

Basic Plan:

- Invoke prior knowledge by discussing model of atom and properties of charges they are familiar with from Chemistry class; note its peculiarities and failures; discuss what a good theory is
- Discuss how charge is separated: rubbing & inducing
Discuss how conductors and insulators react differently to induction
- Discuss the Electrical Force and Electrical fields –
emphasizing reasoning in terms of proportions and superposition

ASK THEM: How are you going to present these ideas as a facilitator?

What are you taught the nature of matter in chemistry class?

What do you know about atoms?

- all matter consists of protons, neutrons, and electrons
- protons and neutrons are in the “nucleus” of the atom and electrons orbit the nucleus in a “cloud”
- protons and neutrons has the same mass (weigh the same), but electrons are much lighter
- protons are positively “charged” and electrons are negatively “charged”
 - same sign = repulsion (+)
 - opposite sign = attraction (–)
 - attraction/repulsion is smaller the farther they are from one another
 - Note: electrons should spread out
 - Why doesn't the nucleus fly apart?! Why don't electrons fall into the nucleus?
- there are equal numbers of protons and electrons in an atom → implications for attracting objects?
- atoms “bond” to other atoms → form molecules when positive nuclei “share” electrons
- molecules “bond” to other molecules in the same way
 - bonds can be quite strong → keep solids rigid!

This is a MODEL of what atoms like, a picture we use to help us understand what is going on.

It is a GOOD picture if this way of thinking about atoms is consistent with our own experience of the world, if our own experiences can be explained in terms of the model. The more phenomena/experiences is “explains”, the better it does.

Einstein: should be as simple as possible but not simpler.

To experience/see electrical forces in our macroscopic world,
we need to have more charge in one place than another.

i.e., we have to separate charges

we have to take –'s (or +'s) from one place to another → then the other kind of charge will be left behind

Usually, a few of the electrons in the outer orbits get removed:

- they are farthest from the nucleus (less attraction than other electrons)
- they experience repulsion from the inner electrons

i.e., the outer electrons are less tightly bound to the atom than the others

How do we separate charges?

- rubbing
 - e.g., shuffling across a carpet → physically tearing atoms apart
 - exerting forces that can overcome attractions holding atoms together
 - could be an equal trade: donate \approx same # of electrons to one another but certain materials tend to trade more in one direction
 - DEMO's
 - styrofoam plate on arm
 - balloon on head/comb through hair
 - rabbit fur/paper towel on pvc pipe
- inducing
 - using electrical forces to separate charges
 - if I have extra + charge on one object, how do nearby atoms react?
 - +'s move away, -'s come closer
 - we say that the charge is “induced” to move
 - do they keep moving?
 - no, they move till mutual attraction balances push/pull from the outside + charge
 - NOTE: in this situation, the 2 objects are always attracted to one another!
 - DEMO's:
 - charged pvc/balloon/comb/s-plate and string/scraps of paper
 - balloon and wall
 - pvc/s-plate and aluminum can & cardboard tube
 - pvc and wood on a pivot
 - pvc and slow-steady stream of water (?)
- conductors vs. insulators: how “loose” are the outer electrons in a material?
 - insulator: not very loose at all
 - conductors: very loose
 - electrons can move clear to the other side of the object
 - will spread out do to mutual repulsion
 - charges move (i.e., “flow”) through conductors very easily
 - two extremes – materials can be somewhere in between, or behavior can change with the situation
 - DEMO: electroscope
 - What happens when a material is next to a lot of charge?
 - electrons get ripped out of material: drawn to charge or pushed away
 - there is a chain reaction: neighboring charge pushed away or drawn into replace (particularly if material is a conductor)
 - if molecules/atoms break down:
 - sparks (lots of bonds breaking) → atoms asunder, electrons free,
 - suddenly air is a good conductor!

Representing Forces: Magnitude (the strength of the push or pull) and Direction

- Magnitude is given by Coulomb's Law:

$$F = k \frac{q_1 q_2}{r^2}$$

k = universal constant that you have to measure

q = amount of "extra" charge on 1 object → more charge, more force

r = distance between the two objects → larger distance, less force

- Direction: this we already know
 - opposites attract, likes repel → along the straight line between the two objects
- tug-of-war: What is the force on the + charge?
 - + inbetween two -'s (-'s are fixed in place)
 - What if it's closer to one than the other?
 - What if it's a little above both of them?
- key idea: the forces add up → their sum determines the direction the + gets pushed in (this overall push is called the "net force")
- With these simple rules we can determine what happens in any situation.
- We use arrows to represent forces: length indicates the strength of the force in that direction.
simple method: add all arrows tail-to-tip
"net force" is in the direction from the tail of the first arrow to the tip of the last one

Electric Field:

If there was a positive charge there, in what direction would it move?

How much force would it feel?

- Magnitude is given by:

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

k = universal constant that you have to measure

q = amount of "extra" charge on the object generating the field → more charge, stronger field

r = distance between the object and the location of interest → farther away, weaker field
(we often talk about putting a "test charge" there)

- Direction: remember, we always ask what direction a + would feel a force in
 - opposites attract, likes repel → along the straight line between the two objects
 - always points away from a + charge
 - always points toward a - charge
- Draw a bunch of arrows around an object to represent. (longer arrows closer to object)
- Add just like forces. e.g., Electric Dipole
What about the tug of war case? (Note: which objects are generating the field?)
- Why bother thinking in terms of electric fields? The effect of 1 object on any nearby objects.
To figure out force on an object travelling nearby is simple: $F = q_{object}E$.
(i.e., on the object experiencing the E-field)

1. Electricity and Scotch Tape

- a. Press a piece of sticky tape, about 15-20 cm in length, firmly onto a smooth unpainted surface, for example, a notebook or an unpainted tabletop. (To make handling them easier, create “handles” by folding each end of the the tape to form portions that are not sticky.) Then peel the tape off the table and hang it from a support (e.g., the edge of a table).

How does the tape behave when you bring objects toward it (e.g., a hand, a pen)?

- b. Make another piece of tape as described above. Bring the second piece of tape toward the first. What happens? Does the distance between the pieces of tape affect the interaction between them?

- c. Press one piece of tape onto the table and write “B” (for bottom) on it. Then press another piece of tape (of approximately the same length) on top of the B tape and label it “T” (for top).

Pull both pieces of tape off the table as a single unit. After they are off the table, separate the T and B tapes. Hang each off the side of the table.

Now, repeat the process so that you have a second pair of T and B tapes.

Describe what happens when pieces of tape are brought near one another:

- two T tapes
- two B tapes
- a T and a B tape

- d. Bring a PVC pipe close to a T tape and then a B tape. What happens?

Rub the PVC pipe with a paper towel, and repeat the experiment. What happens now?

- e. Use the model of electric charge and its behavior discussed in class to explain these observations. You will want to note when charge is separated and when it is induced, and then use this fact to explain why objects are attracted toward or repelled by one another. (Use the other side of this page.)

Also: If you allowed the objects to touch one another, your results may change. Moreover, if the humidity is high, your results may change. Can you explain these facts in terms of the model?

2.

- a. Consider the electric forces in the situation shown here:

All the charges are positive.

Charge A is directly above the charge in the center, which is halfway between the other two charges.

In what direction is the net electric force exerted on charge A? Explain.

- b. Suppose charge A is brought closer to the other charges.

Will it necessarily feel a greater repulsion than before?

(Hint: Consider the forces exerted by the other charges one by one and then their combined effect.)

- c. Suppose the charge of A is doubled.

Would it feel a stronger repulsion from the other charges?

Would the electric field of the other charges become stronger?

- d. Use this simple situation to speculate about the electric field near large, charged plates (like those of the electroscope exhibit). Suppose one plate has a bunch of positive charge on it and the other plate has a large number of negative charges. Each kind of charge spreads out within its plate due to the mutual repulsion of neighboring charges.

(Hint: Can you describe what the electric field near the 3 charges looks like?

Analyzing this simpler situation may give you some insight what happens in the more complex situation you are being asked about.

Physicists often use simple models to gain intuition in this way.)

- i. On the back of this page, sketch how 2 + charges would arrange themselves on a plate.

Then, make the same sketch for 3, 5, 10, 100, and 10,000 charges.

- ii. Suppose there are 10,000 charges on the plates.

In what direction is the electric field between the plates?

- iii. How does the strength of the field vary across the narrow gap?

- iv. What would the electric field look like at the edges?

3. One exhibit on the main floor is a giant electroscope. When you plug the red wire into one of the large metal plates, the plate becomes connected to the positive end of a battery by the conducting wire. The plate is then connected to the two hanging wires inside the exhibit. When the red wire is plugged in, these hanging wires move apart from one another.

(Hint: Consider using pictures to help yourself figure out what is happening and to explain it to others.)

- a. When the red wire is plugged in, electrons in the red wire, the metal plate, and the two hanging wires move towards the positive end of the battery. Eventually, they stop flowing towards the battery, though. Why?

(Note: The electrons do not stop flowing because the first ones to reach the battery combine with the positive charges in the battery and reduce the battery's "pull." The battery will chemically generate new positive charges to replace those that the electrons join – at least until the battery runs out of chemicals and therefore is "dead." The electrons will stop flowing long before the battery becomes "dead.")

- b. If you unplug the red wire, the hanging wires will remain apart.
Why don't they simply return to their normal hanging position after the battery's "pull" is removed?

- c. What do electrons in the other plate do after the wire is plugged in?
Are they affected at all?

- d. If you use the metal instrument attached to the exhibit by a cord to connect the two plates, the hanging wires move back towards one another and simply hang as they did in the beginning. Why?
Where did electrons come from and where did they move to?

- e. Rub your pants with the white plastic card attached to the exhibit by a cord. Bring it close to the plates. In what direction do the hanging wires move? They are affected, because you have charged the plastic card by rubbing it. What kind of charge, positive or negative, is on the card? How can you tell?