PHYS 2321: Physics 2
Week 1 on Charge and Electric Fields

Day 1 outline

1) Safe seating – only touch towlets
2) Attendance – Ever been shocked, electrocuted, or otherwise inconvenienced by electromagnetic phenomena?
3) Discuss syllabus
4) Begin Ch. 23 “Electric Fields”
    a) charge
    b) electrostatic forces
5) Homework for Friday:
    a) read Ch. 23 Sec. 1-4
    b) Ch. 23 Probs. 2-5,7,8,10,14
    c) try practice quizzes and PhET simulation

This powerpoint will appear on class web page.

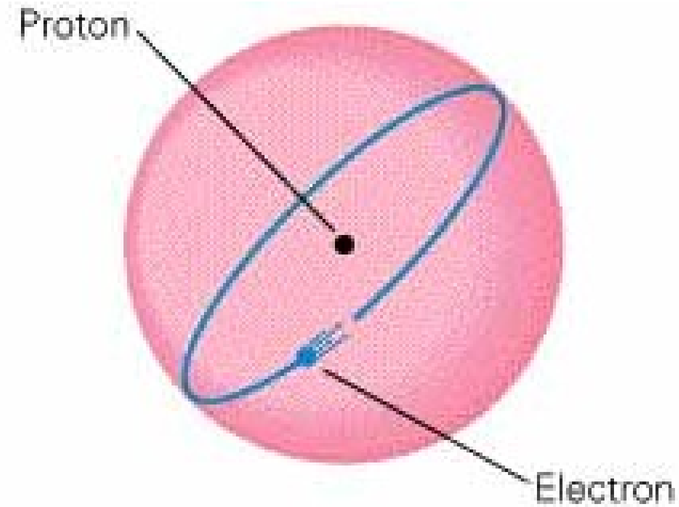
CHARGE !!!

What is charge?

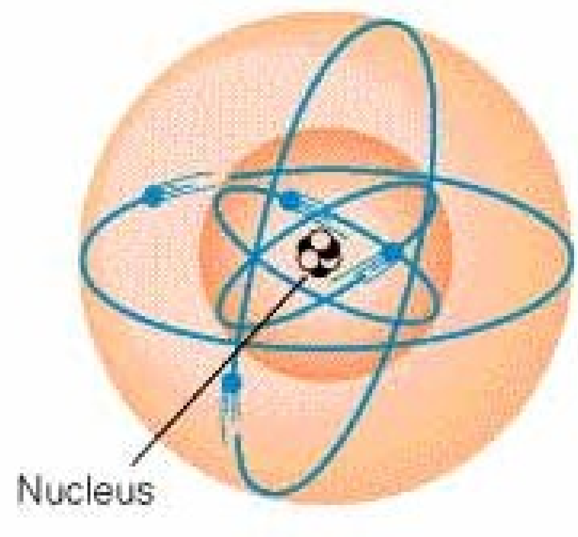
1) A property of sub-atomic particles
2) That which flows in an electric current
3) An imbalance of the + and – particles in an object
4) That which causes “static cling”

1) A property of sub-atomic particles

- Planetary (orbital) Model
  - Neils Bohr (1885-1962)
  - Not really correct, but simple
- Atoms composed of:
  - Protons $m_p = 1.673 \times 10^{-27}$ kg
  - Neutrons $m_n = 1.675 \times 10^{-27}$ kg
  - Electrons $m_e = 9.109 \times 10^{-31}$ kg
- Properties of sub-atomic particles:
  - Mass
  - Charge
  - spin



(a) Hydrogen atom



(b) Beryllium atom

1) A property of sub-atomic particles

- Protons

  $q_p = +1.602 \times 10^{-19}$ C **(C = Coulomb for SI units)**

  $q_p = +e$ ($e = 1.602 \times 10^{-19}$ C, *elementary charge*)

- Electrons

  $q_e = -1.602 \times 10^{-19}$ C

  $q_e = -e$

- Neutrons

  $q_n = 0$ C neutral

- Charge is *Quantized*
  - Any object may have a *net charge* of $q = \pm ne$

    or $q = (n_p - n_e)e$
  - Quarks can actually have charges of $q=+2e/3$ and $-e/3)$

CHARGE !!!

What is charge?

1) A property of sub-atomic particles
2) **That which flows in an electric current**

I = current = flow rate of charge carriers past a 2D boundary
[I] = coulombs/sec = C/s
1 C/s = 1 Ampere

* 1 Amp is a deadly amount of current (>0.1 A)
* 1 Coulomb is an even deadlier amount of charge

Ex) 2 objects with 1 C of excess charge separated by 1 m
Exerts 9×10^9 N on each other !! (note: 4.45 N/lb)

CHARGE !!!

What is charge?

1) A property of sub-atomic particles
2) That which flows in an electric current
3) **An imbalance of the + and – particles in an object**

a) We say an object is “charged” when there are more + particles than – particles, or more – particles than + particles.

Ex) What is the charge on a sphere containing $Np=10^{20}$ protons

and $Ne=1.1\text{x}10^{20}$ electrons?

Ans: since $Ne > Np$, $q = (Ne-Np)\ (-e)$

$$q = (1.1-1.0)\text{x}10^{20} \text{ X } (-1.6\text{x}10^{-19} \text{ C})$$

$$q = -1.6 \text{ C}$$

b) Large imbalances are rare because oppositely charged particles attract.

Ex) How many electrons are contained in 1 cm^3 of neutral copper?

Ans: about a mole, $\sim 10^{23}$! (Each Cu atom has 29 e-)

3) An imbalance of the + and – particles in an object

Conservation of Charge

- The net charge of an isolated system remains constant.
  - Rubbing two objects together does not create new charge, it separates + from -
  - Material with higher “electronegativity” obtains more e-
  - Pair-production: when a high energy photon (gamma-ray) becomes two, oppositely charged particles.
    - Ex) $\gamma \rightarrow e^- + e+$
  - Annhilation: when a particle meets its antiparticle and they become a high-energy photon
    - Ex) $e^- + e+ \rightarrow \gamma$

CHARGE !!!

What is charge?

1) A property of sub-atomic particles
2) That which flows in an electric current
3) An imbalance of the + and – particles in an object
4) **That which causes "static cling"**

- Static electric force is called the "Coulomb force" in physics.
- Large scale objects (like pants) are normally neutral.
- They become charged by:

  a) rubbing against a <u>different</u> material

  b) pealing apart two objects stuck together

  c) disassociation of molecules

  d) photoelectric effect (can make metals +)

  e) bombardment by charged particles (α or β beams)

PHYS 2321: Physics 2
Week 1 on Charge and Electric Fields

Day 2 outline

1) Safe seating – only touch towlets
2) Attendance – Pictures
3) Homework for Friday:
   a) read Ch. 23 Sec. 1-4
   b) Ch. 23 Probs. 2-5,7,8,10,14 (due Fri 11:59pm, G.Drive)
   c) try practice quizzes and PhET simulation
4) Today: Charge and Coulomb's Law
   a) demos showing charge separation and static electric forces
   b) Coulomb's Law

This powerpoint will appear on class web page.

CHARGE Demos

Recall that:

1. An object is “charged” when there is an imbalance of + and - particles.
2. We can tell that something is charged by the electrostatic force is exerts (“static cling”).

We can also tell that something *was* charged when a spark is seen or heard.

CHARGE Demos

Balloons

1. Touch red and blue balloons against wall. What happens?

   No force.

2. Bring red balloon close to blue balloon. Anything?

   No force.

3. Rub two balloons together, then hold close to wall. Anything?

   No force.

4. Rub red balloon against hair, then touch against wall.
   What happens?

   Attraction! (To both hair and wall).

5. Bring blue balloon close to red balloon. Anything?

   Weak attraction.

6. Touch blue balloon against red. Will blue now stick to wall?

   Not much force.

CHARGE Demos

Balloons (cont.)

7. Rub blue balloon against hair. Hold red close to blue. Anything?
   Repulsion!

Conclusions?

* Sticking to wall is not due to “stickiness” of balloons but because they are getting charged by rubbing.
* Two balloons prepared in the same way (rubbed against hair) will repel each other. → *Like charges repel.*
* The wall was never rubbed, but it was attracted to a charged balloon.
  This requires more thought ...

CHARGE Demos

Balloons + tape

8. A piece of Scotch tape pulled off of the back of another piece of Scotch tape gets charged. What happens when tape is held close to a (neutral) hand?

   Attraction!

9. What happens when held close to a negative balloon?

   Attraction!

10. What is likely the sign of the tape's charge?

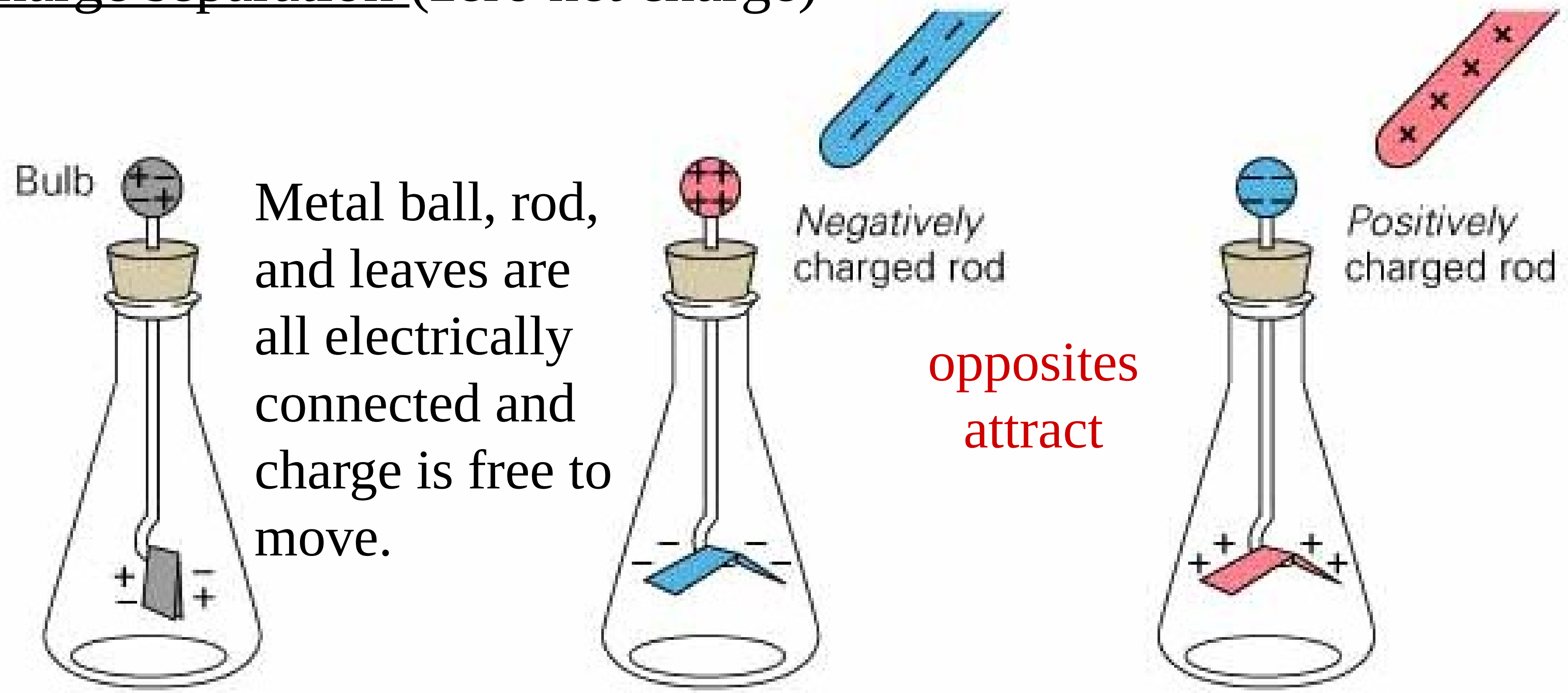
   Positive.   (there's another possibility involving induction...)

Conclusions:

* "Unsticking" two objects can lead to charging.
* Tape was attracted to negative balloon. –> *opposites attract.*

Electroscope – used to study electric charge

- A neutral electroscope can determine if an object is charged
- A charged object *induces* a charge separation – an INDUCED charge separation (zero net charge)



Metal ball, rod, and leaves are all electrically connected and charge is free to move.

opposites attract

(a) Neutral electroscope has charges evenly distributed; leaves are close together.

(b) Electrostatic forces cause leaves to separate.

CHARGE Demos

Balloon + electroscope.

11. Hold charged balloon close to electrode of electroscope. Anything?

Petals rise.

12. Suppose we define the balloon's charge to be negative, what is the charge on the petals?

Negative, because like charges repel.

Other objects + electroscope

13. Rub a plastic rod with wool/felt cloth. Is it charged?

Probably raises petals. Should be negative.

14. Rub glass rod with silk. Charged?

Should be positive.

15. Rub metal bar with cloth. (Need to hold bar with insulator!)

Hard to observe charging. Can metal be charged?

CHARGE Demos

Balloon + aluminum bob.

16. Hold negative balloon next to untouched (neutral) bob. What happens?

 Bob attracts towards balloon.

17. Rub negative balloon against aluminum bob. What happens?

 If enough charge transfers, the bob will now repel!

18. Bring a neutral object (finger?) close to the bob. What happens?

 Attraction. Alum bob must be charged!

19. Hold the bob in bare hand. Any change?

 No attraction. Bob no longer charged.

Conclusions:

*Metal can be charged by direct contact.

*Metal can be easily discharged by contact with something that is grounded.

CHARGE Demos

Balloon + electroscope.

20. Move charged balloon close and far from electroscope. Notice a change in the petals?

Usually, petals will rise as balloon nears.

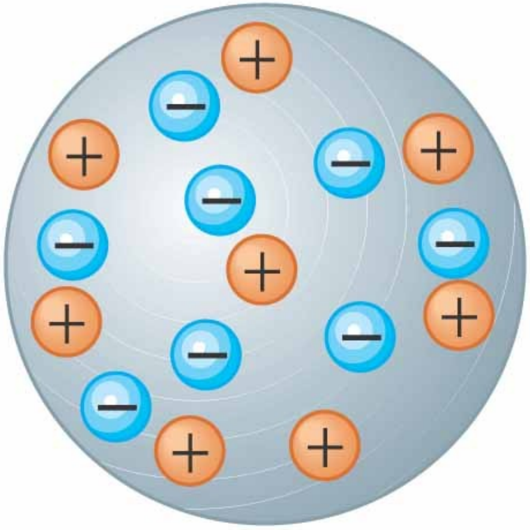
Conclusion:

*Electric forces/fields weaken with distance.

Now, back to the question of why a charged object attracts to a neutral one …

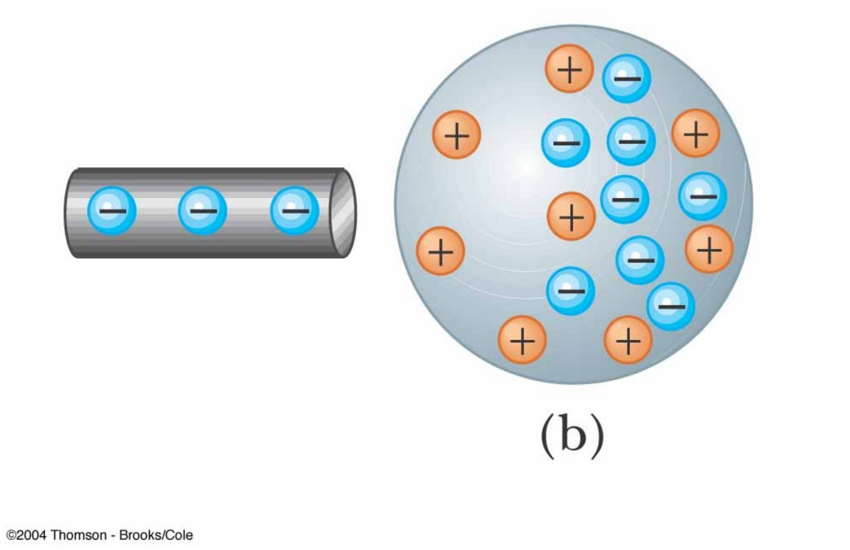
Charging by Induction

- Charging by induction requires no contact with the object inducing the charge
- Assume we start with a neutral metallic sphere
  - The sphere has the same number of positive and negative charges


(a)

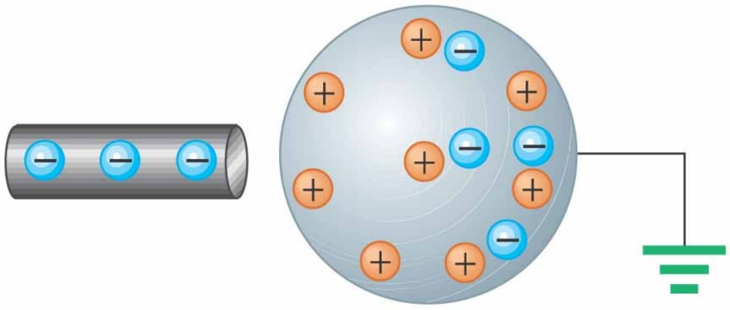
Charging by Induction, 2

- A charged rubber rod is placed near the sphere
  - It does **not** touch the sphere
- The electrons in the neutral sphere are redistributed



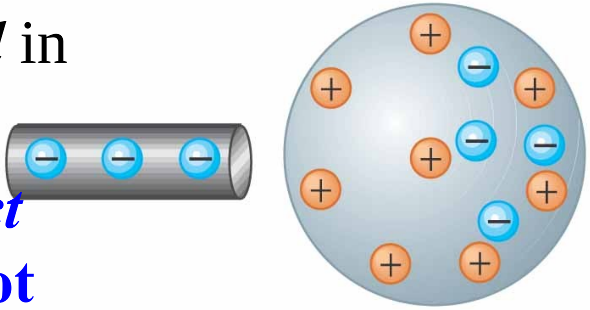
Charging by Induction, 3

- The sphere is grounded
- Some electrons can leave the sphere through the ground wire


(c)

Charging by Induction, 4

- The ground wire is removed
- There will now be more positive charges
- The charges are not uniformly distributed
- The positive charge has been ***induced*** in the sphere

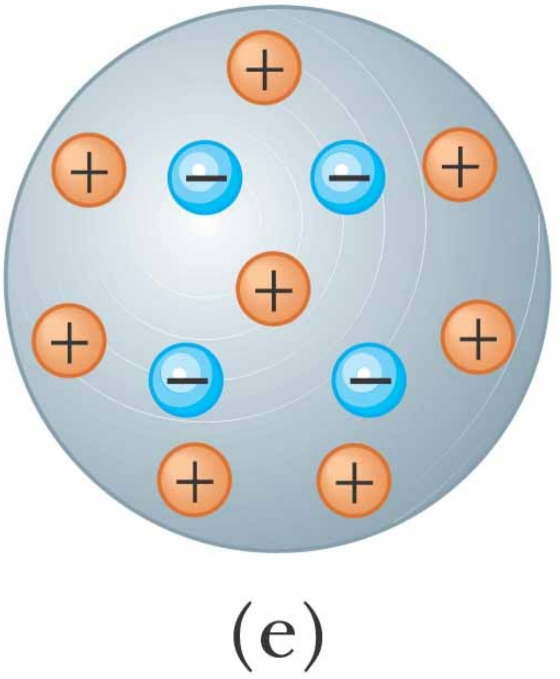

(d)

A charged insulator brought *in contact* with a conductor can stick to it and not loose its excess charge.

A charged conductor will not stick to another conductor for long because excess charge flows!

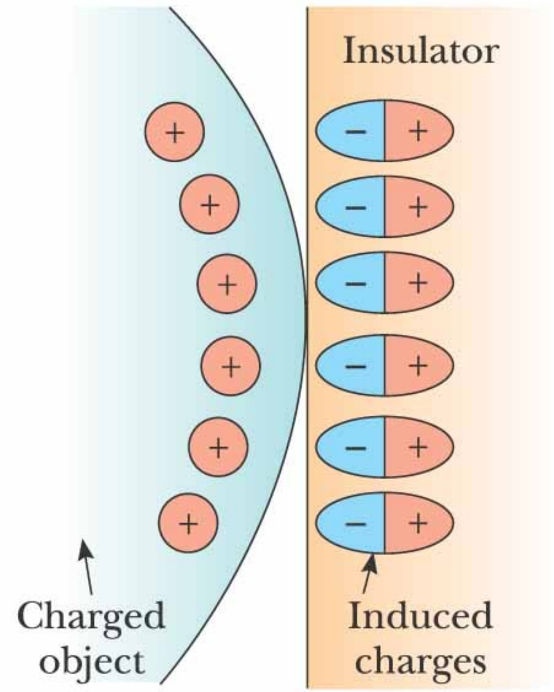
Charging by Induction, 5

- The rod is removed
- The electrons remaining on the sphere redistribute themselves
- There is still a net positive charge on the sphere
- The charge is now uniformly distributed



Charge Rearrangement in Insulators

- A similar electrostatic induction can take place in insulators
- The charges within the molecules of the material are rearranged
- The molecules of the insulator become *polarized*



(a)

CHARGE Demos

Wimshurst machine – separates charge via induction.

21. If starting "cold", operator should hold a charged object (plastic wand) opposite a "neutralizer bar". Why?

This charges sectors on the opposite side via induction.

22. What happens after prolonged cranking?

Sparks occur between electrodes. This indicate very strong electric fields that break down the insulative property of air and allow it to briefly conduct.

23. Connect one collection brush to the electroscope. What happens?

Petals rise until spark makes them drop → spark transfers charge

24. Connect a collection brush to the "spinner". It spins!

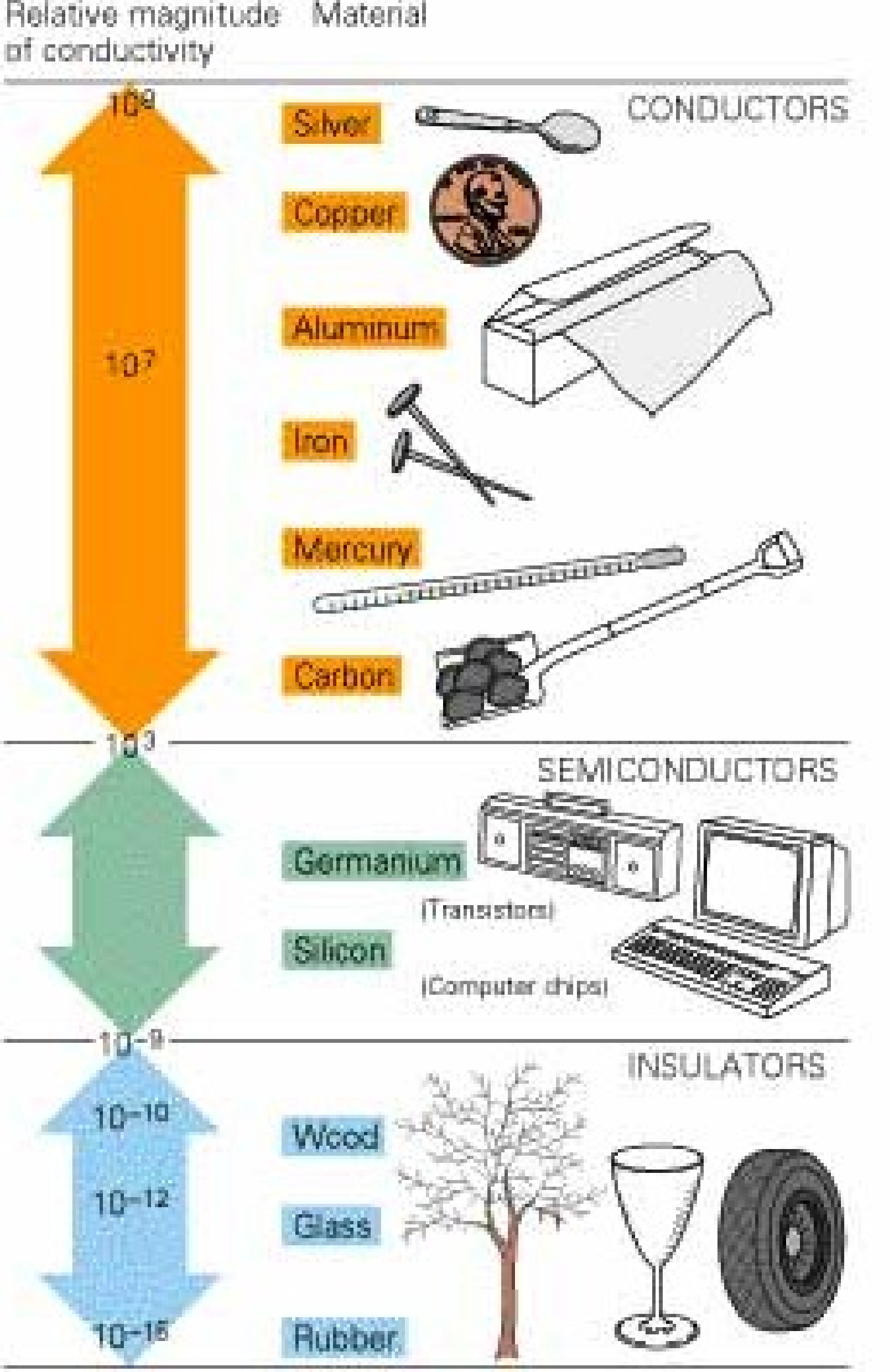
25. Put the aluminum bob between the electrodes and crank.

The bob alternates the sign of its charge on each contact.

How wimshurst machine works: https://www.youtube.com/watch?v=nA4aCd5qFWs

Electrical Conduction

- Electrical conductivity is a property of a material
  - Ability to transmit electrical charge
  - Depends on bond strength of outer electrons
    - loosely or tightly bound
- Conductors
  - Metals (electrons very mobile)
    - valance electrons easily move
  - Water conducts b/c of impurities (ions)
- Semi-conductors
- Insulators (poor conductors)
  - Plastics, pure water, rubber

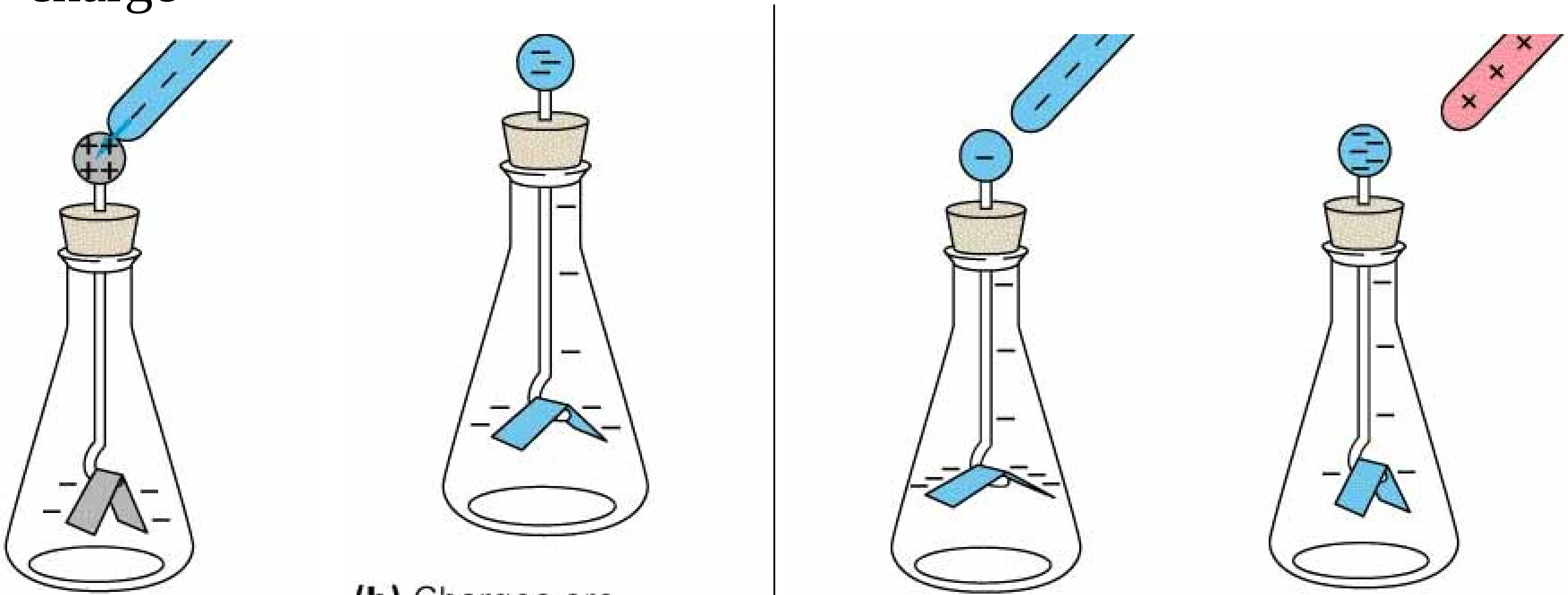


Charging …

- **CONTACT OR CONDUCTION**

  + and – charges cancel, leaving behind a net charge

  – Note that (c) and (d) can distinguish between the two types of charge



(a) Neutral electroscope is touched with negatively charged rod.

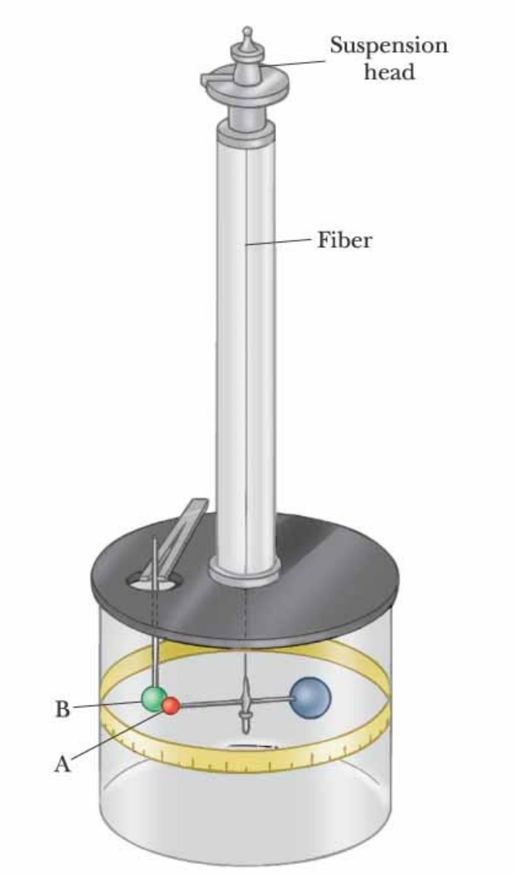
(b) Charges are transferred to bulb; electroscope has net negative charge.

(c) Negatively charged rod repels electrons; leaves separate furthe

(d) Positively charged rod attracts electrons; leaves collapse.

Coulomb’s Law

- Charles Coulomb measured the magnitudes of electric forces between two small charged spheres
- He found the force depended on the charges and the distance between them
- $F \propto 1/r^2$



Point Charge

- The term **point charge** refers to a particle of zero size that carries an electric charge
  - The electrical behavior of electrons and protons is well described by modeling them as point charges

Coulomb's Law, 2

- The electrical force between two stationary point charges is given by Coulomb's Law
- The force is inversely proportional to the square of the separation r between the charges and directed along the line joining them
- The force is proportional to the product of the charges, q_1 and q_2, on the two particles

Coulomb’s Law, 3

- The force is attractive if the charges are of opposite sign
- The force is repulsive if the charges are of like sign
- The force is a conservative force

Coulomb’s Law, Equation

- The *magnitude* of the Coulomb force is:

$$F_e = k_e \frac{|q_1|\,|q_2|}{r^2}$$

- The SI unit of charge is the **coulomb** (C)
- k_e is called the **Coulomb constant**
  - $k_e = 8.9876 \times 10^9\ \mathrm{N{\cdot}m^2/C^2} = 1/(4\pi e_o)$
  - e_o is the **permittivity of free space**
  - $e_o = 8.8542 \times 10^{-12}\ \mathrm{C^2 / N{\cdot}m^2}$

Coulomb's Law, Notes

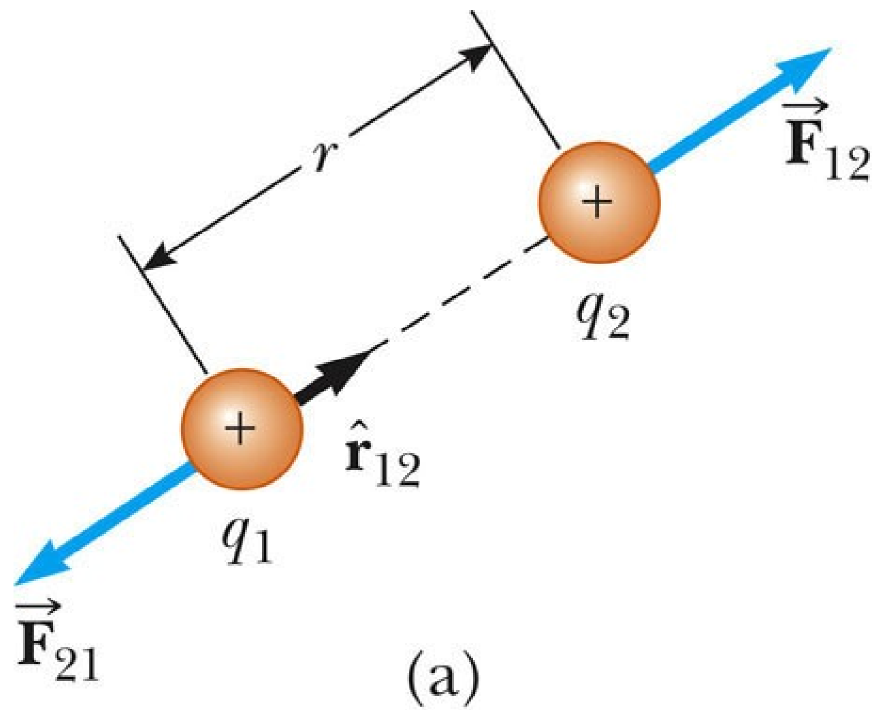
- Remember the charges need to be in coulombs
  - e is the smallest unit of charge
    - except quarks
  - $e = 1.6 \times 10^{-19}$ C
  - So 1 C needs 6.24×10^{18} electrons or protons
- Typical charges can be in the μC range
- Remember that force is a *vector* quantity

Vector Nature of Electric Forces

- In vector form,

$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

- $\hat{r}_{12}$ is a unit vector directed from q_1 to q_2
- The like charges produce a repulsive force between them
- Use the active figure to move the charges and observe the force



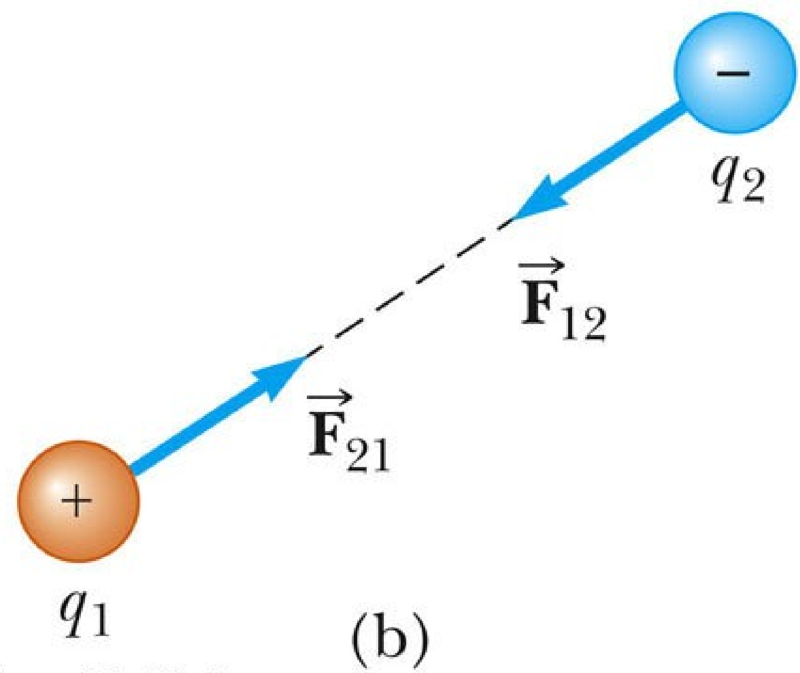
PLAY ACTIVE FIGURE

Vector Nature of Electrical Forces, 2

- Electrical forces obey Newton's Third Law
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2
  - $\vec{F}_{21} = -\vec{F}_{12}$
- With like signs for the charges, the product $q_1 q_2$ is positive and the force is repulsive

Vector Nature of Electrical Forces, 3

- Two point charges are separated by a distance *r*
- The unlike charges produce an attractive force between them
- With unlike signs for the charges, the product q_1q_2 is negative and the force is attractive
  - Use the active figure to investigate the force for different positions



PLAY
ACTIVE FIGURE

A Final Note about Directions

- The sign of the product of q_1q_2 gives the *relative* direction of the force between q_1 and q_2
- The *absolute* direction is determined by the actual location of the charges

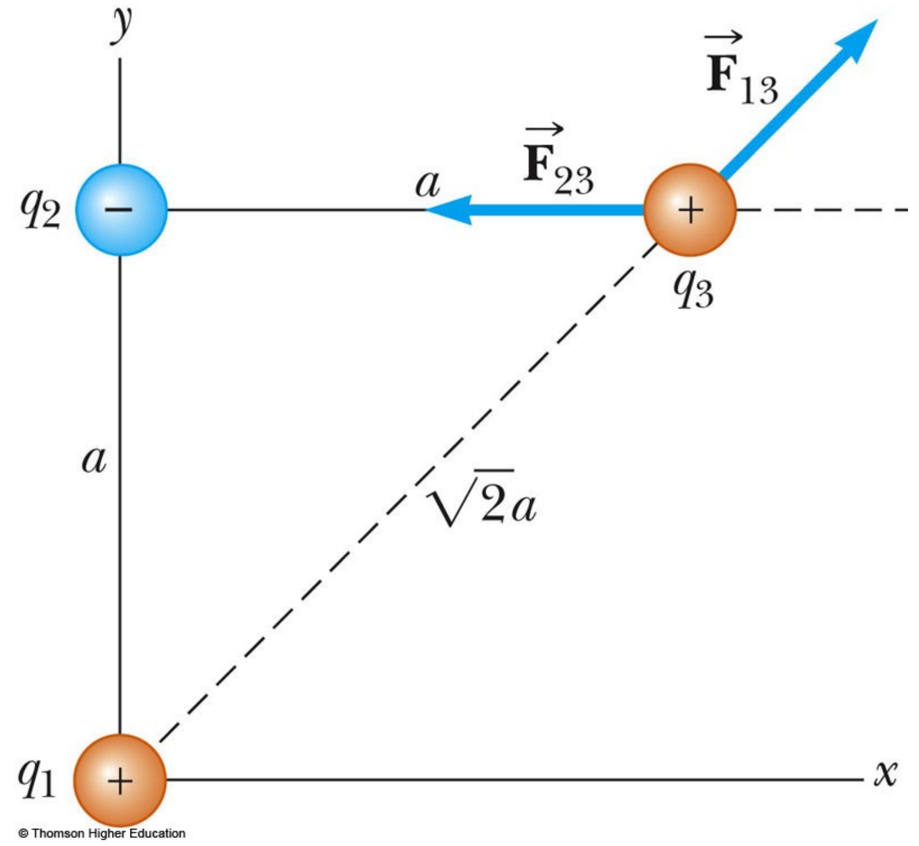
The Superposition Principle

- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present
  - Remember to add the forces *as vectors*
- The resultant force on q_1 is the vector sum of all the forces exerted on it by other charges:

$$\vec{F}_1 = \vec{F}_{21} + \vec{F}_{31} + \vec{F}_{41}$$

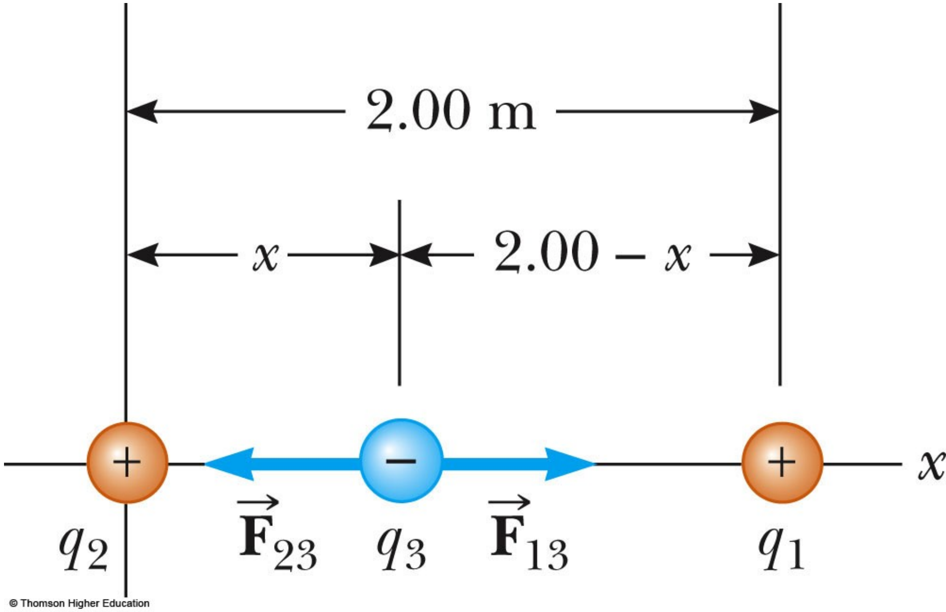
Superposition Principle, Example

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



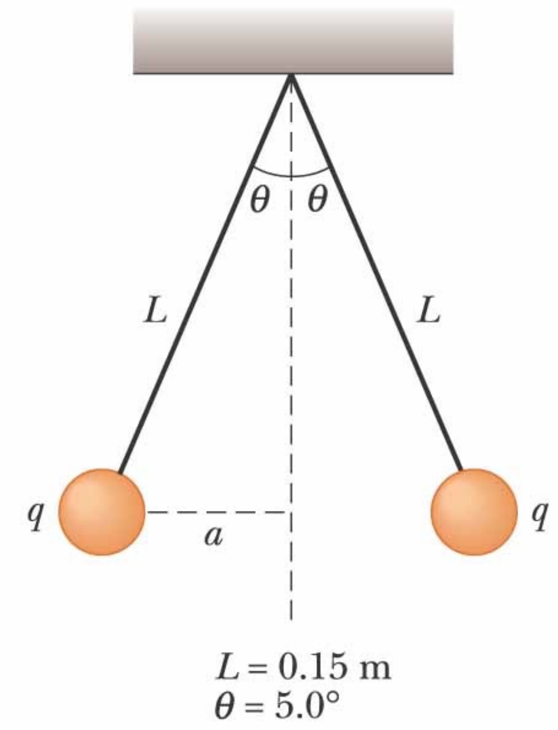
Zero Resultant Force, Example

- Where is the resultant force equal to zero?
  - The magnitudes of the individual forces will be equal
  - Directions will be opposite
- Will result in a quadratic
- Choose the root that gives the forces in opposite directions



Electrical Force with Other Forces, Example

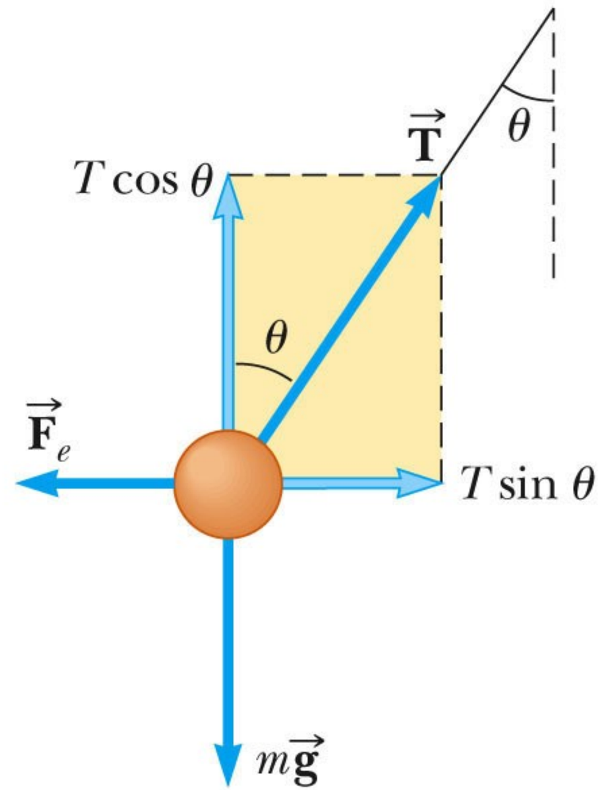
- The spheres are in equilibrium
- Since they are separated, they exert a repulsive force on each other
  - Charges are like charges
- Proceed as usual with equilibrium problems, noting one force is an electrical force



(a)

Electrical Force with Other Forces, Example cont.

- The free body diagram includes the components of the tension, the electrical force, and the weight
- Solve for $|q|$
- You cannot determine the sign of q, only that they both have same sign



(b)