# PHYS 1444 – Section 003
# Review #1

*Tuesday, October 2, 2012*

*Dr. Andrew Brandt*

Ch 25 HW deadline 11pm, will repost solutions then

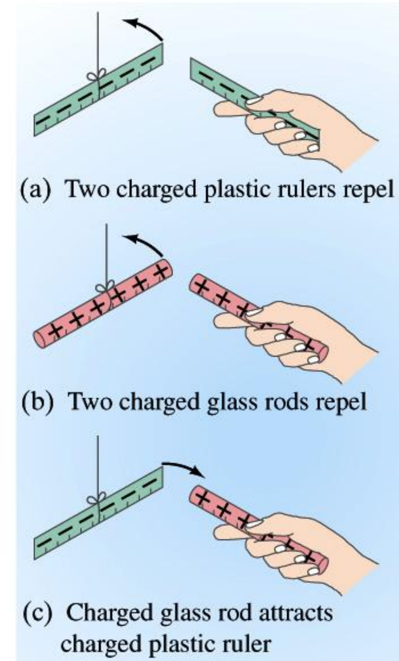
Test Thursday bring a scantron

# Grading

- Exams: 50%
  - Best two of three exams (2 midterms + final)
  - Comprehensive final
  - Exams will be curved if necessary
  - No makeup tests
- Homework: 20%
- Pop quizzes10%
- Lab score: 20%

# Electric Charge and Conservation

- Two types of electric charge
  - Like charges repel while unlike charges attract
- The **<u>net amount of electric charge produced in any process is ZERO!!</u>**
- When a positively charged metal object is brought close to an uncharged metal object
  - If the objects touch each other, the free charges flow until an equilibrium state is reached (charges flow in a conductor.)
  - If the objects are close, the free electrons in the neutral object still move within the metal toward the charged object leaving the opposite end of the object positively charged.(induced charge)



# Coulomb's Law – The Formula

$$F \propto \frac{Q_1 \times Q_2}{r^2} \quad \xrightarrow{\text{Formula}} \quad F = k\frac{Q_1 Q_2}{r^2}$$

A vector quantity. Newtons

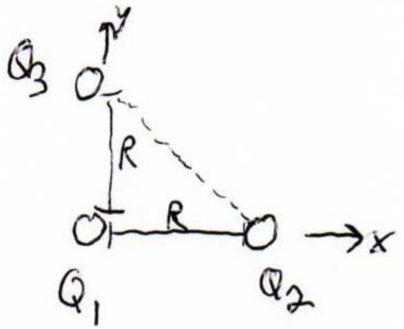
- Direction of electric (Coulomb) force (Newtons) is always along the line joining the two objects.
- Unit of charge is called Coulomb, C, in SI.
- Elementary charge, the smallest charge, is that of an electron: -e where $e = 1.602 \times 10^{-19} C$

# Vector Problems

- **Calculate magnitude of vectors (Ex. force using Coulomb's Law)**
- **Split vectors into x and y components and add these separately, using diagram to help determine sign**
- **Calculate magnitude of resultant $|F|=\sqrt{(F_x^2+F_y^2)}$**
- **Use $\theta = \tan^{-1}(F_y/F_x)$ to get angle**

Example:

What is the force on charge 3 due to charge 1 and 2

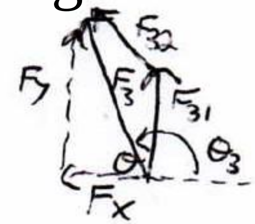



$Q_1 = +2Q$

$Q_2 = +3Q$

$Q_3 = +Q$

Angle:




$$\theta = \tan^{-1}\left(\frac{|F_y|}{|F_x|}\right) = 71^\circ$$

$$\therefore \theta_3 = 180 - \theta = 109^\circ$$

$$|F_{31}| = |F_{13}| = \frac{kQ_1Q_3}{R^2} = \frac{k(2Q)Q}{R^2} = \frac{2kQ^2}{R^2} = \boxed{2f} \quad \text{where } f = \frac{kQ^2}{R^2}$$

$$|F_{32}| = |F_{23}| = \frac{kQ_2Q_3}{(\sqrt{2}R)^2} = \frac{k(3Q)Q}{(\sqrt{2}R)^2} = \frac{3kQ^2}{2R^2} = \boxed{\frac{3}{2}f}$$

After calculating magnitudes, take x+y components and then get total force

$$F_{3x} = F_{31x} + F_{32x} = |F_{31}|\cos\theta_{31} + |F_{32}|\cos\theta_{32} \qquad F_{3y} = F_{31y} + F_{32y} = |F_{31}|\sin\theta_{31} + |F_{32}|\sin\theta_{32}$$

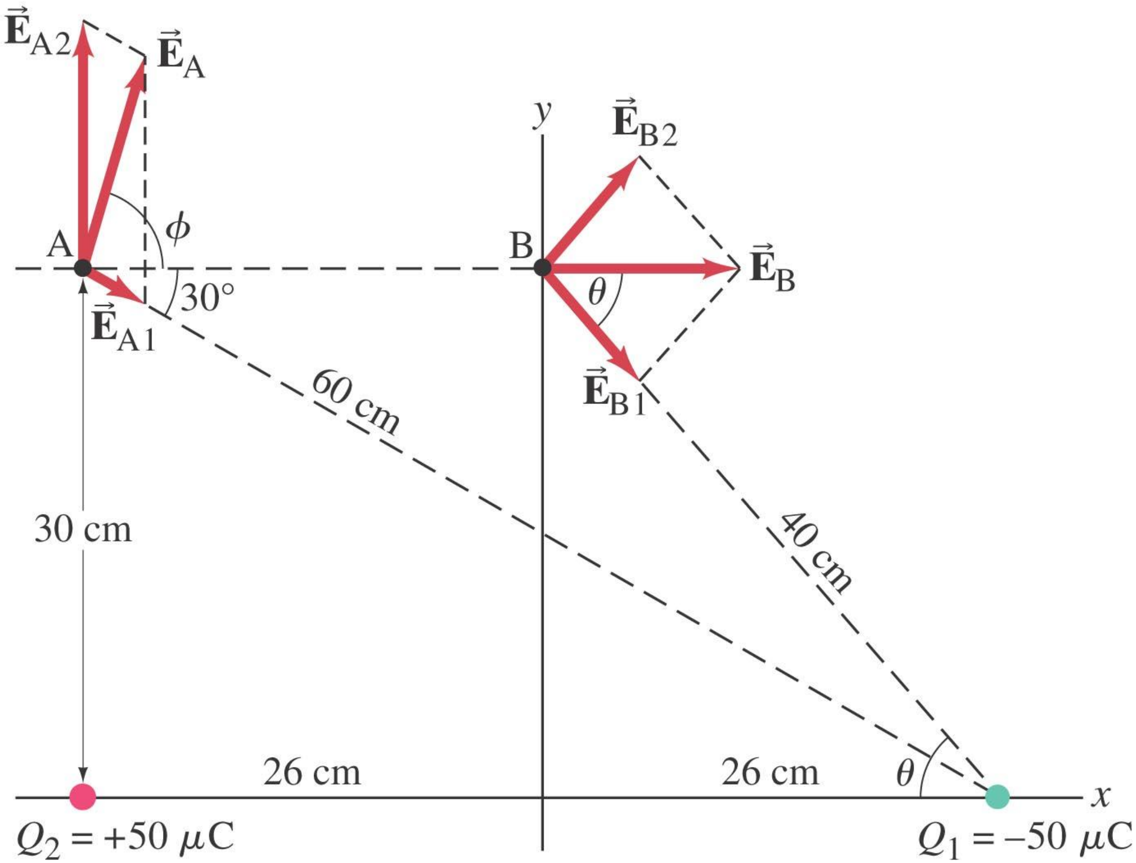
$$|F_3| = \sqrt{F_{3x}^2 + F_{3y}^2} = \sqrt{(-1.06f)^2 + (3.06f)^2} = 3.24f$$

# The Electric Field

- The electric field at any point in space is defined as the force exerted on a tiny positive test charge divided by magnitude of the test charge $\vec{E} = \frac{\vec{F}}{q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$
- The electric field inside a conductor is ZERO in a static situation

# Example 21-8

Calculate the total electric field (a) at point A and (b) at point B in the figure due to both charges, $Q_1$ and $Q_2$.




Solution: The geometry is shown in the figure. For each point, the process is: calculate the magnitude of the electric field due to each charge; calculate the x and y components of each field; add the components; recombine to give the total field.

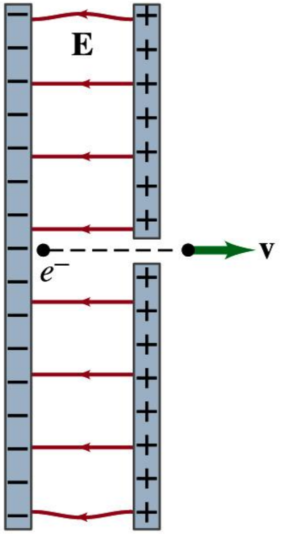
a. $E = 4.5 \times 10^6$ N/C, 76 above the x axis.

b. $E = 3.6 \times 10^6$ N/C, along the x axis.

# Example 21 – 14

- **Electron accelerated by electric field**. An electron (mass m = $9.1\times10^{-31}$ kg) is accelerated from rest in a uniform field E (E = $2.0\times10^{4}$ N/C) between two parallel charged plates (d=1.5 cm), andpasses through a tiny hole in the positive plate.

  (a) With what speed does it leave the hole?



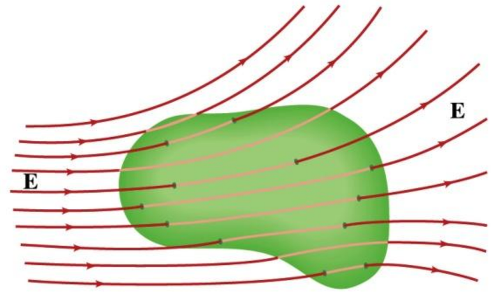

$$F = qE = ma$$

$$v^2 = v_0^2 + 2ax$$

Dipoles, torque, etc.

# Electric Flux

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = 0.$$

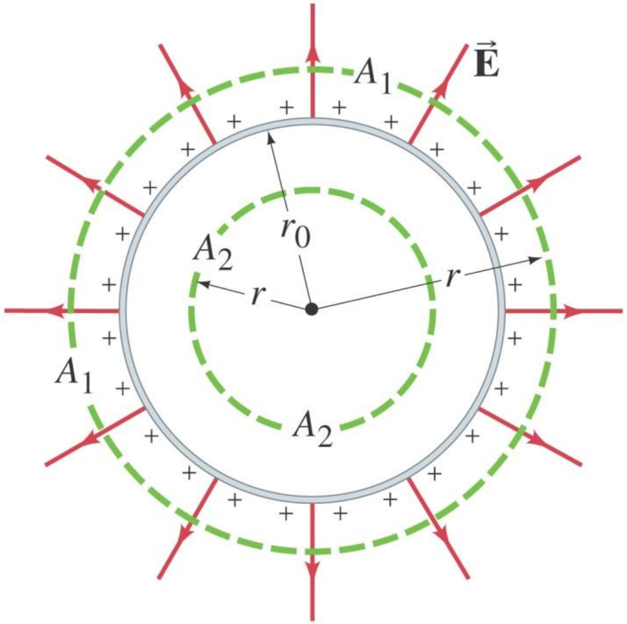


# Gauss' Law

- The precise relation between flux and the enclosed charge is given by Gauss' Law $$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$
  - $\varepsilon_0$ is the permittivity of free space in the Coulomb's law
- A few important points on Gauss' Law
  - Freedom to choose surface
  - Distribution of charges inside surface does not matter only total charge
  - Charges outside the surface do not contribute to $Q_{encl}$.

Example 22-3: Spherical conductor.

A thin spherical shell of radius $r_0$ possesses a total net charge $Q$ that is uniformly distributed on it. Determine the electric field at points (a) outside the shell, and (b) within the shell. (c) What if the conductor were a solid sphere?




$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$

Figure 22-11. Cross-sectional drawing of a thin spherical shell of radius $r_0$ carrying a net charge $Q$ uniformly distributed. $A_1$ and $A_2$ represent two gaussian surfaces we use to determine Example 22–3.

Solution: a. The gaussian surface $A_1$, outside the shell, encloses the charge Q. We know the field must be radial, so $E = Q/(4\pi\varepsilon_0 r^2)$.

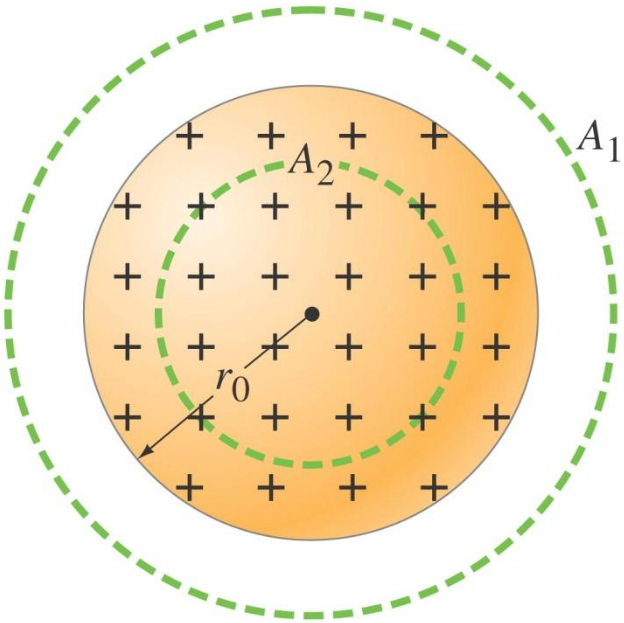
b. The gaussian surface $A_2$, inside the shell, encloses no charge; therefore the field must be zero.

c. All the excess charge on a conductor resides on its surface, so these answers hold for a solid sphere as well.

**Key to these questions is how much charge is enclosed**

Example 22-4: Solid sphere of charge.

An electric charge $Q$ is distributed uniformly throughout a **nonconducting** sphere of radius $r_0$. Determine the electric field (a) outside the sphere ($r > r_0$) and (b) inside the sphere ($r < r_0$).

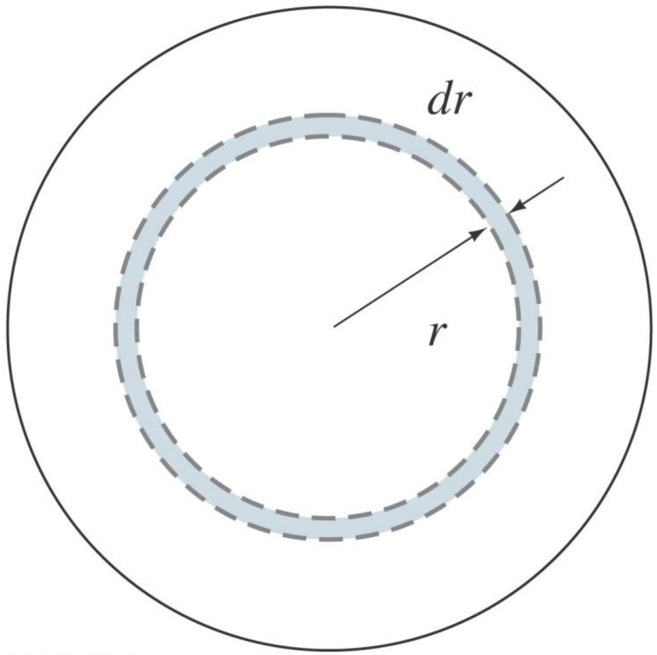



Solution: a. Outside the sphere, a gaussian surface encloses the total charge Q. Therefore, $E = Q/(4\pi\varepsilon_0 r^2)$.

b. Within the sphere, a spherical gaussian surface encloses a fraction of the charge $Qr^3/r_0^3$ (the ratio of the volumes, as the charge density is constant). Integrating and solving for the field gives $E = Qr/(4\pi\varepsilon_0 r_0^3)$.

Example 22-5: Nonuniformly charged solid sphere.

Suppose the charge density of a solid sphere is given by $\rho_E = \alpha r^2$, where $\alpha$ is a constant. (a) Find $\alpha$ in terms of the total charge $Q$ on the sphere and its radius $r_0$. (b) Find the electric field as a function of $r$ inside the sphere.




Solution: a. Consider the sphere to be made of a series of spherical shells, each of radius r and thickness dr. The volume of each is $dV = 4\pi r^2\, dr$. To find the total charge: $Q = \int \rho_E\, dV = 4\pi\alpha r_0^5/5$, giving $\alpha = 5Q/4\pi r_0^5$.

b. The charge enclosed in a sphere of radius r will be $Qr^5/r_0^5$. Gauss's law then gives $E = Qr^3/4\pi\varepsilon_0 r_0^5$.

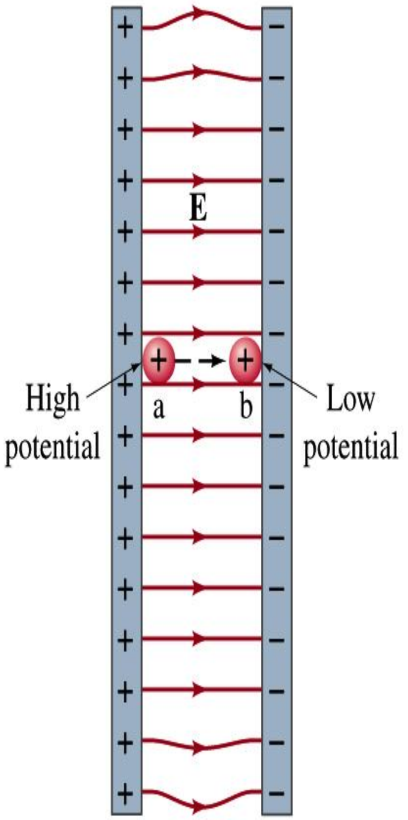
# Electric Potential Energy

- Concept of energy is very useful solving mechanical problems
- Conservation of energy makes solving complex problems easier.
- Defined for conservative forces (independent of path)

# Electric Potential Energy

- **What is the definition of change in electric potential energy $U_b - U_a$?**
  - **The potential gained by the charge as it moves from point *a* to point *b*.**
  - **The negative work done on the charge by the electric force to move it from *a* to *b*.**

- Parallel plates w/ equal but opposite charges
  - The field between the plates is uniform since the gap is small and the plates are infinitely long…
- What happens when we place a small charge, +q, on a point at the positive plate and let go?
  - The electric force will accelerate the charge toward negative plate and it gains kinetic energy

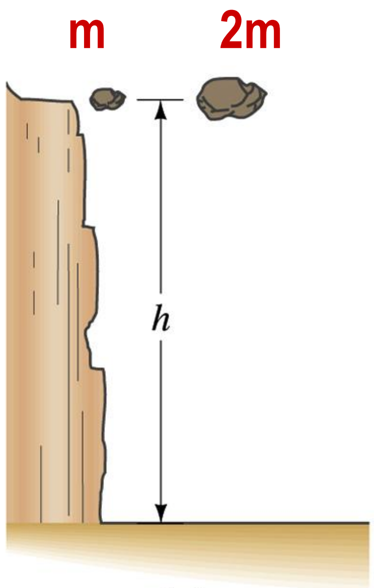


# Electric Potential

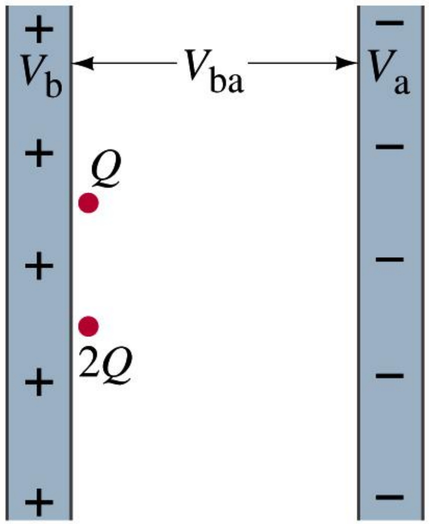
- The electric field (E) is defined as electric force per unit charge: F/q   (vector quantity)
- Electric potential (V) is defined as electrical potential energy per unit charge U/q (scalar)

# Comparisons of Potential Energies

- Let's compare gravitational and electric potential energies




(a)




(b)

- What are the potential energies of the rocks?
  - mgh and 2mgh
- Which rock has a bigger potential energy?
  - The rock with a larger mass
- Why?
  - It's got a bigger mass.

- What are the potential energies of the charges?
  - $+QV_{ba}$ and $+2QV_{ba}$
- Which object has a bigger potential energy?
  - The object with a larger charge.
- Why?
  - It's got a bigger charge.

**The "potential" is the same but the heavier rock or larger charge can do a greater work.**

# Properties of the Electric Potential

- What are the differences between the electric potential and the electric field?
  - Electric potential (U/q)

    $$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

    - Simply add the potential from each of the charges to obtain the total potential from multiple charges, since potential is a scalar quantity
  - Electric field (F/q)

    $$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

    - Need vector sums to obtain the total field from multiple charges
- Potential for a positive charge is large near a positive charge and decreases to 0 at large distances.
- Potential for the negative charge is small (large magnitude but negative) near the charge and increases with distance to 0

# E Determined from V

- Potential difference between two points is

$$V_b - V_a = -\int_a^b \vec{E} \cdot d\vec{l}$$

- So in a differential form, we can write

$$dV = -\vec{E} \cdot d\vec{l} = -E_l dl$$

  - What are dV and $E_\ell$?
    - dV is the infinitesimal potential difference between two points separated by the distance $d\ell$
    - $E_\ell$ is the field component along the direction of $d\ell$.

- Thus we can write the field component $E_\ell$ as

$$E_l = -\frac{dV}{dl}$$

**Physical Meaning?**

The component of the electric field in any direction is equal to the negative rate of change of the electric potential as a function of distance in that direction.!!

# Electrostatic Potential Energy; Three Charges

- Work is needed to bring all three charges together
  - Work needed to bring $Q_1$ to a certain place without the presence of any charge is 0.
  - Work needed to bring $Q_2$ to a distance to $Q_1$ is $U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r_{12}}$
  - Work need to bring $Q_3$ to a distance to $Q_1$ and $Q_2$ is

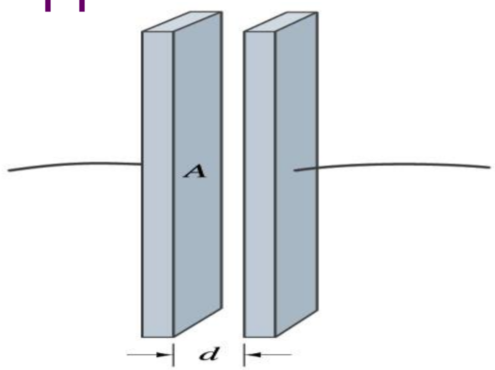
$$U_3 = U_{13} + U_{23} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_3}{r_{13}} + \frac{1}{4\pi\varepsilon_0}\frac{Q_2Q_3}{r_{23}}$$

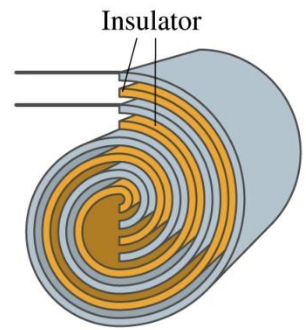
- So the total electrostatic potential of the three charge system is

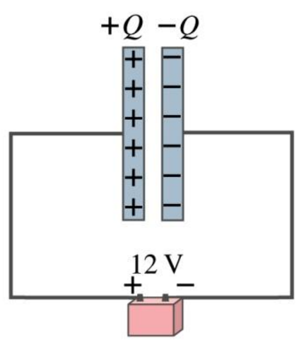
$$U = U_{12} + U_{13} + U_{23} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1Q_2}{r_{12}} + \frac{Q_1Q_3}{r_{13}} + \frac{Q_2Q_3}{r_{23}}\right)$$

# Capacitors

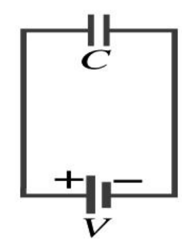
- A simple capacitor consists of a pair of parallel plates of area $\mathcal{A}$ separated by a distance $d$.
  - A cylindrical capacitors are essentially parallel plates wrapped around as a cylinder.



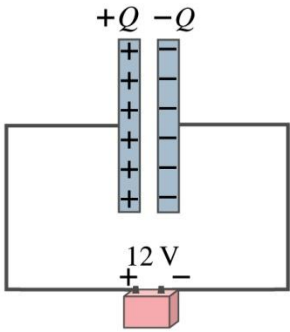




**Circuit Diagram**



# Capacitors

- If a battery is connected  to a capacitor, the capacitor gets charged quickly, one plate positive and the other neg with an equal amount..




- For a given capacitor, the amount of charge stored in capacitor is proportional to the potential difference $V_{ba}$ between the plates. C is a proportionality constant, called capacitance of the device.

$$Q = CV_{ba}$$

**C is a property of a capacitor so does not depend on Q or V.**

- See Ex. 24.1 for example

# Electric Energy Storage

- What work is needed to add a small amount of charge (dq) when the potential difference across the plates is V?

$dW = Vdq$

- Since V=q/C, the work needed to store total charge Q is

$$W = \int_0^Q V dq = \frac{1}{C}\int_0^Q q dq = \frac{Q^2}{2C}$$

- Thus, the energy stored in a capacitor when the capacitor carries charges +Q and –Q is

$$U = \frac{Q^2}{2C}$$

- Since Q=CV, we can rewrite

$$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

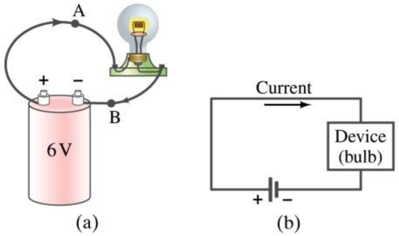
# Dielectrics

- Capacitors generally have an insulating sheet of material, called a dielectric, between the plates to
  - Increase the breakdown voltage above that in air
  - Allows the plates get closer together without touching
    - Increases capacitance ( recall $C=\varepsilon_0 A/d$)
  - Also increases the capacitance by the dielectric constant

$$C = KC_0$$

    - Where $C_0$ is the intrinsic capacitance when the gap is vacuum, and K or $\kappa$ is the dielectric constant

# Electric Current




- Electric Current: Any flow of charge
  - Current can flow whenever there is potential difference between the ends of a conductor
  - Electric current in a wire can be defined as the net amount of charge that passes through a wire's full cross section at any point per unit time
  - Average current is defined as: $\bar{I} = \Delta Q / \Delta t$
  - The instantaneous current is: $I = dQ/dt$
  - Current is a scalar
  - Current is flow of charge, charge is conserved, so current in equals current out at a given point on circuit

C/s

1A=1C/s

# Ohm's Law: Resistance

- The exact amount of current flow in a wire depends on
  - The voltage
  - The resistance of the wire to the flow of electrons
- The higher the resistance the less the current for the given potential difference V

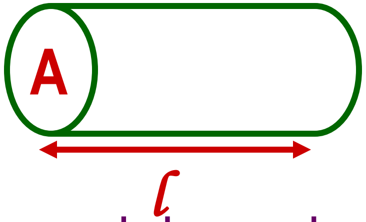
$$V = IR$$

$$1.0\Omega = 1.0V / A$$

# Resistivity

- It is experimentally found that the resistance R of a metal wire is directly proportional to its length $l$ and inversely proportional to its cross-sectional area A

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




  - The proportionality constant ρ is called the **resistivity** and depends on the material used. The higher the resistivity the higher the resistance
  - The reciprocal of the resistivity is called the **conductivity**, σ,

$$\sigma = \frac{1}{\rho}$$

# Electric Power

- Power -the rate at which work is done or the energy is transferred
- <u>P=IV can apply to any devices while the formulae involving resistance only apply to Ohmic resistors.</u>

$I^2R$ used for heat loss

$$P = I^2 R = \frac{V^2}{R}$$

Temperature dependence

$$\rho_T = \rho_0 \left[ 1 + \alpha \;\; T - T_0 \;\; \right]$$

# 1444 Test I Eq. Sheet

$|F|=\sqrt{(F_x^2+F_y^2)}$

$\theta = \tan^{-1}(F_y/F_x)$

Electron charge:

$e = 1.602\times10^{-19}\,C$

Electron mass: $m_e = 9.1\text{x}10^{-31}$ kg

Proton mass: $m_p = 1.67\text{x}10^{-27}$ kg

Colomb's Law:

$$F = k\frac{Q_1Q_2}{r^2} \qquad k = 8.988\times10^9\ \text{N}\cdot\text{m}^2/C^2 \qquad \varepsilon_0 = 1/4\pi k = 8.85\times10^{-12}\ C^2/N\cdot m^2$$

Dipole: $\vec{\tau} = \vec{p}\times\vec{E}$ $\quad U = -\vec{p}\cdot\vec{E}$

Flux: $\Phi_E = \int \vec{E}\cdot d\vec{A}$

Gauss Law: $\oint \vec{E}\cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$

Electric Field: $\vec{E} = \frac{\vec{F}}{q}$ $\quad E_l = -\frac{dV}{dl}$

For a point charge: $|E| = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ $\qquad$ V=Ed (uniform field)

Eqs. of motion: $x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$

$v_{xf} = v_{xi} + a_x t$ $\qquad v^2 = v_0^2 + 2ax$

K.E.=$mv^2/2$

Ugrav=mgh g=9.8 m/$s^2$

Uelec=qV

Q=CV C=capacitance

parallel plate: $C = \kappa\frac{\varepsilon_0 A}{d}$

dielectric: $\kappa \geq 1$

Cap. stored energy: $U = \frac{Q^2}{2C}$

Ohm's Law: V=IR

Power: P=IV

Current: I=q/t

AC: $V = V_0 \sin 2\pi ft$

Resistivity: $R = \rho\frac{l}{A}$ $\quad \sigma = \frac{1}{\rho}$

$$\rho_T = \rho_0\left[1+\alpha\ T-T_0\ \right]$$

$C_{eq}=C_1+C_2$ (parallel)

$1/C_{eq}=1/C_1+1/C_2$ (series)

# A quiz

QUIZ 3 1444 Chapter 24 Name:

1) Which statement is true? An electronvolt
   a) is a unit of electrical potential
   b) is an SI unit
   c) is an energy unit with a value much less than a Joule
   d) none of the above

2) The equivalent capacitance of two capacitors in series is
   a) more than
   b) less than
   c) equal to

   the capacitance of the two capacitors in parallel

3) The capacitance of a capacitor depends on
   a) voltage between plates
   b) charge on plates
   c) area of plates
   d) all of the above

4) Compared to having a vacuum between parallel plates, having a dielectric
   a) decreases the capacitance
   b) allows the plates to be closer together
   c) increases the electric field between the plates
   d) all of the above

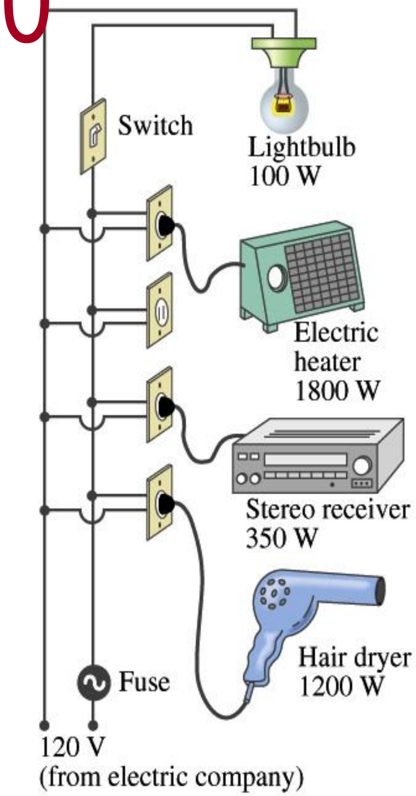
5) Which statement is TRUE? Parallel plates attached to a battery
   a) have an approximately uniform electrical field between the plates
   b) act as a capacitor
   c) store electrical energy
   d) all of the above

Tuesday, October 2 2012

# Example 25 – 10

**Will a 30A fuse blow?**

Determine the total current drawn by all the devices in the circuit in the figure.




The total current is the sum of current drawn by the individual devices.

$P = IV$ Solve for I $\Rightarrow$ $I = P/V$

Bulb $I_B = 100W/120V = 0.8A$

Heater $I_H = 1800W/120V = 15.0A$

Stereo $I_S = 135W/120V = 2.9A$

Dryer $I_D = 1200W/120V = 10.0A$

Total current

$$I_T = I_B + I_H + I_S + I_D = 0.8A + 15.0A + 2.9A + 10.0A = 28.7A$$

What is the total power? $P_T = P_B + P_H + P_S + P_D = 100W + 1800W + 350W + 1200W = 3450W$