## Note on Posted Slides

- These are the slides that I intended to show in class on Wed. Mar. 13, 2013.
- They contain important ideas and questions from your reading.
- Due to time constraints, I was probably not able to show all the slides during class.
- They are all posted here for completeness.

PHY205H1S
Physics of Everyday Life
Class 16:
**Electrostatics**

- Electrical Forces and Charges
- Conservation of Charge
- Coulomb's Law
- Conductors and Insulators
- Charging
- Charge Polarization
- Electric Field
- Electric Potential
- Electric Energy Storage

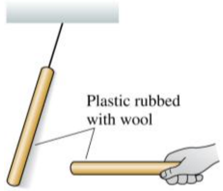
## Electricity

- Electricity is the name given to a wide range of electrical phenomena, such as
  - lightning.
  - spark when we strike a match.
  - what holds atoms together.
- Electrostatics involves electric charges,
  - the forces between them,
  - the aura that surrounds them, and
  - their behavior in materials.

## Benjamin Franklin (1706-1790)

- Recognized that there were two types of electric charge.
- When a glass rod was rubbed with silk, it became charged in one way; Franklin called this "positive"
- When a piece of amber was rubbed with animal fur, it became charged in the opposite way; Franklin called this "negative".

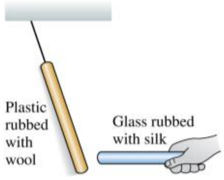
## Discovering Electricity: Experiment 2




- Rub both plastic (or amber!) rods with wool or fur.
- Now the hanging rod tries to move away from the handheld rod when you bring the two close together.
- Two glass rods rubbed with silk also repel each other.

There is a *long-range repulsive force*, requiring no contact, between two identical objects that have been charged in the *same* way.

## Discovering Electricity: Experiment 3



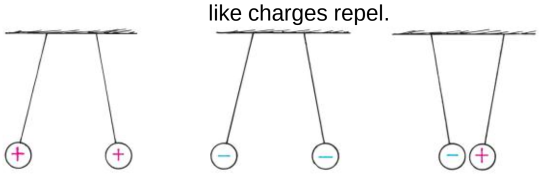

- Bring a glass rod that has been rubbed with silk close to a hanging plastic rod that has been rubbed with wool.
- These two rods *attract* each other.

These particular two types of rods are different materials, charged in a somewhat different way, and they *attract* each other rather than repel.

## Electric Force

- When two objects have electric charges, there is a long-range force between them called the **electric force**.
- The rule for the electric force is:

Opposite charges attract one another;
like charges repel.



## 20th Century Discovery: Atomic Structure

Protons

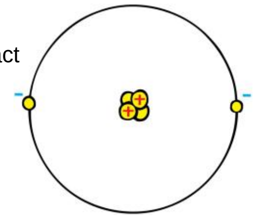
- Positive electric charges
- Repel positives, but attract negatives

Electrons

- Negative electric charges
- Repel negatives, but attract positives

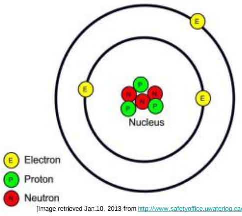
Neutrons

- No electric charge
- “neutral”



## Fundamental facts about atoms

1. Every atom is composed of a positively charged nucleus surrounded by negatively charged electrons.
2. Each of the electrons in any atom has the same quantity of negative charge and the same mass.

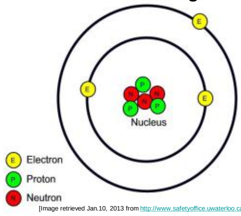



Lithium Atom
Net charge = 0

[Image retrieved Jan.10, 2013 from http://www.safetyoffice.uwaterloo.ca/hse/radiation/rad_sealed/matter/atom_structure.htm ]

## Fundamental facts about atoms

3. Protons and neutrons compose the nucleus. Protons are about 1800 times more massive than electrons, but each one carries an amount of positive charge equal to the negative charge of electrons. Neutrons have slightly more mass than protons and have no net charge.

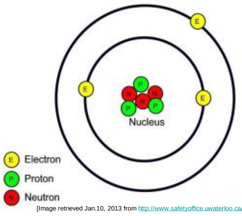



Lithium Atom
Net charge = 0

[Image retrieved Jan.10, 2013 from http://www.safetyoffice.uwaterloo.ca/hse/radiation/rad_sealed/matter/atom_structure.htm ]

## Fundamental facts about atoms

4. Atoms usually have as many electrons as protons, so the atom has zero net charge.




Lithium Atom
Net charge = 0

[Image retrieved Jan.10, 2013 from http://www.safetyoffice.uwaterloo.ca/hse/radiation/rad_sealed/matter/atom_structure.htm ]

## An “Ion” is a charged atom

- Positive ion — an atom which has lost one or more of its electrons, and so has a positive net charge.
- Negative ion — an atom which has gained one or more electrons, and so has a negative net charge.

**Electric Force and Charges**
**CHECK YOUR NEIGHBOR**

When you rub a glass rod with silk, the glass rod becomes positively charged. (As per Benjamin Franklin's definition of "positive".)
What is going on here?

A. The silk is adding electrons to the glass.
B. The silk is adding protons to the glass.
C. The silk is removing electrons from the glass.
D. The silk is removing protons to the glass.
E. The frictional force is generating positive charge within the glass.

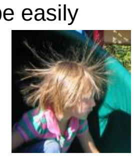
**Electric Force and Charges**
**CHECK YOUR NEIGHBOR**

When you rub a plastic rod with fur or wool, the plastic rod becomes negatively charged. (As per Benjamin Franklin's definition of "negative".)
What is going on here?

A. The fur or wool is adding electrons to the plastic.
B. The fur or wool is adding protons to the plastic.
C. The fur or wool is removing electrons from the plastic.
D. The fur or wool is removing protons to the plastic.
E. The frictional force is generating positive charge within the plastic.

## Electrons in an atom

- Innermost—attracted very strongly to oppositely charged atomic nucleus
- Outermost—attracted loosely and can be easily dislodged



Examples:

- When rubbing a comb through your hair, electrons transfer from your hair to the comb. Your hair has a deficiency of electrons (positively charged).
- When rubbing a glass rod with silk, electrons transfer from the rod onto the silk and the rod becomes positively charged.

[image from http://www.sciencebuddies.org/blog/2011/02/the-shock-of-static-electricity.php ]

# Conservation of Charge

## Conservation of charge

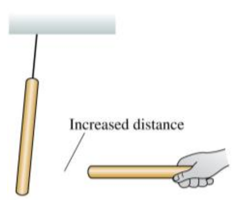
- In any charging process, no electrons are created or destroyed. Electrons are simply transferred from one material to another.

**Electric Force and Charges**
**CHECK YOUR NEIGHBOR**

When you rub a glass rod with silk, the glass rod becomes positively charged.
What do you expect will happen to the piece of silk?

A. The silk will also become positively charged.
B. The silk will become negatively charged.
C. The silk will remain neutral.

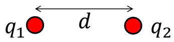
## Discovering Electricity: Experiment 4




- Rub rods with wool or silk and observe the forces between them.
- These forces are greater for rods that have been rubbed more vigorously.
- The strength of the forces decreases as the separation between the rods increases.

The force between two charged objects depends on the distance between them.

# Coulomb's Law




- The magnitude of the force, *F*, between two point charges depends on the product of their charges, and the distance between them.
- In equation form:

$$F = k\frac{q_1 q_2}{d^2} \qquad k = 9\times10^9\ \mathrm{Nm^2/C^2}$$

- Unit of charge is **coulomb**, C
- Similar to Newton's law of gravitation for masses
- Underlies the bonding forces between molecules
- Electrical forces may be either attractive or repulsive.
- Gravitational forces are only attractive.

**Coulomb's Law**
**CHECK YOUR NEIGHBOR**

According to Coulomb's law, a pair of particles that are placed twice as far apart will experience forces that are

A. half as strong.
B. one-quarter as strong.
C. twice as strong.
D. 4 times as strong.

**Discussion question.**
**Charges A and B exert repulsive forces on each other. $q_A = 4q_B$. Which statement is true?**


A. $F_{\text{A on B}} > F_{\text{B on A}}$
B. $F_{\text{A on B}} < F_{\text{B on A}}$
C. $F_{\text{A on B}} = F_{\text{B on A}}$

# Conductors and Insulators

- **Conductors**: Materials in which one or more of the electrons in the outer shell of its atoms are not anchored to the nuclei of particular atoms but are free to wander in the material
  - Example: Metals such as copper and aluminum

- **Insulators:** Materials in which electrons are tightly bound and belong to particular atoms and are not free to wander about among other atoms in the material, making them flow
  - Example: Rubber, glass

# Superconductors

- Superconductors: Materials acquire zero resistance (infinite conductivity) to the flow of charge.
  - Once electric current is established in a superconductor, the electrons flow indefinitely.
  - With no electrical resistance, current passes through a superconductor without losing energy.
  - No heat loss occurs when charges flow.

**Conductors and Insulators**
**CHECK YOUR NEIGHBOR**

When you buy a water pipe in a hardware store, the water isn't included. When you buy copper wire, electrons

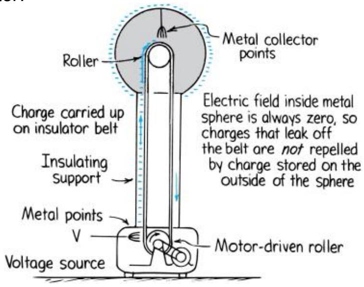
A. must be supplied by you, just as water must be supplied for a water pipe.
B. are already in the wire.
C. may fall out, which is why wires are insulated.
D. None of the above.

# Test 2 is marked

- Versions 1 and 2, written at 2pm, contain completely different questions than versions 3 and 4, written at 5pm.
- 180 students wrote the 2pm test and their raw average was 23.9 / 36.
- 164 students wrote the 5pm test, and their raw average was 25.4 / 36.
- I believe the reason for the different averages was that the 2pm test was a bit more difficult
- Therefore, I adjusted the marks of every student who wrote version 1 or 2 by +1.5.
- There was no adjustment for versions 3 or 4.
- The adjusted average is 25.4 / 36 = 71%

# Electric Energy Storage

- A common laboratory device for producing high voltages and creating static electricity is the *Van de Graaff generator*.




# Charging

- Charging by friction and contact.

  Example:

  Stroking cats fur, combing your hair, rubbing your shoes on a carpet

- Electrons transfer from one material to another by simply touching. For example,
  - when a negatively charged rod is placed in contact with a neutral object, some electrons will move to the neutral object.

- Charging by induction
  - If you bring a charged object *near a conducting surface, electrons are made to* move in the surface material, even without physical contact.
  - Example: The negative charge at the bottom of the cloud induces a positive charge on the buildings below.

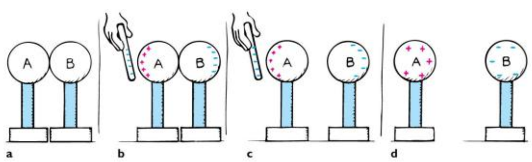
# Charging by Induction

Induction: Consider two insulated metal spheres A and B.

a. They touch each other, so in effect they form a single uncharged conductor.

b. When a negatively charged rod is brought near A, electrons in the metal, being free to move, are repelled as far as possible until their mutual repulsion is big enough to balance the influence of the rod. The charge is redistributed.

c. If A and B are separated while the rod is still present, each will be equal and oppositely charged.

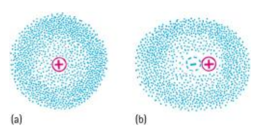



# Charge Polarization

- One side of the atom or molecule is induced into becoming more negative (or positive) than the opposite side. The atom or molecule is said to be **electrically polarized.**
- An electron buzzing around the atomic nucleus produces an electron cloud.

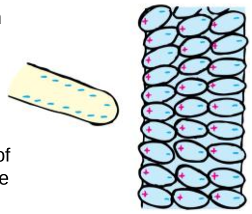
a. The center of the negative cloud normally coincides with the center of the positive nucleus in an atom.

b. When an external negative charge is brought nearby to the right, the electron cloud is distorted so that the centers of negative and positive charge no longer coincide. The atom is now electrically polarized



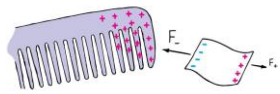
## Charge Polarization

- If the charged rod is negative, then the positive part of the atom or molecule is tugged in a direction toward the rod, and the negative side of the atom or molecule is pushed in a direction away from the rod.
- The positive and negative parts of the atoms and molecules become aligned. They are electrically polarized.



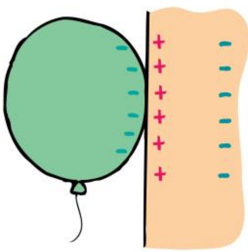
## Charge Polarization

- When a charged comb is brought nearby, molecules in the paper are polarized.
- The sign of charge closest to the comb is opposite to the comb's charge.
- Charges of the same sign are slightly more distant. Closeness wins, and the bits of paper experience a net attraction.

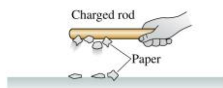


## Charge Polarization

- Rub an inflated balloon on your hair, and it becomes charged.
- Place the balloon against the wall, and it sticks.
- This is because the charge on the balloon induces an opposite surface charge on the wall.
- Again, closeness wins, for the charge on the balloon is slightly closer to the opposite induced charge than to the charge of same sign



## Discovering Electricity: Experiment 5

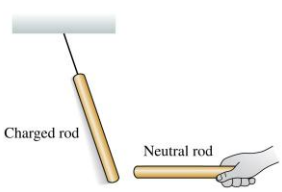



- Hold a charged (i.e., rubbed) plastic rod over small pieces of paper on the table.
- The pieces of paper leap up and stick to the rod.
- A charged glass rod does the same.
- However, a neutral rod has no effect on the pieces of paper.

There is an attractive force between a charged object and a *neutral* (uncharged) object.



## Discovering Electricity: Experiment 6




- Rub a plastic rod with wool and a glass rod with silk.
- Hang both by threads, some distance apart.
- Both rods are attracted to a *neutral* object that is held close.

There is an attractive force between a charged object and a *neutral* (uncharged) object.



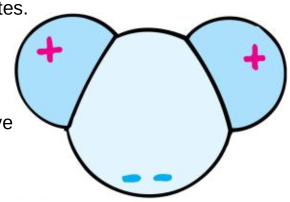
**Discussion Question**

**A sock has just come out of the dryer. You hypothesize that the sock might have a positive charge. To test your hypothesis, which of the following experiments might work?**

A. see if the sock attracts a negatively charged plastic rod.
B. see if the sock repels a positively charged glass rod.
C. Both A and B.
D. Either A or B.

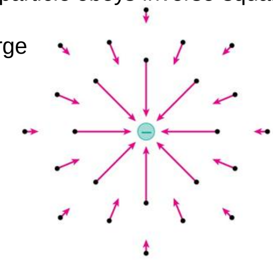
## Charge Polarization

- Many molecules—$H_2O$, for example—are electrically polarized in their normal states.
- The distribution of electric charge is not perfectly even.
- There is a little more negative charge on one side of the molecule than the other.
- Such molecules are said to be *electric dipoles*.



## Electric Field

- Space surrounding an electric charge (an energetic aura)
- Describes electric force
- Around a charged particle obeys inverse-square law
- Force per unit charge

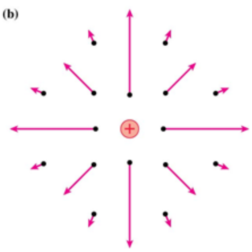


## Electric Field

Electric field direction

- Same direction as the force on a positive charge
- Opposite direction to the force on an electron

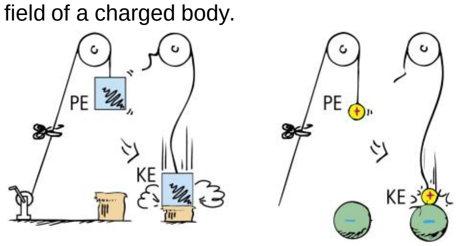
(b)



## Electric Potential

Electric potential energy

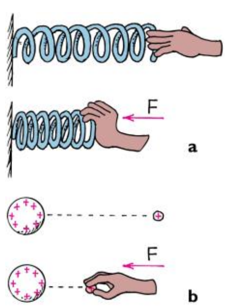
- Energy possessed by a charged particle due to its location in an electric field. Work is required to push a charged particle against the electric field of a charged body.




## Electric Potential Energy

(a) The spring has more elastic PE when compressed.

(b) The small charge similarly has more PE when pushed closer to the charged sphere. In both cases, the increased PE is the result of work input.




## Electric Potential

Electric potential (voltage)

- Energy *per charge* possessed by a charged particle due to its location
- May be called *voltage*—potential energy per charge
- In equation form:

$$\text{Electric potential} = \frac{\text{electric potential energy}}{\text{amount of charge}}$$

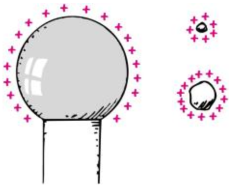
## Electric Potential

Electric potential (voltage)

Unit of measurement: volt, $1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$

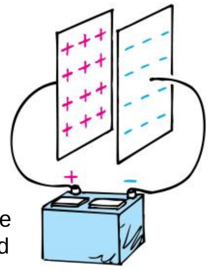
Example:

- Twice the charge in same location has twice the electric potential energy but the same electric potential.



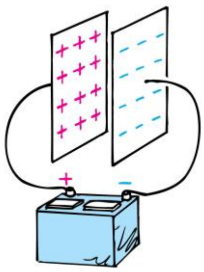
## Electric Energy Storage

- Electrical energy can be stored in a common device called a **capacitor.**
- The simplest capacitor is a pair of conducting plates separated by a small distance, but not touching each other.
- When the plates are connected to a charging device, such as the battery, electrons are transferred from one plate to the other.



## Electric Energy Storage

- This occurs as the positive battery terminal pulls electrons from the plate connected to it.
- These electrons, in effect, are pumped through the battery and through the negative terminal to the opposite plate.

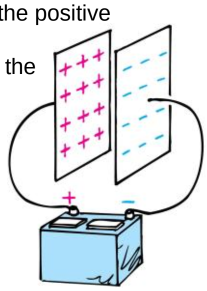


## Electric Energy Storage

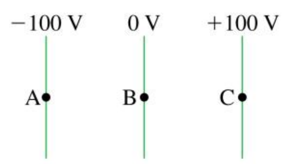
- The charging process is complete when the potential difference between the plates equals the potential difference between the battery terminals—the battery voltage.
- The greater the battery voltage, and the larger and closer the plates, the greater the charge that can be stored.
- The energy stored in a capacitor comes from the work required to charge it.
- Once charged, an electric field exists inside the capacitor, pointing from the + to the - plate.

### The electric potential inside a capacitor

A. is constant.
B. increases from the negative to the positive plate.
C. decreases from the negative to the positive plate.



**A proton is released from rest at point B, where the potential is 0 V. Afterward, the proton**




A. moves toward A with a steady speed.
B. moves toward A with an increasing speed.
C. moves toward C with a steady speed.
D. moves toward C with an increasing speed.
E. remains at rest at B.

## Before class on Monday

- Please read Chapter 23, or at least watch the 12-minute pre-class video for class 17.
- In tutorial you will receive the last problem set of the semester: Problem Set 5.

- Something to think about:
- When you “blow a fuse” in your house and the lights go off, what has happened, and why?