

PHYSICS 1442-003

Fall 2011

Lecture 2

Electric Charge and

Electric Field

Coulomb's Law

- Mathematically,
$$F = k \frac{|Q_1| |Q_2|}{r^2}$$
- k is a proportionality constant
 - In SI units, k has the value
 - $k = 8.988 \times 10^9 \text{ N m}^2/\text{C}^2$
- Charges produced by rubbing ordinary objects (a comb or plastic ruler) are in the μC range ($1 \mu\text{C} = 10^{-6} \text{ C}$)
 - Remember, Coulombs must be used in the equation
- Remember that force is a *vector* quantity

Coulomb's Law

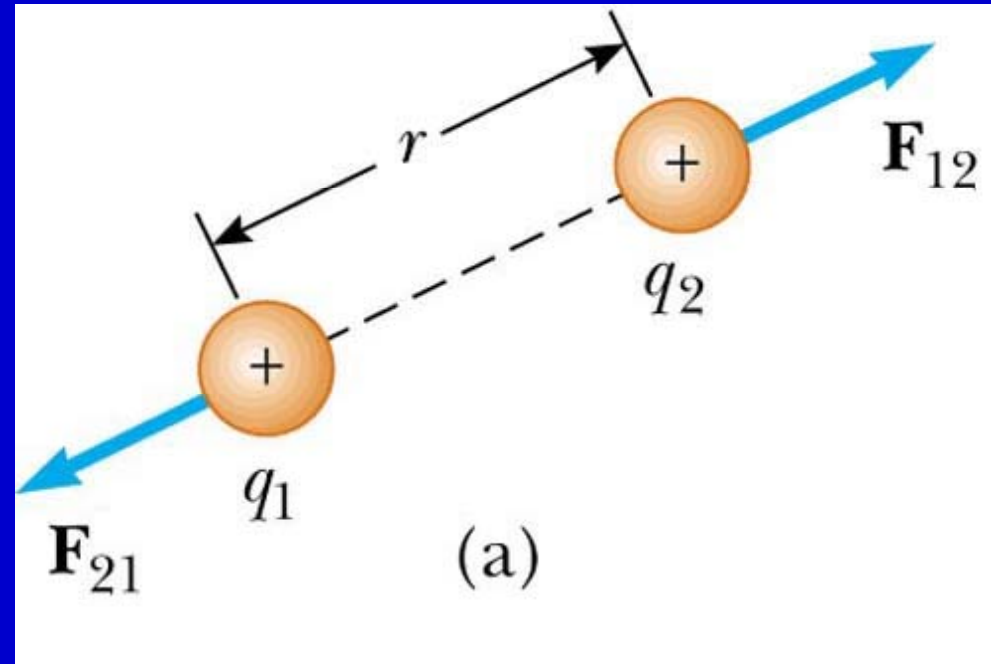
The proportionality constant k can also be written in terms of ϵ_0 , the permittivity of free space:

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$$

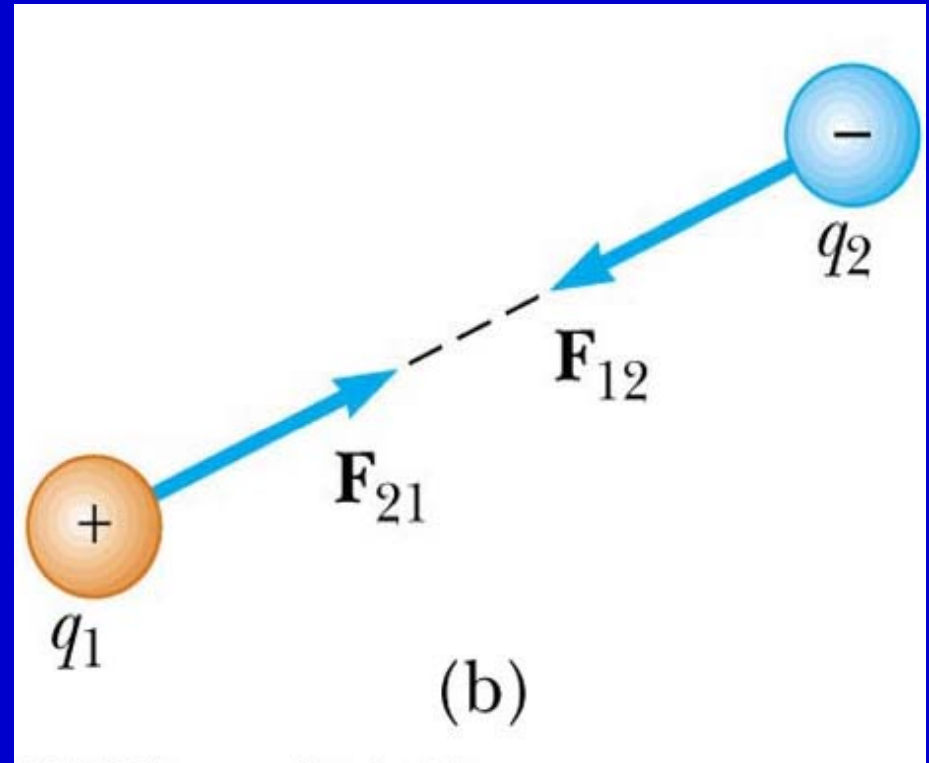
Vector Nature of Electric Forces

- Two point charges are separated by a distance r
- The like charges produce a repulsive force between them
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2



Vector Nature of Forces

- Two point charges are separated by a distance r
- The unlike charges produce an attractive force between them
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2



The Superposition Principle

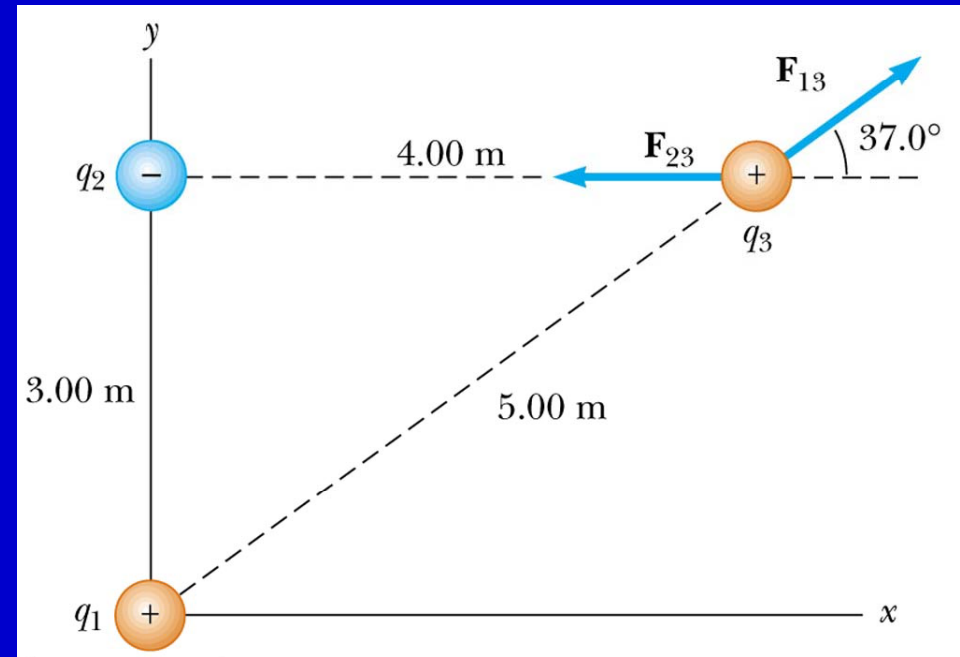
- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present.

$$\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \dots$$

- Remember to add the forces *vectorially*

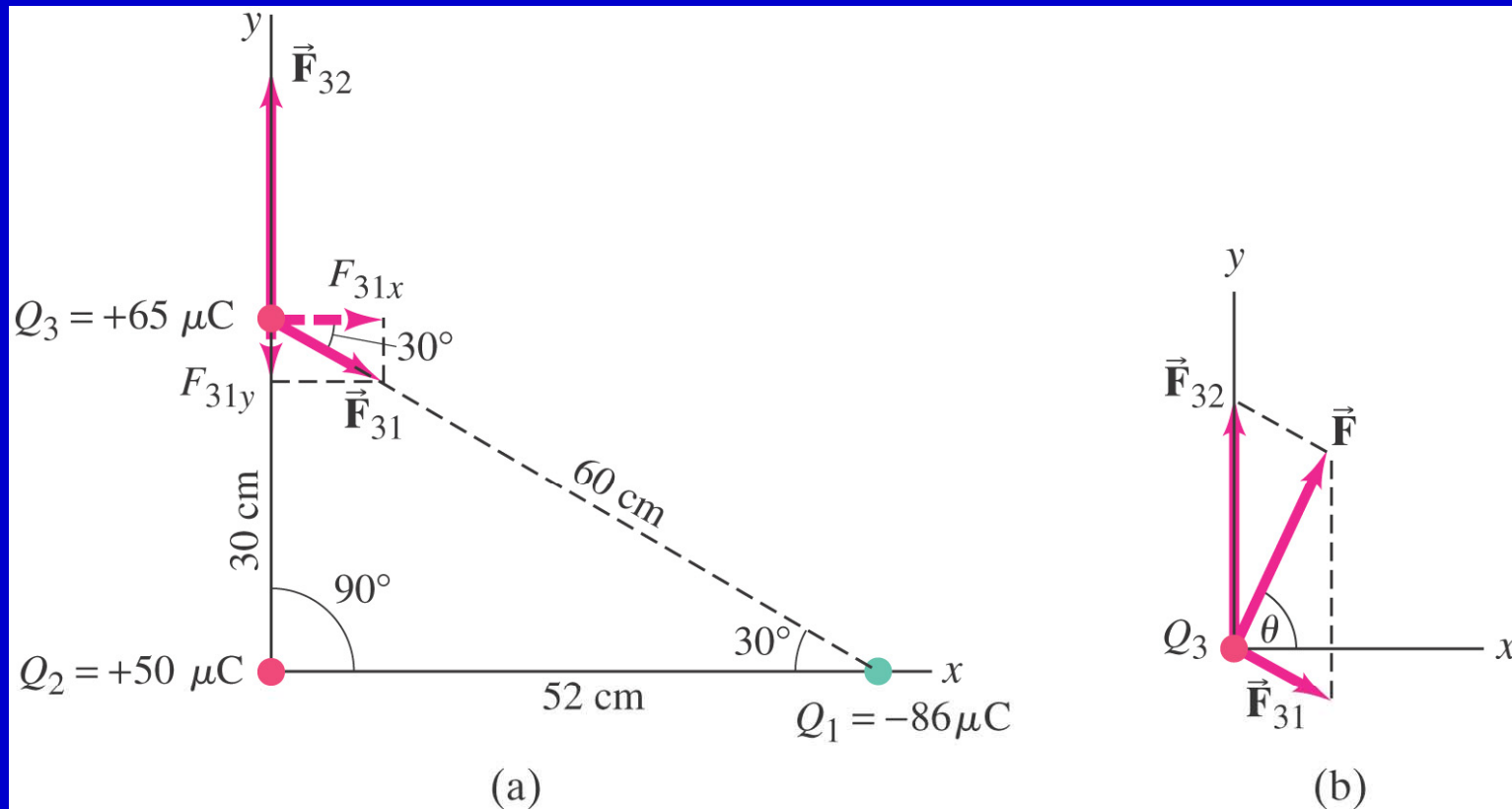
Superposition Principle Example

- The force exerted by q_1 on q_3 is \mathbf{F}_{13}
- The force exerted by q_2 on q_3 is \mathbf{F}_{23}
- The *total force* exerted on q_3 is the vector sum of \mathbf{F}_{13} and \mathbf{F}_{23}



Coulomb's law strictly applies only to point charges.

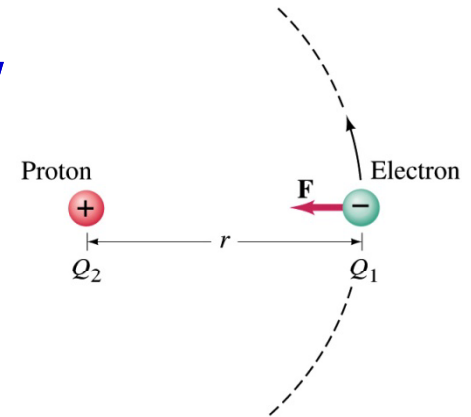
Superposition: for multiple point charges, the forces on each charge from every other charge can be calculated and then added as vectors.



■ **Electric force on electron by proton.**

Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the proton ($Q_2 = +e$) that is its nucleus.

- Assume the electron “orbits” the proton at its average distance of $r = 0.53 \times 10^{-10} \text{ m}$.



Using Coulomb's law
$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2} = k \frac{Q_1 Q_2}{r^2}$$

The charges are: $Q_1 = -e = -1.602 \times 10^{-19} \text{ C}$ and $Q_2 = +e = 1.602 \times 10^{-19} \text{ C}$

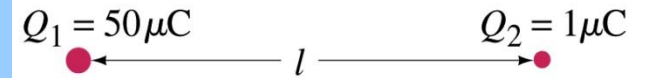
So the magnitude of the force is

$$F = \left| k \frac{Q_1 Q_2}{r^2} \right| = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2 \frac{(1.6 \times 10^{-19} \text{ C})(1.6 \times 10^{-19} \text{ C})}{(0.53 \times 10^{-10} \text{ m})^2} = 8.2 \times 10^{-8} \text{ N}$$

Which direction? Toward each other..

■ Which charge exerts greater force?

Two positive point charges, $Q_1=50\mu\text{C}$ and $Q_2=1\mu\text{C}$, are separated by a distance L . Which is larger in magnitude, the force that Q_1 exerts on Q_2 or the force that Q_2 exerts on Q_1 ?



What is the force that Q_1 exerts on Q_2 ?

$$F_{12} = k \frac{Q_1 Q_2}{L^2}$$

What is the force that Q_2 exerts on Q_1 ?

$$F_{21} = k \frac{Q_2 Q_1}{L^2}$$

Therefore the magnitudes of the two forces are identical!!

Well then what is different? The direction.

Which direction? Opposite to each other!

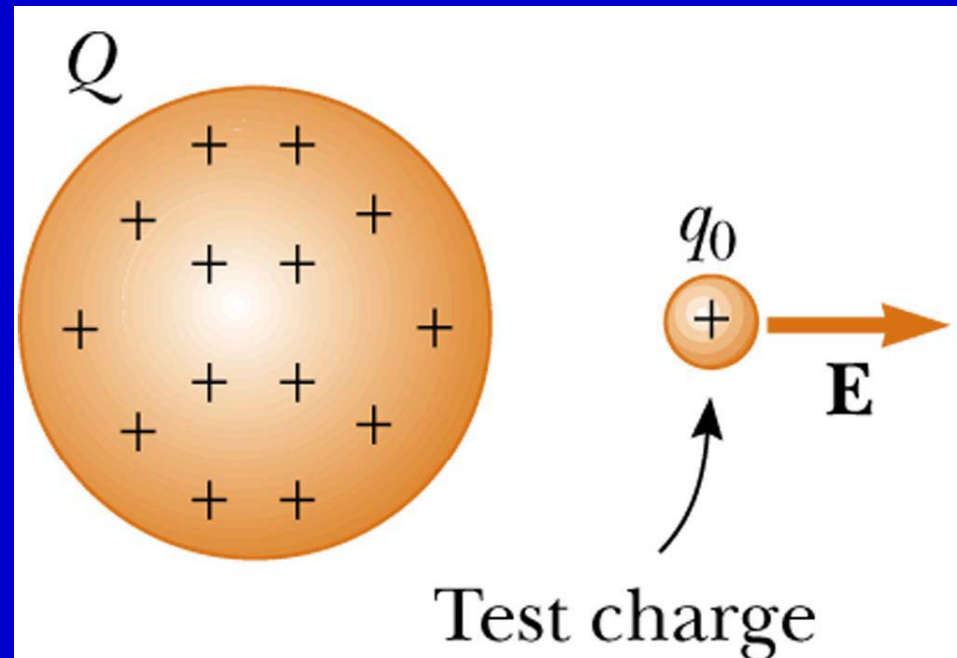
What is this law? Newton's third law, the law of action and reaction!!

Electrical Field

- Maxwell developed an approach to discussing fields
- An *electric field* is said to exist in the region of space around a charged object
 - When another charged object enters this electric field, the field exerts a *force* on the second charged object

Electric Field

- A charged particle, with charge Q , produces an electric field in the region of space around it
- A small *test charge*, q_0 , placed in the field, will experience a force



$$\mathbf{F} = q_0 \cdot \mathbf{E}$$

Electric Field

- Mathematically,

$$\mathbf{E} = \frac{\mathbf{F}}{q_o}$$

- Use this for the magnitude of the field
- The electric field is a vector quantity
- The direction of the field is defined to be the direction of the electric force that would be exerted on a small positive test charge placed at that point

The Electric Field

For a point charge:

$$E = k \frac{Q}{r^2}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

The Electric Field

Force on a point charge q in an electric field:

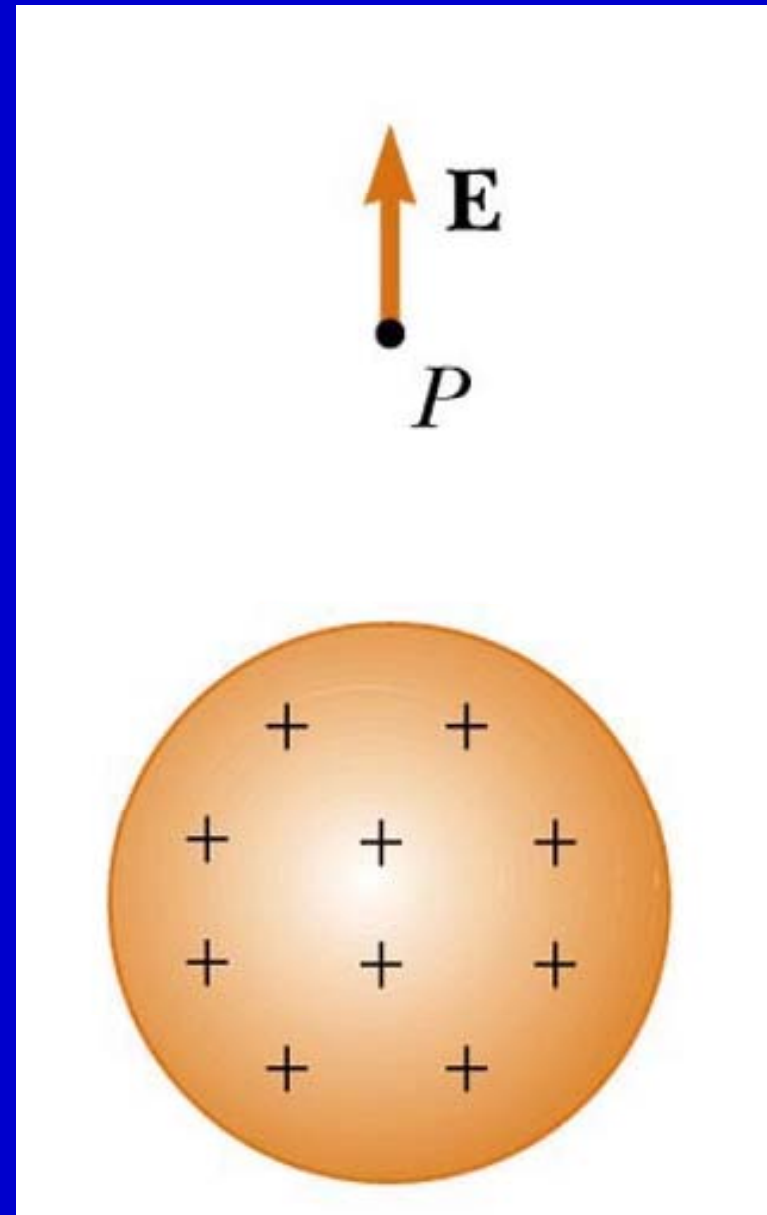
$$\vec{\mathbf{F}} = q\vec{\mathbf{E}}$$

Superposition principle for electric fields:

$$\vec{\mathbf{E}} = \vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2 + \dots$$

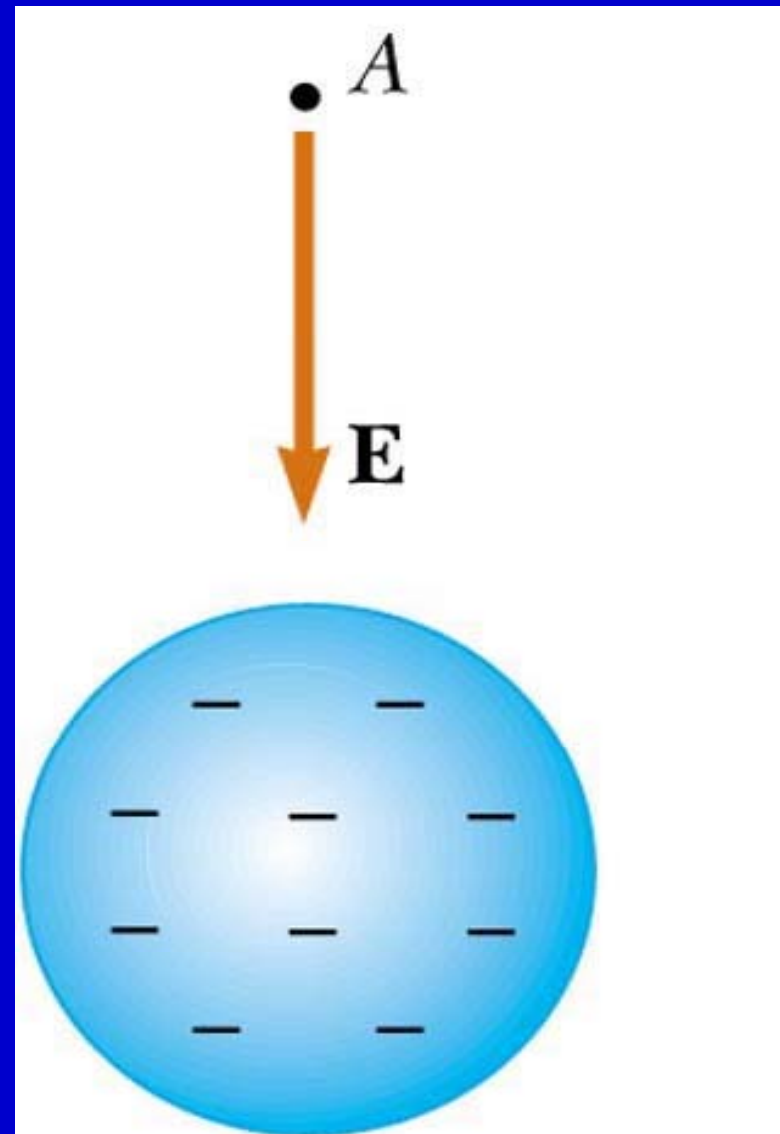
Direction of Electric Field

- The electric field produced by a positive charge is directed away from the charge
 - A positive test charge would be repelled from the positive source charge



Direction of Electric Field

- The electric field produced by a negative charge is directed toward the charge
 - A positive test charge would be attracted to the negative source charge



More About a Test Charge and The Electric Field

- The test charge is required to be a small charge
 - It can cause no rearrangement of the charges on the source charge
- The electric field exists whether or not there is a test charge present
- The Superposition Principle can be applied to the electric field if a group of charges is present

Problem Solving Strategy

■ Units

- When using k , charges must be in Coulombs, distances in meters and force in Newtons
- If values are given in other units, they must be converted

■ Applying Coulomb's Law to point charges

- Use the superposition principle for more than two charges
- Use Coulomb's Law to find the individual forces
- Directions of forces are found by noting that like charges repel and unlike charges attract

Problem Solving Strategies

- Calculating Electric Fields of point charges
 - The Superposition Principle can be applied if more than one charge is present
 - Use the equation to find the electric field due to the individual charges
 - The direction is given by the direction of the force on a positive test charge

QUICK QUIZ 3

A test charge of $+3 \mu\text{C}$ is at a point P where the electric field due to other charges is directed to the right and has a magnitude of $4 \times 10^6 \text{ N/C}$. If the test charge is replaced with a $-3 \mu\text{C}$ charge, the electric field at P

- (a) has the same magnitude but changes direction,
- (b) increases in magnitude and changes direction,
- (c) remains the same, or
- (d) decreases in magnitude and changes direction.

QUICK QUIZ 3 ANSWER

(c). The electric field at point P is due to charges *other* than the test charge.

Thus, it is unchanged when the test charge is altered.

However, the direction of the force this field exerts on the test charge is reversed when the sign of the test charge is changed.

QUICK QUIZ 4

A Styrofoam ball covered with a conducting paint has a mass of 5.0×10^{-3} kg and has a charge of $4.0 \mu\text{C}$.

What electric field directed upward will produce an electric force on the ball that will balance the weight of the ball?

- (a) 8.2×10^2 N/C
- (b) 1.2×10^4 N/C
- (c) 2.0×10^{-2} N/C
- (d) 5.1×10^6 N/C

QUICK QUIZ 4 ANSWER

(b). The magnitude of the upward electrical force must equal the weight of the ball. That is: $qE = mg$, so

$$E = \frac{mg}{q} = \frac{(5.0 \times 10^{-3} \text{ kg})(9.80 \text{ m/s}^2)}{4.0 \times 10^{-6} \text{ C}}$$
$$= 1.2 \times 10^4 \text{ N/C}$$

Electric Field Lines

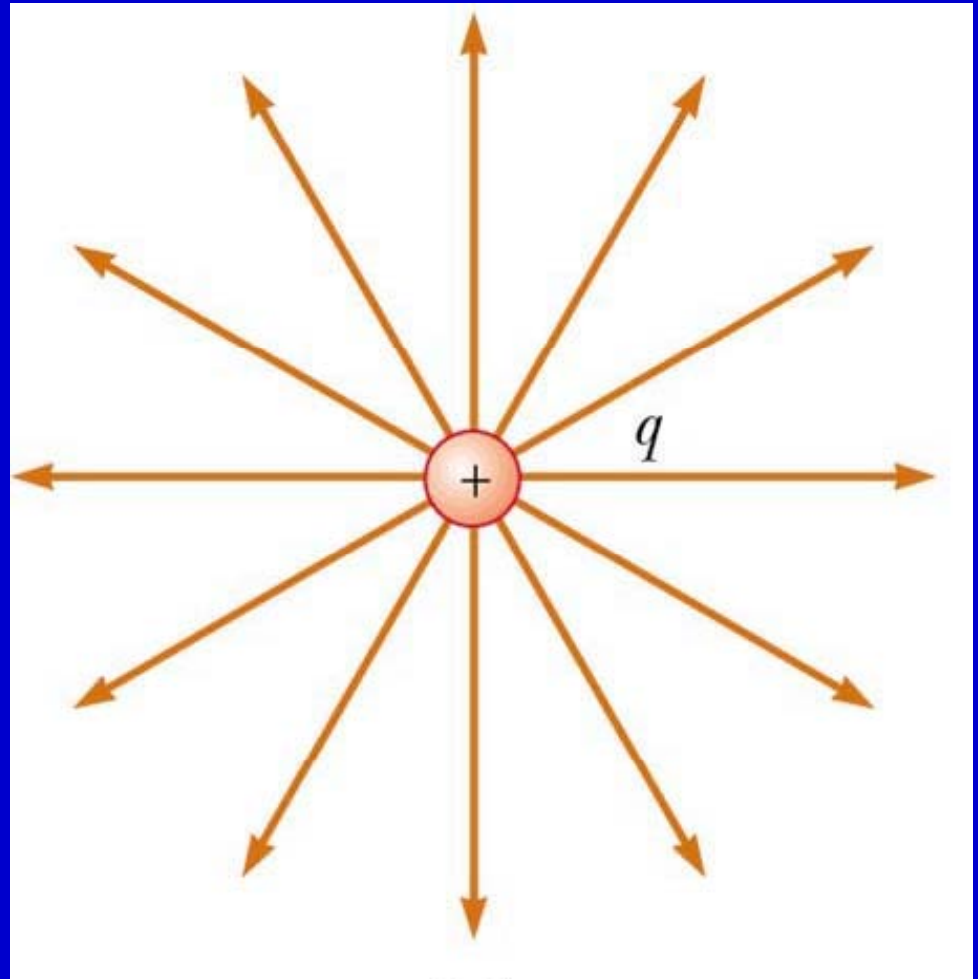
- A convenient aid for visualizing electric field patterns is to draw lines pointing in the direction of the field vector at any point
- These are called *electric field lines* and were introduced by Michael Faraday
- These lines start on a positive charge and end on a negative charge.

Electric Field Lines

- The field lines are related to the field by
 - The electric field vector, \mathbf{E} , is tangent to the electric field lines at each point
 - The number of lines per unit area through a surface perpendicular to the lines is proportional to the strength of the electric field in a given region

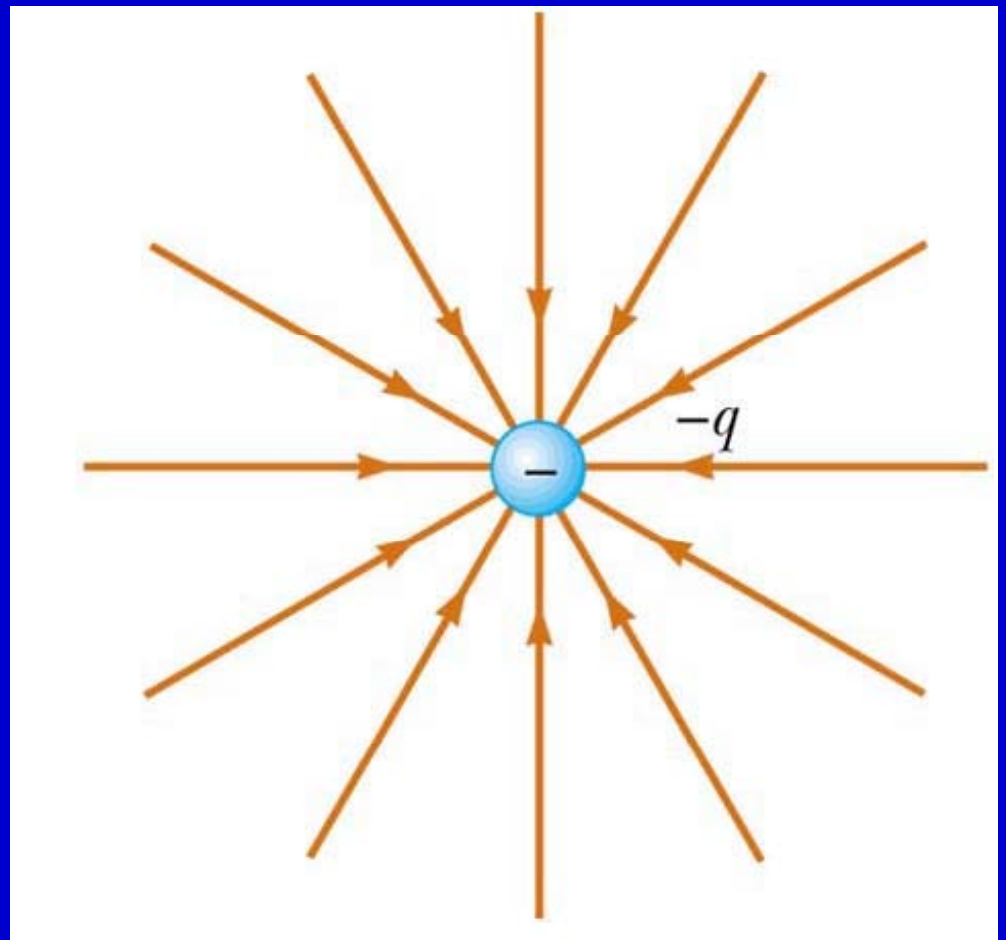
Electric Field Line Patterns

- Point charge
- The lines radiate equally in all directions
- For a positive source charge, the lines will radiate outward



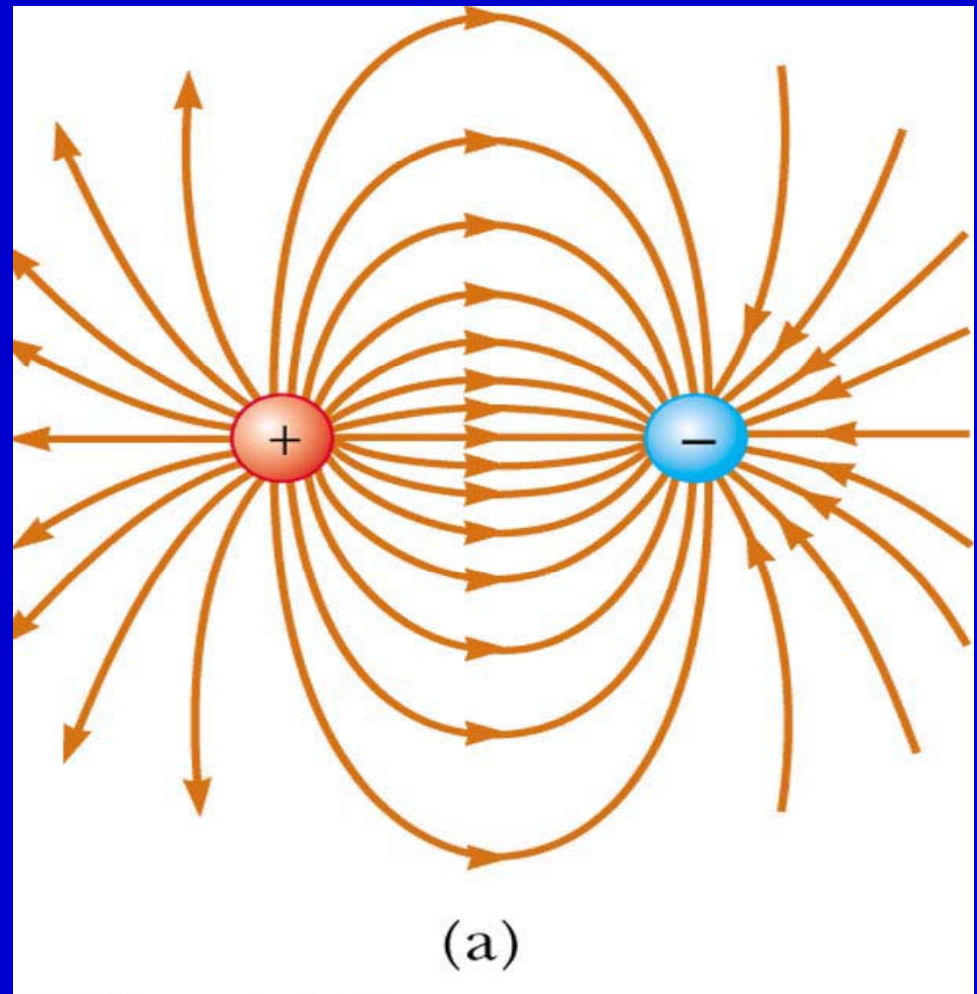
Electric Field Line Patterns

- For a negative source charge, the lines will point inward

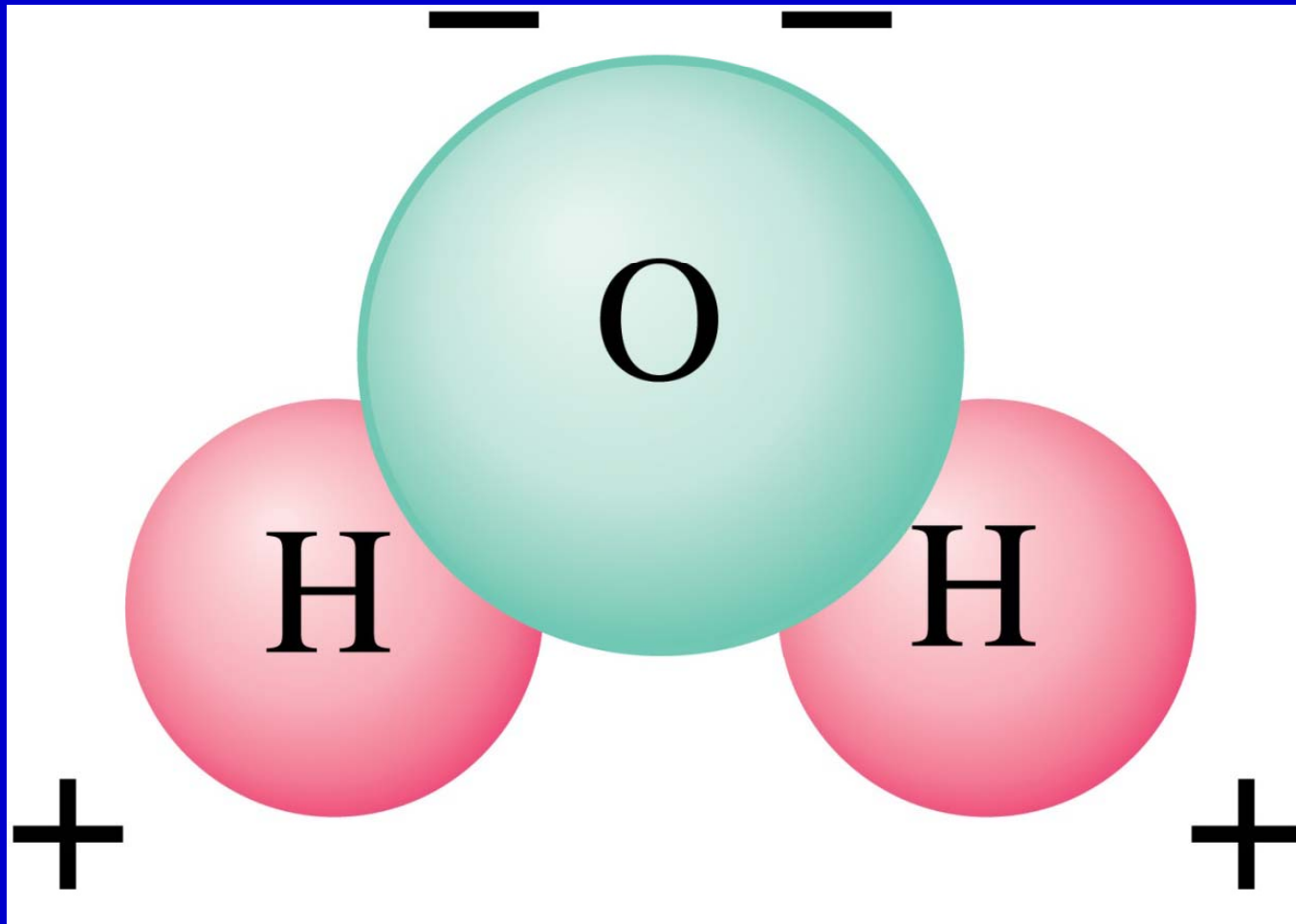


Electric Field Line Patterns

- An electric *dipole* consists of two equal and opposite charges
- The high density of lines between the charges indicates the strong electric field in this region

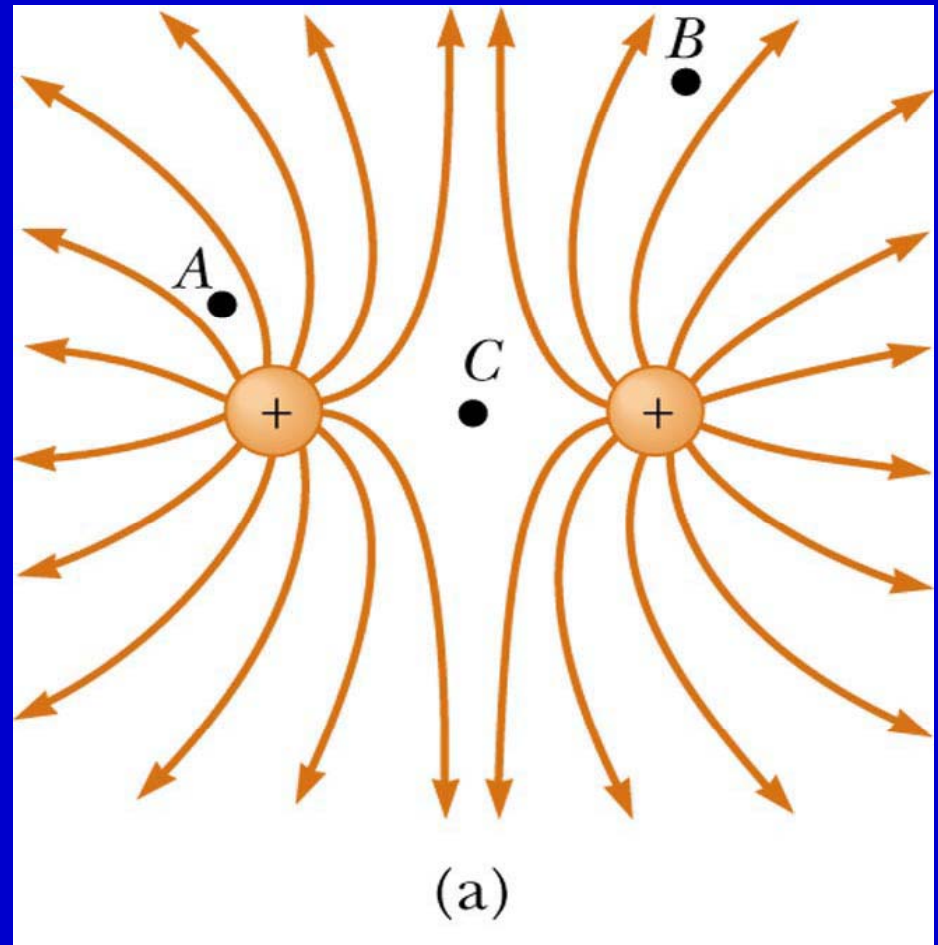


Polar molecule: neutral overall, but charge not evenly distributed



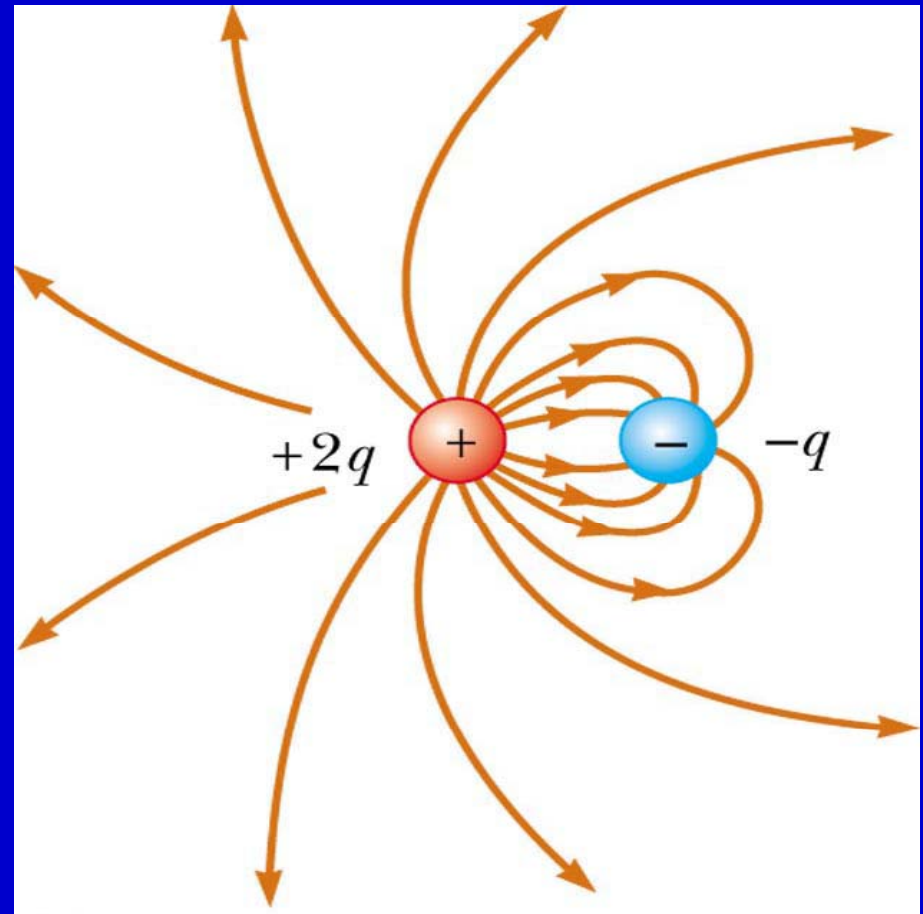
Electric Field Line Patterns

- Two equal but like point charges
- At a great distance from the charges, the field would be approximately that of a single charge of $2q$
- The bulging out of the field lines between the charges indicates the repulsion between the charges



Electric Field Patterns

- Unequal and unlike charges
- Note that two lines leave the $+2q$ charge for each line that terminates on $-q$



Rules for Drawing Electric Field Lines

- The lines for a group of charges must begin on positive charges and end on negative charges
 - In the case of an excess of charge, some lines will begin or end infinitely far away
- The number of lines drawn leaving a positive charge or ending on a negative charge is proportional to the magnitude of the charge
- No two field lines can cross each other

Conductors in Electrostatic Equilibrium

- When no net motion of charge occurs within a conductor, the conductor is said to be in electrostatic equilibrium
- An isolated conductor has the following properties:
 - The electric field is zero everywhere inside the conducting material
 - Any excess charge on an isolated conductor resides entirely on its surface
 - The electric field just outside a charged conductor is perpendicular to the conductor's surface
 - On an irregularly shaped conductor, the charge accumulates at locations where the radius of curvature of the surface is smallest (that is, at sharp points)

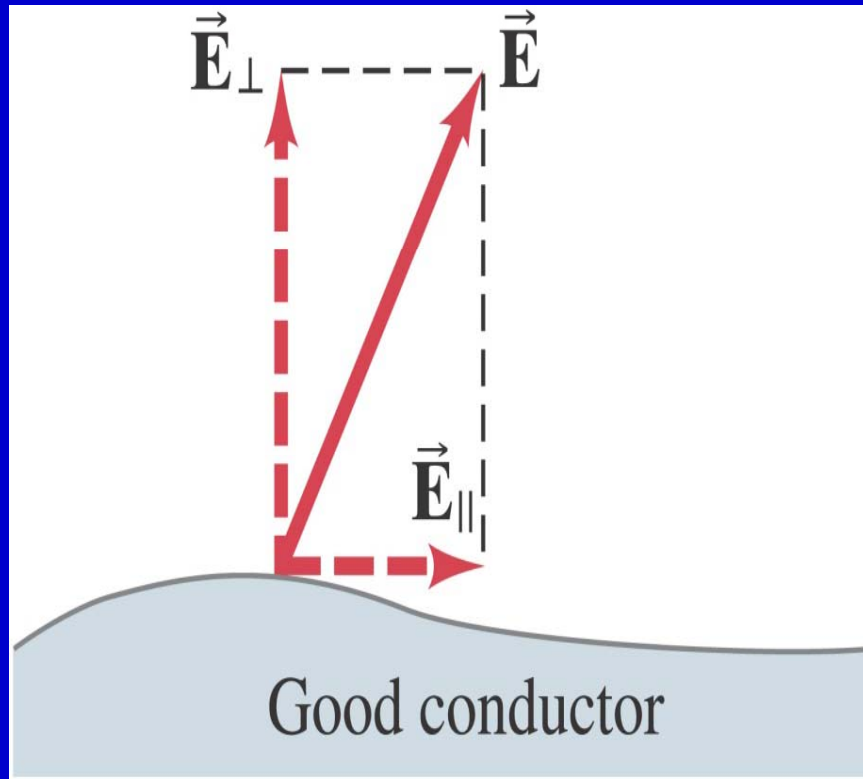
Property 1

- The electric field is zero everywhere inside the conducting material
 - Consider if this were *not* true
 - if there were an electric field inside the conductor, the free charge there would move and there would be a flow of charge
 - If there were a movement of charge, the conductor would not be in equilibrium

Property 2

- Any excess charge on an isolated conductor resides entirely on its surface
 - A direct result of the $1/r^2$ repulsion between like charges in Coulomb's Law
 - If some excess of charge could be placed inside the conductor, the repulsive forces would push them as far apart as possible, causing them to migrate to the surface

Property 3



- The electric field just outside a charged conductor is perpendicular to the conductor's surface
 - Consider what would happen if this was not true
 - The component along the surface would cause the charge to move
 - It would not be in equilibrium