
- 1 eV = 1.6×10^{-19} J

Potential Energy Compared to Potential

- Electric potential is characteristic of the field only.
  - Independent of any test charge that may be placed in the field
- Electric potential energy is characteristic of the charge-field system.
  - Due to an interaction between the field and the charge placed in the field

Electric Potential and Charge Movements

- When released from rest, positive charges accelerate spontaneously from regions of high potential to low potential.
- When released from rest, negative charges will accelerated from regions of low potential toward region of high potential.
- Work must be done on a negative charges to make them go in the direction of lower electric potential.

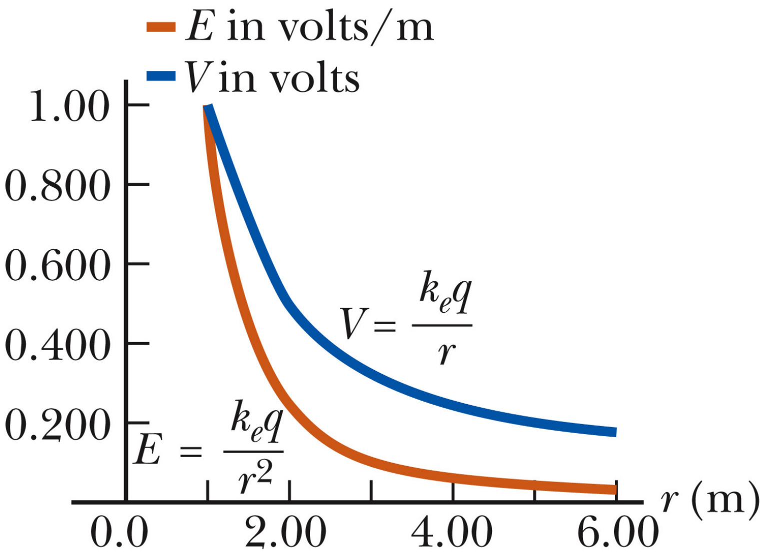
Electric Potential of a Point Charge

- The point of zero electric potential is taken to be at an infinite distance from the charge.
- The potential created by a point charge q at any distance r from the charge is

$$V = k_e \frac{q}{r}$$

Electric Field and Electric Potential Depend on Distance

- The electric field is proportional to $1/r^2$
- The electric potential is proportional to $1/r$



Section 16.2

Electric Potential of Multiple Point Charges

- Superposition principle applies
- The total electric potential at some point P due to several point charges is the *algebraic* sum of the electric potentials due to the individual charges.
  - The algebraic sum is used because potentials are scalar quantities.

A proton (+1.6 x 10^{-19} C) moves 10 cm on a path in the direction of a uniform electric field of strength 3.0 N/C. How much work is done on the proton by the electrical field?

a.4.8 x 10^{-20} J

b.-4.8 x 10^{-20} J

c.1.6 x 10^{-20} J

d.zero

A 9.0-V battery is connected between two parallel metal plates 4.0 mm apart. What is the magnitude of the electric field between the plates?

a.2.3×10^3 N/C
b.9.0 N/C
c.2.3 N/C
d.0.75×10^{-6} N/C

An electron in a cathode ray tube is accelerated through a potential difference of 5.0 kV. What kinetic energy does the electron gain in the process? ($e = 1.6 \times 10^{-19}$ C)

a. 1.6×10^{-16} J

b. 8.0×10^{-16} J

c. 1.6×10^{-22} J

d. 8.0×10^{22} J

Two point charges of values +3.4 and +6.6 μC, respectively, are separated by 0.20 m. What is the potential energy of this 2-charge system? ($k_e = 8.99 \times 10^9$ Nm^2/C^2)

a.+0.34 J
b.−0.75 J
c.+1.0 J
d.−3.4 J

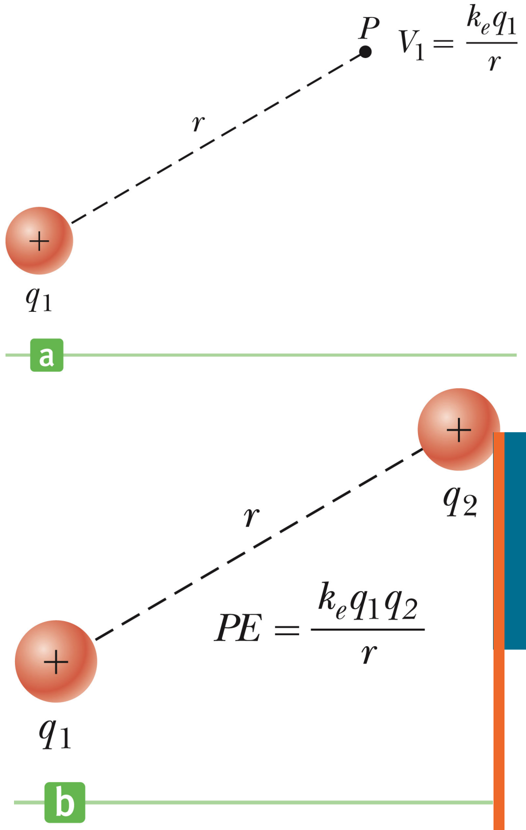
Examples

- Ch 16 1,5,6

Electrical Potential Energy of Two Charges

- V_1 is the electric potential due to q_1 at some point P
- The work required to bring q_2 from infinity to P without acceleration is q_2V_1
- This work is equal to the potential energy of the two particle system

$$PE = q_2V_1 = k_e\frac{q_1q_2}{r}$$



Notes About Electric Potential Energy of Two Charges

- If the charges have the *same* sign, PE is positive.
  - Positive work must be done to force the two charges near one another.
  - The like charges would repel.
- If the charges have *opposite* signs, PE is negative.
  - The force would be attractive.
  - Work must be done to hold back the unlike charges from accelerating as they are brought close together.

Problem Solving with Electric Potential (Point Charges)

- Draw a diagram of all charges.
    - Note the point of interest.
- Calculate the distance from each charge to the point of interest.
- Use the basic equation $V = k_e q/r$
    - Include the sign
    - The potential is positive if the charge is positive and negative if the charge is negative.

Problem Solving with Electric Potential, Cont.

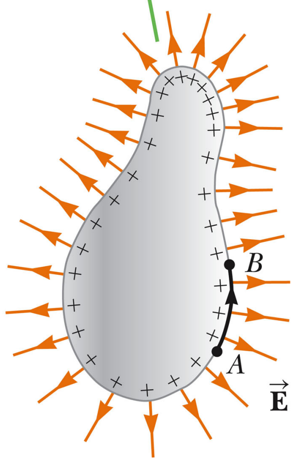
- Use the superposition principle when you have multiple charges.
    - Take the algebraic sum
- Remember that potential is a scalar quantity.
    - So no components to worry about

Potentials and Charged Conductors

- Since $W = -q(V_B - V_A)$, no net work is required to move a charge between two points that are at the same electric potential.
    - $W = 0$ when $V_A = V_B$
- All points on the surface of a charged conductor in electrostatic equilibrium are at the same potential.
- Therefore, the electric potential is constant everywhere on the surface of a charged conductor in electrostatic equilibrium.

Conductors in Equilibrium

- The conductor has an excess of positive charge.
- All of the charge resides at the surface.
- $E = 0$ inside the conductor.
- The electric field just outside the conductor is perpendicular to the surface.
- The potential is a constant everywhere on the surface of the conductor.
- The potential everywhere inside the conductor is constant and equal to its value at the surface.



Notice from the spacing of the positive signs that the surface charge density is nonuniform.

Capacitance

- A capacitor is a device used in a variety of electric circuits.
- The *capacitance*, C, of a capacitor is defined as the ratio of the magnitude of the charge on either conductor (plate) to the magnitude of the potential difference between the conductors (plates).

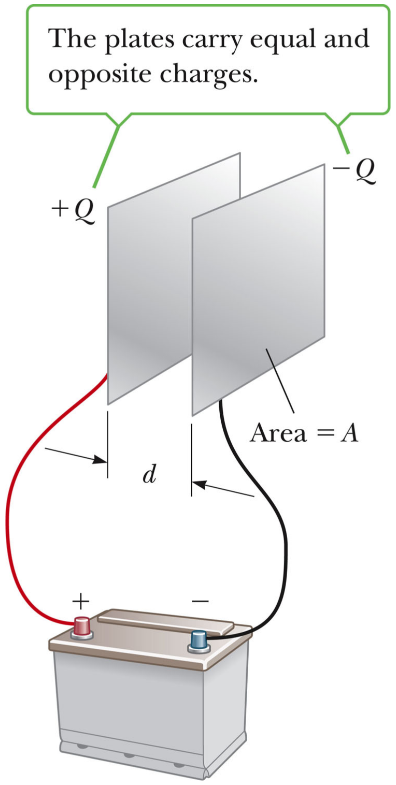
Capacitance, Cont.

- $$C \equiv \frac{Q}{\Delta V}$$
- Units: Farad (F)
  - – 1 F = 1 C / V
  - – A Farad is very large
    - Often will see μF or pF

- ΔV is the potential difference across a circuit element or device.
- V represents the actual potential due to a given charge at a given location.

Parallel-Plate Capacitor, Example

- The capacitor consists of two parallel plates.
- Each has area A.
- They are separated by a distance d.
- The plates carry equal and opposite charges.
- When connected to the battery, charge is pulled off one plate and transferred to the other plate.
- The transfer stops when $\Delta V_{cap} = \Delta V_{battery}$



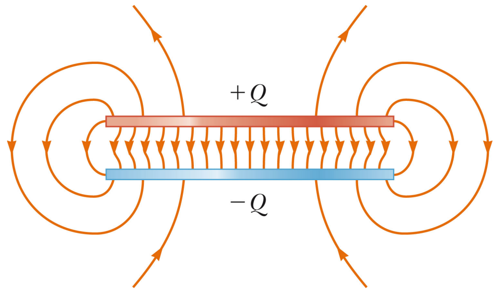
Section 16.7

Parallel-Plate Capacitor

- The capacitance of a device depends on the geometric arrangement of the conductors.
- For a parallel-plate capacitor whose plates are separated by air:

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

Electric Field in a Parallel-Plate Capacitor



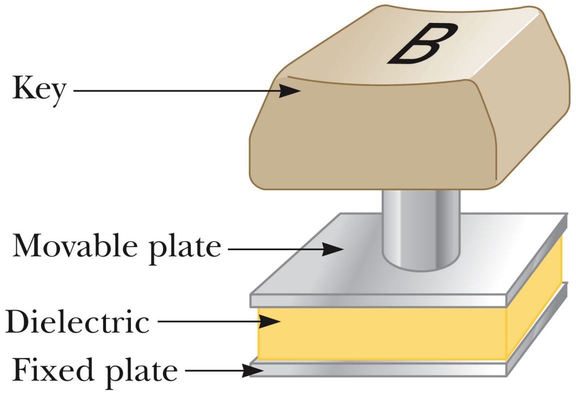
- The electric field between the plates is uniform.
  - Near the center
  - Nonuniform near the edges
- The field may be taken as constant throughout the region between the plates.

Application – Camera Flash

- The flash attachment on a camera uses a capacitor.
  - A battery is used to charge the capacitor.
  - The energy stored in the capacitor is released when the button is pushed to take a picture.
  - The charge is delivered very quickly, illuminating the subject when more light is needed.

Application – Computers

- Computers use capacitors in many ways.
  - Some keyboards use capacitors at the bases of the keys.
  - When the key is pressed, the capacitor spacing decreases and the capacitance increases.
  - The key is recognized by the change in capacitance.



Key Concepts

- For potential and potential energy the regions from high to low point in the direction a positively charged particle would go
- Potential obeys the principle of superposition
- Keep your signs when doing energy and potential problems

Key Equations

For only conservative forces - $\Delta KE + \Delta PE_{cons} = 0$

$$W_{done} = \Delta KE = -\Delta PE_{cons}$$ Joules

$$W_{electric} = \Delta KE = -\Delta PE_{electric} = q\vec{E}\Delta X$$

$$q\Delta V = \Delta PE$$

Constant linear field - $|\vec{E}\Delta x| = |\Delta V|$ Volts

Capacitance

$$C = \frac{q}{\Delta V}$$

$$C = \epsilon_0 \frac{A}{d}$$

Potential due to a point charge $V_{point} = \frac{kq}{r}$