Lesson Plan – Introduction to Charge

Lesson One (Day 1+) of Electrostatics Unit Plan

Time allotted for this lesson: 70 minutes (1 ½ periods)

Purpose/Rationale

Electricity and magnetism occupy a major portion of the introductory physics course. Although the two are undeniably important and fundamental components of science and technology, they are often approached in a way that reflects more the interests of physicists than the needs of students. The focus of this introduction and the unit as a whole is to promote an understanding more in line with that of the students, to explain the phenomenon of electricity and its properties, rather than focus on the mathematical sophistication.

The large majority of students have essentially no familiarity with the basic phenomena of electricity in contrast with a high level of familiarity with the ideas of force and motion. Their experience might be limited to pressing power buttons and changing household batteries. Without a basic knowledge of the phenomena, students don't know what the *theory* of electric fields is attempting to explain. Students have grown up in a technological society, and may comfortably use the words of electrostatics, referring to voltage, current, conductors, insulators and electrons, but this is a false impression of knowledge.

This first lesson tries to first probe at student misconceptions and to introduce the phenomena of electrostatics on the most basic level.

Objectives

- Students will be able to identify the attraction or repulsion of charged object as a Force.
- Students will be able to the action of charging and the states of charged or uncharged
- Students will be able to empirically test if an object is charged or uncharged.
- Students will be able to empirically test if a charged object is positively charged or negatively charged.
- Students will be able to identify when an uncharged object is being attracted to a charged one.

Standards

PH.1 a) c) e)

PH.2 d)

PH.3 b) c) d) e)

Materials and Resources

¾ inch Scotch Tape (several rolls), Wool/fur, Polyethylene/rubber rod, markers, comb, small pieces of torn paper, small aluminum wrapped Styrofoam balls, string, stand, refrigerator magnet

Safety and Classroom Management Issues

Normal classroom procedures apply. Students will be expected to participate in the class discussion.

Procedures

Unit Pretest (12 minutes):

Students are given a 15 question multiple choice test focused on drawing out misconceptions and prior knowledge regarding electrostatics. Students have 12 minutes to complete the exam or answer as many questions as possible. During this pretest begin to set up the Explore lab.

Engage (5 minutes):

(Day 1 DO NOW: Think about why the two balls are visibly repelling each other?) In front of the class students are exposed to a setup of an aluminum wrapped Styrofoam ball suspended on a string being repelled by an identical aluminum wrapped ball supported on an insulated plastic stand. Include a drawing that labels the different materials in the set up. Open the class to a quick discussion to gauge student's prior knowledge. In preparation for the response that this phenomena is not related to magnetism one can show that a common refrigerator magnet does not attract or repel an aluminum wrapped ball. (Bringing the magnet near the setup might cause an attraction due to polarization, so it is wise to use an identical, but separate third ball to avoid confusion).

Before the activity proceeds, it is beneficial to introduce the idea of "charging." Show that an ordinary plastic comb does not pick up pieces of paper, but once being run through ones hair the comb has a new property that allows it to pick up paper and move wrapped balls. Repeat with wool rubbed with a rubber rod and silk rubbed with a glass rod. Identify the change as "charging" an object, and that after the change it can be said that the object is "charged". Emphasize that "charging" and "charged" are just names that tell us nothing about what is actually happening.

Explore (35):

Students follow an activity sheet and use Scotch Tape to explore the new electrostatic force and to devise a method for testing if an object is positively or negatively charged.

Explain (5):

(Day 2 DO NOW: *for the next lesson written on the board.* A negatively charged metal sphere is touched against an identical uncharged sphere. After the contact, what is the charge on each of the spheres?)

A power point reinforces the concepts of the lab and introduces the history of the naming system focusing on Benjamin Franklin's contributions to Electrostatics. At this point no mention of the quantum nature of charge has or will be introduced. It is the intention to slowly build and understanding from simple empirical experiments before a complete *charge model*. An uncharged objects attraction to a charged one is addressed, but left for later explanation.

Elaborate (10):

The tribolectric scale is introduced in the Power Point. Using the tape test for charge discovered by the students as a class students make predictions about different objects on a scale, enforcing the idea that rubber rubbed with wool/fur is negative and glass rubbed with cotton/silk is positive.

Evaluate:

The Lab the students complete is graded for completion and accuracy with emphasis on the analysis and conclusion questions.

This is a class copy. Please complete the lab in your lab notebook.

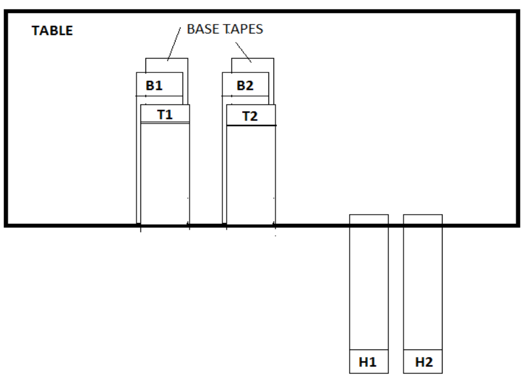
Name:_______________
Date:_______________
LP(s):_______________

Lab: Testing Charge

Objective: To develop an empirical method to determine if something is positively or negatively charged.
Materials: ¾ inch Scotch Tape, Wool/fur, polyethylene/rubber rod, marker
Setup:

1. Pull off two lengths off two ~10cm (4 inch) lengths of tape and smooth them down onto the table. We will call these BASE tapes. THESE PIECES NEVER MOVE AGAIN. They only serve as a surface.
2. Pull off two more 10 cm lengths of tape and stick them down on top of the two BASE tapes, but leave the last ~2.5cm to form a tab when folded back. Label the tabs with a B1 and B2 for BOTTOM tapes
3. Pull off two more 10 cm lengths of tape and stick them down on top of the two BOTTOM tapes, but leave the last ~2.5cm to form a tab when folded back. Label the tabs with a T1 and T2 for TOP tapes
4. Pull off two more 10 cm lengths of tape hang them so almost all of the tape is hanging over the edge of the table. Again create a tab at one end and label it with an H1 and H2 for HANGING tapes.

After doing these steps you should have 8 strips of tape laid out similarly to the following:



Procedure:

1. Make sure the HANGING pieces are not attracted to your hand. IF they are allow more time to pass.
2. By holding the BOTTOM tapes tabs SLOWLY pull BOTH the TOP and BOTTOM tapes. Keep them together. <u>Stroke them gently between your fingers a few times until they no longer attract to your hand.</u>
3. Hold a T tab and a B tab in each hand and pull them apart <u>rapidly</u>. * If one piece is completely curled up you should reset the experiment
4. Through this procedure you are able to create T tapes, B tapes and H tapes. Feel free to reset the experiment any time if you mess up your pieces. DO NOT LET PIECES TOUCH AFTER THIS STEP.
5. Hand the tabs of the tape pieces to a partner for testing. *THE PERSON WHO RIPPED THE PIECES APART SHOULD NOT BE DOING THE TESTING.

Data & Testing:

You will bring together differently labeled tapes together in different combinations. Do so by holding one piece in each hand so that each tape hangs down vertically. Bring two tapes near each other and observe whether the two pieces **ATTRACT** or **REPEL**, for example if B1 and B2 are held near each other you should observe that the two REPEL so you would record REPEL in the top left entry of the table. Record all your findings in a table. Leave the last **–** ROD column blank for now.

	BOTTOM 2	**TOP 2**	**HANGING 2**	**–ROD**
BOTTOM 1				
TOP 1				
HANGING 1			NOTHING	

Now charge a hard rubber or polyethylene rod by rubbing it with wool vigorously. *You can also rub it against your hair. Now hold rod the rod at some distance to B1, T1, and H1 and record your results. DO NOT GET TOO CLOSE TO THE TAPE WITH THE ROD.

Analysis and Conclusion:

1. You should have observed that some of the pieces of tape appeared to be "charged" and some appear to be "uncharged". BY DEFINITION, not for any physical reason, a rubber rod rubbed with wool is NEGATIVELY charged. We'll elaborate on this fact later (It's fine if you used your hair instead of wool). By using this definition of charge for a rod, assign HANGING, TOP, and BOTTOM pieces of tapes as being POSTIVELY CHARGED, NEGATIVELY CHARGE, or uncharged and therefore NEUTRAL.
2. It is not logically impossible to have a third type of charge outside of our definition of positive and negative. However, this has never been experimentally observed. Let's suppose that by rubbing the rod with a very special type of material gives it this never before observed third type of charge. How do you think the TOP, BOTTOM, and HANGING pieces of tape would react when this third type of charge is brought nearby?
3. Compare and Contrast this new Electric Force with the more familiar gravitational force that we have already learned about? How do you think the strength of these to forces compare? How do the sizes of the two forces change with distance? Can gravity ever be repulsive?

ELECTROSTATICS PRETEST

DO NOT WRITE ON THIS TEST

There are 15 multiple choice questions, each with 5 possible choices. You have 12 minutes to answer as many questions as you can to the best of your ability.

1) Electrons are negatively charged. Protons are positively charged. The magnitudes of these positive and negative charges can be compared. How do the magnitudes of these two fundamental charges compare?

A) The electron's negative charge is much smaller in size than the proton's positive charge
B) The electron's negative charge is much greater in size than the proton's positive charge
C) The electron's negative charge is equal in size to the proton's positive charge.
D) The strength of an electron's negative charge and a proton's positive charge depends on the atom in which the two particles are contained.
E) The charge of both is so small it has yet to be measured with any real accuracy

2) Electric charge is produced by

A) creating electrons
B) creating electrons and protons
C) separating electrons and protons in a material
D) changing neutrons to protons
E) none of the above

3) Metals are generally good conductors of electricity. This property can be explained by the fact that most metals are different from other atoms because they

A) heat rapidly; a high temperature produces higher energy electrons
B) possess a far greater number of electrons than most other elements
C) bond easily with smaller elements which act to store a large amount of charge
D) cool rapidly; a high temperature inhibits the flow of electric charge
E) bond together to form a tightly packed structure where the outermost electrons of each atom are completely detached and free to move from atom to atom.

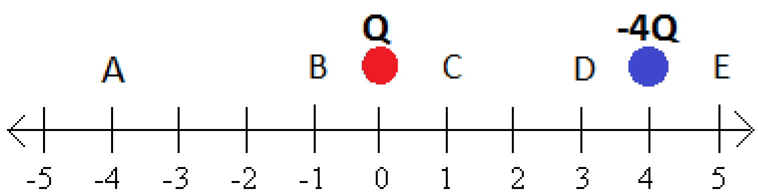
4) Suppose a smaller conducting sphere has a negative -10 nC charge. It is brought in contact with a second larger conducting sphere that is initially uncharged. After the contact, what is the charge on the *larger* conducting sphere?

A) 0 nC
B) Between 0 and -5 nC
C) -5 nC
D) Between -5 and -10 nC
E) -10 nC

5) Static electricity is caused by

A) The friction between any materials, such as wool socks rubbing against carpet.
B) The friction between any insulators, such as wool socks rubbing against carpet.
C) The friction between any insulator and a conductor, such as your hand and a door knob
D) The contact between two surfaces with different affinities for electrons.
E) The buildup of charge in a conductor

6) There are initially two charged objects already in place along a number line. The object at "0" has a positive charge with a magnitude of Q. The object at "4" has a negative charge with a magnitude of 2Q. We want to introduce a *new* object somewhere along the number line. If this new object has a negative charge of -Q, at what location (A, B, C, D or E) could we place this object and have it stay at rest? (The net force acting on it equals zero.)



7) Rubbing a glass rod with a piece of silk will cause the glass rod to become positively charged. What is happening?

A) The electric charge in the rod, much like Kinetic Energy, is reduced by the friction from rubbing the silk
B) The silk is slightly positively charged to begin with and attracts some of the rods electric charge off the rod
C) The rod is slightly negatively charged to begin with which attracts some of the silks positive charge
D) Some electrons are moved from the rod to the silk
E) Some positrons are moved from the silk to the rod

8) After running a plastic comb through your hair you notice that the comb is able to attract and pick up small pieces of paper off a table. How is this possible?

A) Molecules in the insulating paper are polarized by the external charge of the comb. The new alignment of charge allows for a net force to be exerted on the paper.
B) Electrons on the surface of the paper move on the surface of the paper away from the negatively charged comb
C) The paper is positively charged from being in contact with the grounded table. Running the comb through your hair causes the comb to become negatively charged. Opposite charges attract.
D) All insulators, like the paper, are attracted to the negative charges on the comb.
E) The paper was less negatively charged than the rod.

9) A pith-ball electroscope consists of a small nonconductive piece of Styrofoam that is suspended by a non-conducting thread. The ball is also covered with a conductive coat of aluminum. When the pith-ball is allowed to touch a positively charged glass rod, the pith-ball will almost immediately jump away from the rod. Strangely enough, after that contact, the pith-ball will move away from the glass rod whenever it is brought close. What happened when the aluminum covered pith-ball touched the positively charged glass rod?

A) The charges switched so that the ball becomes positively charged and the rod becomes negatively charged
B) The rod has a large positive charge. When it comes in contact with the pith ball it forces the neutral object to take some of its charge.
C) The molecules in the rod are polarized to mirror the alignment of molecules in the pith ball..
D) The negatively charged pith ball touches the positively charged rod, causing both to become neutrally charged. Like charges repel.
E) A number of electrons on the surface of the aluminum that contacted the rod, jumped to the rod, leaving both the rod and the ball positively charged.

10) The universe is completely empty, except for two protons that suddenly appear at rest 1 meter away from each other. What happens next?

A) The gravitational force between the two protons eventually brings the two particles crashing into each other
B) The electrostatic force pushes the protons apart briefly until the electrostatic force balances with the gravitational force, once the forces are balanced both protons eventually come to rest at the same time and never move again.
C) The electrostatic force pushes the protons apart briefly until the electrostatic force balances with the gravitational force, the protons continue to move away from one another at a *constant* velocity
D) The electrostatic repulsion between the two protons is much greater than the gravitational attraction between the two protons, the two protons fly away from each other with a greater and greater acceleration
E) The electrostatic repulsion between the two protons is much greater than the gravitational attraction between the two protons, the two protons fly away from each other, but with a decreasing acceleration.

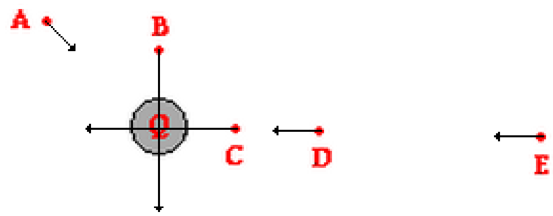
11) How many different ways can object be charged? Choose the best answer.

A) Two, an object can be positively or negatively charge. However a third type of charge is not impossible, but it has never been observed.
B) Two, an object can be positively or negatively charged, a third type of charge is impossible because of a universal symmetry
C) Two, an object can be charged or uncharged
D) Three, an object can be positively charged, negatively charged, or neutrally charged.
E) None of the above

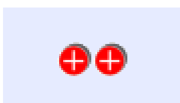
12) A "ground" in electrostatics is often used to discharge objects. What is a "ground?"

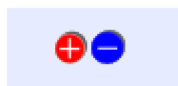
A) Ground refers specifically to Earth, which acts as a large conductor that typically has an excess of positive charge, and is easily able to receive negative charge, or provide positive charge.
B) Ground refers specifically to Earth, which acts as a large conductor that typically has an excess of negative charge, and is easily able to receive positive charge, or provide negative charge.
C) Ground refers to any conductor in contact with a charged object.
D) Ground refers to any sufficiently large uncharged conductor in contact with a charged object which is capable of significantly reducing the charge on that object.
E) The negative terminal of any electrical power source.

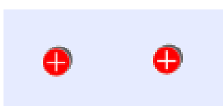
13) A <u>negative</u> source charge (Q) is shown. The source charge contributes to a change in the electric field. Various location around the charge are labeled. With an electric field vector indicating the relative strength and direction of the electric field. However, one of the five field vectors is incorrect. At which location (A, B, C, D, or E) is the electric field vector ($\vec{E}$) incorrectly drawn?



14) A positively charged object is shown on the left in each picture. The magnitude of the charges in each picture is identical to the leftmost positive charge. In which picture is the magnitude of the force acting on the left most positive charge the greatest?

A) 

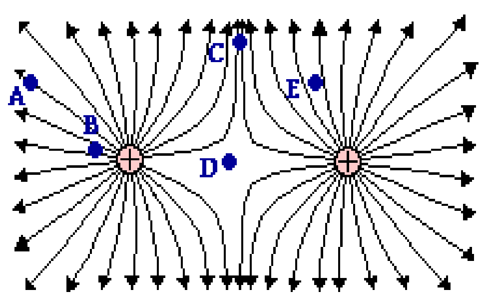
B) 

C) 

D) 

E) A and B picture an net force that is identical in magnitude.

15) At which of the following points is the electric field strength the weakest?



Key

1. C
2. C
3. E
4. D
5. D
6. A
7. D
8. A
9. E
10. E
11. A
12. D
13. E
14. E
15. D

Lesson Plan – Conductors, Insulators, and Grounding

Lesson Two (Day 2) – Electrostatics Unit Plan

Time Allotted for this Lesson: 30 minutes. (1/2 period)

Purpose/Rationale

In order to understand the phenomena of polarization students must first understand the macroscopic workings of an insulator and conductor. From the understanding of a conductor, along with the understanding of like charge repulsion from Lesson 1, students can develop an understanding of what is meant by grounding.

Objectives

- Students will be able to define a conductor and insulator
- Students will be able to apply an analogy to understand ground and charge distribution
- Students will be able to predict how charge is distributed when a charged conductor is brought into contact with an uncharged conductor, based on relative size.

Standards

PH.3 b) c) d) e)

PH.4 a) b)

Materials and Resources

Van de Graaff generator, meter stick, metal rod, insulating stand, suspended aluminum wrapped Styrofoam balls, two equally sized clear plastic cups, one large flat bottomed clear bowl, aluminum pie pans.

Safety and Classroom Management Issues

Normal classroom procedures apply. Students will be expected to participate in the class discussion. Students will be closely monitored while the Van de Graaff generator is in use.

Procedures

Engage (5 minutes):

This lesson will more than likely start half way through the second day's period. To refocus the class and grab their attention a demonstration is used. A charged rubber rod is brought near both a suspended Styrofoam ball and then again near aluminum wrapped Styrofoam ball. Students will observe two different outcomes, finding that the charge is transferred to the aluminum wrapped ball. Students are asked to think about how the negative charge on the ball is distributed and why that might be.

Explore (10 minutes):

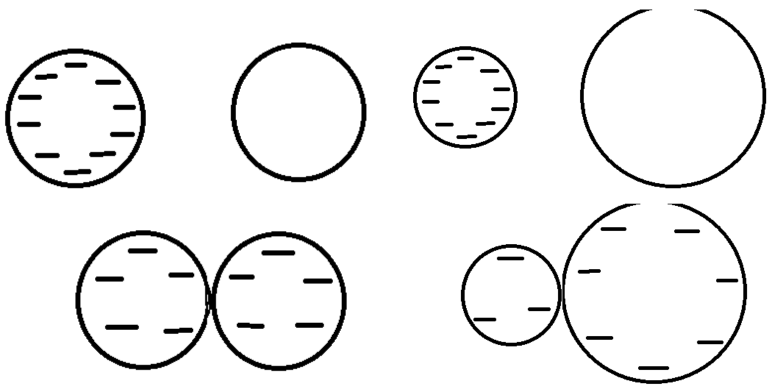
A Van de Graaff Generator is introduced and is quickly explained and shown via the suspended ball, to have a uniform negative charge over its surface. (attach a negatively charged ball to the end of a meter stick) A meter and a metal rod will be used to demonstrate the difference between a conductor and an insulator. The ground for the generator serves as a nice tool in the demonstration. If fixed close to the generator a spark will jump from generator or ground. Introduce the word ground, but again emphasize that we have not yet come to understand what it means. Students can see that when the metal rod is in contact the generator the sparking stops, this is not the case with the meter stick because there is no path to ground.

At this point current can be defined as the movement of charge. Explain that electrostatics is the study of static, or nonmoving charge.

Stacking pie cans on the generator also makes for a fun demonstration of conductors as they acquire like charges and fly apart.

Explain (5 minutes):

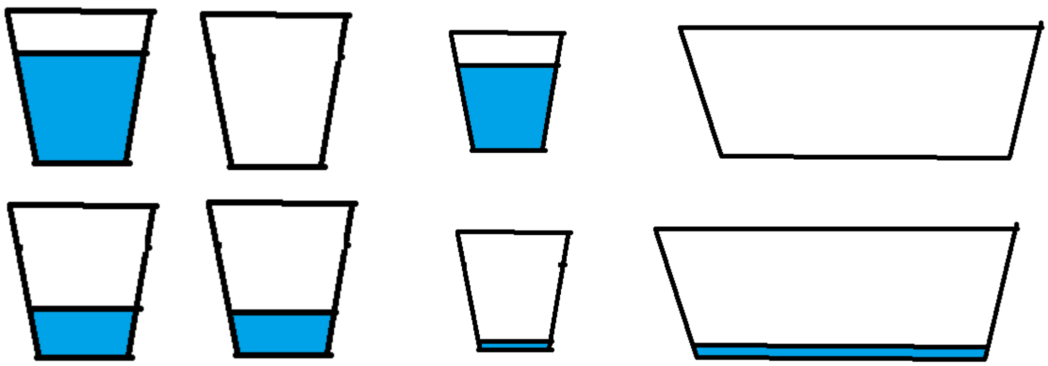
The concept of ground is explained by showing how two conductors in contact attempt to equally share a charge distribution. First this is show with pictures.



This will act to familiarize students with an abstract way of “drawing” a charge distribution. Ground is defined as a conductor capable of absorbing a large amount of charge. The cause of this can be explained by the repulsion of like charges and the free flow of charge on the surface of a conductor.

Elaborate (10 minutes):

To reinforce the abstract nature of charge distribution and the idea of ground a demonstration/analogy involving cups of water. Enforce the idea that conductors in water do not attempt to have the same charge, but the same charge distribution. In the water analogy, different cups of water do not attempt to have the same amount of water, but instead the same water level. In both cases the total amount of charge, or the total amount of water is Conserved. Guide the demonstrations with these pictures.



Have students imagine that grounding with the earth is like taking a small cup of water balancing it to the same water level as a huge swimming pool. The charge distribution of both in the end will be very small, and seemingly zero.

Evaluate:

A simple exit slip informally assess student understanding of the demonstrations and to have students reflect on the unit so far. The format for the exit slip is included in the power point and students are asked to use their own paper.

EXIT SLIP

NAME:_____________________________ DATE:__________________________________

What happens when a charged conducting sphere comes in contact with contact with an uncharged conducting sphere of equal size. What happens to the charge?

What happens when a charged conducting sphere comes in contact with contact with an uncharged conducting sphere of much greater size. What happens to the charge?

One question I still have:

Lesson Plan – Polarization and the Quantization of Charge

Lesson Three (Day 3-5) – Electrostatics Unit Plan

Time Allotted for this Lesson: 100 minutes. (2 Full periods)

Purpose/Rationale

Days 3 and 4 emphasizes force, both the forces between point charges and the still unexplained force of a charged object on a neutral object. This serves to introduce Polarization in both conductors and insulators and explain more of the phenomena students have already observed. The Quantum Charge model is also introduced for the first time.

Objectives

- Students will be able to place abstract plus and minus signs to identify the charge distribution from an electrostatic phenomena
- Students will be able explain phenomena by using a quantization charge model.
- Students will be able to define an electric dipole.
- Students will be able to apply Newton's Third Law to electric phenomena.

Standards

PH.1 a) c) e)

PH.2 e)

PH.3 b) c) d) e)

PH.4 a) b)

Materials and Resources

Wool/fur, polyethylene/rubber rods, Cotton, glass rods, electroscopes, small pieces of foil and paper, sink and water source

Safety and Classroom Management Issues

Normal classroom procedures apply. Students will be expected to participate in the class discussion. The electroscopes are fragile and made of glass. Make sure students follow lab procedure when working with the equipment.

Procedures

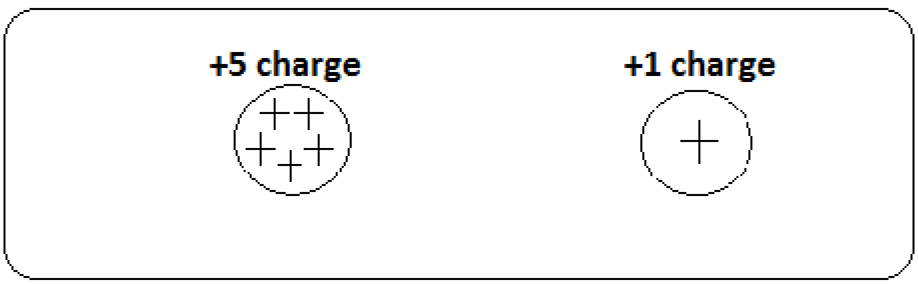
Engage (5 minutes)

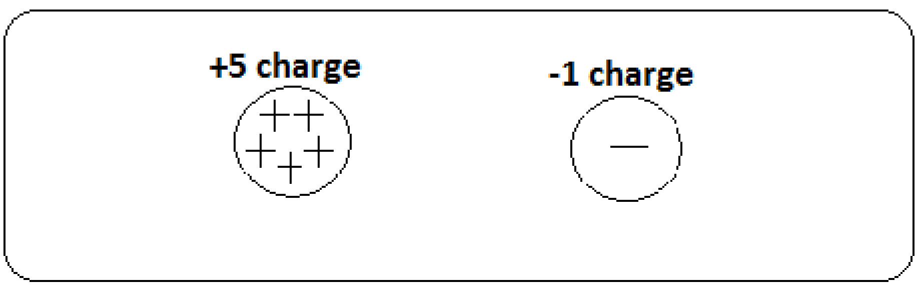
(Day 4 Do Now: What will happen when a charged rod is brought near a flowing stream of water?)

Show how a rods, whether positively or negatively charged can pick up paper, aluminum foil and bend water. These demonstrations can serve as a reference for later explaining how polarization can differ in its mechanism, but remains the same in its result: A charged object attracts an uncharged object.

Explore (25 minutes)

A nice start to having students understand polarization is to have them draw two sets of charges at different distances according to the picture below on the board (no units on the charges yet) and ask students to draw the force vectors, with the length proportional to the size of the force.

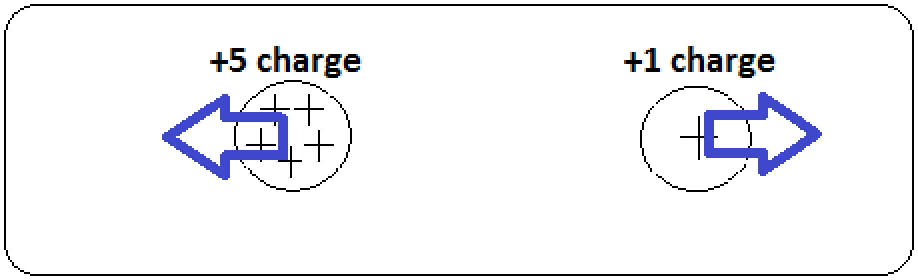


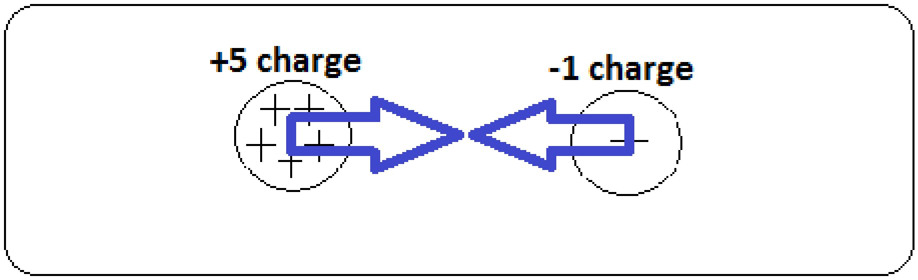


Later in the unit a demonstration will serve to solidify Newton's Third Law in the student's minds.

It is important to explain that you are drawing charged objects, and the plus and minus signs are an abstraction of that.

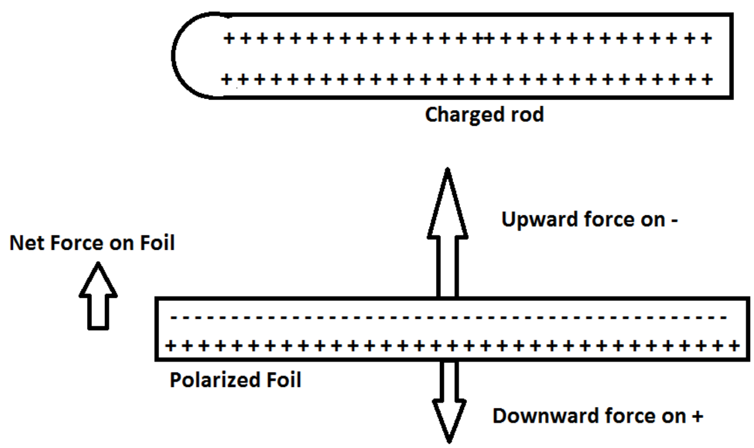
Although not quantitative, make sure through a series of questions and the display of the solution,





that students come to the conclusion that 1) Newton's third law applies to the electrostatic force like any other force. 2) the electric force weakens as the distance between the charges increase. This is sufficient to understand polarization forces.

Use a charged rod to pick up a small piece of aluminum foil. Ask them to discuss this observation with their neighbors and try to explain it based on what they have already learned about charges. Cue them with words. Emphasize and cue them with the main ideas of force, distance, and conductors. With the students develop this picture:



This can cause difficulties.
First remind students of the strange behavior they have observed, that has yet to be explained. "Charged objects attract small uncharged ones." Explain that we have reached the point where we are ready to tackle this phenomena.

The main point that needs to be developed is that neutral objects may not be absent of charge, but instead have an equal amount of positive and negative charges.

Purpose the idea that this fundamental interaction in all objects, not just charged ones is perhaps what holds us and everything else together.

A difficulty for many students is an unstated and unexamined assumption that the top layer of charges "shields" the lower layer of charges from the force of the charged rod Even after recognizing the polarization they will show only the force on the upper charged layer. Convince them that the rod exerts forces on all the charges.

From this point, of the foil having positive and negative charges, and an understanding from the Engage section early in class, the concepts of the polarization demo can be explained.

As a follow up ask what the foil would do if the rod was negatively charged instead of positively charged. Draw that picture as well.

Explain (30 minutes or 70 minutes):

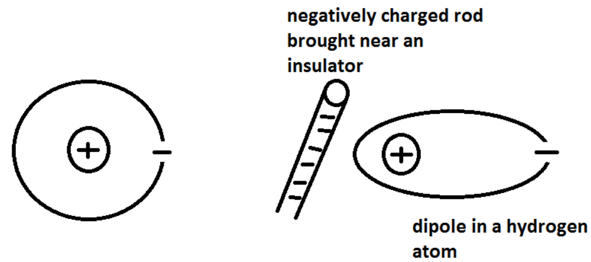
The rest of the period and likely part of the following period is dedicated to convincing the students a quantum model of electrostatics. Students will have likely heard of an atom and its subatomic constituents, but a powerpoint and notes reviewing the basics of these is necessary. A unit is yet to be applied to the electron and proton's charge, at this point it is only referred to as a fundamental charge, emphasizing the magnitude of this fundamental charge is the same for both.

Avoid introducing Milikan's Oil drop until the introduction of electric fields, the evidence will not make sense to the students, and is unlikely to convince any of them. However, if students are skeptical assure them that they are in good company, siting historical quotes, and assure them that the more quantitative evidence is to come.

Include several multiple choice questions in class about the fundamental charges of different atomic arrangements. Have the class raise their hands to chose A, B, C, or D to gauge the classes understanding. Make sure that all students are participating for these questions. Include relevant similar questions to ones that were scene on the pretest that focus on misconceptions

Conclude on the atomic structures of conductors and insulators.

Construct a picture with the class of a dipole interaction in a simple hydrogen atom. Use this as a basis for understanding polarization in insulators.



Emphasize that in almost all scenarios, excluding plasmas and ionic solutions, that it is the electrons that are moving. Use this as a basis for explaining the conservation of charge.

Go over several previous demonstrations, using the class wide multiple choice response to gauge understanding. Repeat some of the demonstrations to spark interest.

Based on the Exit slips. I choses to spend an additional shortened 40 minute class period on Polarization and the Quantization of charge. It was clear from the student responses on exit slips that a power point in conjunction with the pictorial representations shown was not enough to fully understand the phenomena. To facilitate student learning hands on models were constructed out of cardboard and other materials to differentiate polarization in conductors and insulators, including both permanent and induced molecular dipoles. It is worth noting that the water bending demonstration is often explained by permanent dipole polarization, it also involves the polarization of ions in the water.

The concept of grounding was also returned to, many students had difficulties visualizing the grounding of a positively charged conductor. Analogies involving “students” in different sized classrooms were used to help students visualize the movement of electrons.

Elaborate (50 minutes):

(Day 4 DO NOW: Florida and Indonesia share some things in common. They both have similar population densities, and they both a similar number of lightning strikes per year. So why do Floridians suffer far more deaths by lightning per year than Indonesians?)

Students complete a lab using electroscopes to test and reinforce their understanding of polarization, using the new quantum charge model to explain the phenomena.

If there is time use the Van de Graaff generator to answer the DO NOW. Have a spark jump through a hole in a Styrofoam plate to demonstrate the path of least resistance, and talk about golfing and Florida.

Evaluate:

The Lab the students complete is graded for completion and accuracy with emphasis on the analysis and conclusion questions. A very simple rubric was used to evaluate the student drawings.

A page from the Concept Development book is assigned on day 3 and evaluated informally on the completion of the page at the beginning of day 4.

Students were given an exit slip after the first day. I felt the students needed more help understanding the material and therefore spent an additional day on Polarization in different materials, following this day I gave students the same exit slip to reassess understanding.

EXIT SLIP

NAME:____________________________ DATE:_________________________________

What happens when a charged conducting sphere comes in contact with contact with an uncharged conducting sphere of much greater size. What happens to the charge? How does this relate to ground?

Why does it not make sense to talk about the movement of positive charge?

*How does polarization in an insulator differ from polarization in a conductor?

One question I still have:

Name:_______________
Date:_______________
LP(s):_______________

Lab: Electroscopes

Objective: To develop further understanding of conduction and polarization in conductors.
Materials: Electroscope, Wool/fur, rubber/polyethylene rod, Silk/Cotton, Glass rod

Setup: The electroscope consists of 3 main parts:

1. A metal sphere at the top which provides a conductive path to the electroscope leaves. This portion can also be touched to ground the electroscope.
2. An insulating glass container that prevents unwanted charges from being introduced
3. Conductive foil leaves inside that can be observed to make inferences about the location of charges in the electroscope.

Analysis & Data: Note that there are 12 plus signs equally distributed in the drawing given of the electroscope in the data table. It is impossible to represent every positive and negative charge in the electroscope. Using plus signs and minus signs serves as a method to abstractly indicate regions of positive and negative charges. You will be recreating the electroscope picture several times throughout this lab. In each recreation you make the 12 positive charges given should remain in exactly the same place. Remember that protons, and thus positive charge, cannot move in the electroscope.

Instead it is your job in each drawing to PLACE MINUS SIGNS, in an appropriate number, and in an appropriate distribution. Whenever the procedure asks you to DRAW the electroscope, you are being asked to RECREATE THE DRAWING GIVEN (w/ the same + signs), POSITION THE FOIL LEAFS TO MATCH WHAT YOU OBSERVE, and then PLACE MINUS SIGNS. In addition determine if the net charge of the electroscope is POSITIVE, NEGATIVE, or NEUTRAL. Determine if the electrical phenomena could be described as CONDUCTION or POLARIZATION.

> *Your drawings do NOT need to be perfect, but it does the location of the charges and the orientations of the foil leaves should be clear to receive full credit.

Procedure:

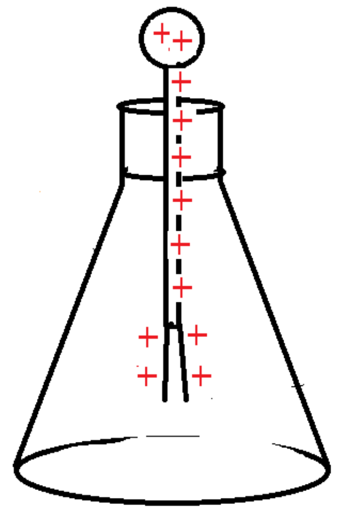
1. Rub the rubber rod with a polyethylene grocery bag. Refer to the tribolelectric series on display to determine the charge this gives the rubber rod. Touch the rod to the top of the electroscope. Move your rod away from the electroscope. Discuss what you observed with your LP and fill in the step 1 row in your data table. GROUND your electroscope by touching the top of it.

2. Rub the rubber rod in your hair or against a dry area of skin. Refer to the tribolelectric series on display to determine the charge this gives the rod. Touch the rod to the top of the electroscope. Move your rod away from the electroscope. Discuss what you observed with your LP and fill in the step 2 row in your data table. GROUND your electroscope by touching the top of it.

3. Charge the rubber rod with the bag. Move the rod NEAR the top of the electroscope. DO NOT LET THE ROD MAKE CONTACT. With the rod held near the top of the electroscope discuss what you observe and fill in the step 3 row in your data table.

4. Charge the rubber rod with your hair or your skin. Move the rod NEAR the top of the electroscope. DO NOT LET THE ROD MAKE CONTACT. With the rod held near the top of the electroscope discuss what you observe and fill in the step 3 row in your data table.

Analysis & Data (CONT'):

Step	Polarization or Conduction	Relative # of POSITIVE charges	Relative # of NEGATIVE charges	NET CHARGE of the electroscope	
1.		12			
…. "Procedure step number"	…..	12	…..	……	RECREATE THE DRAWING GIVEN (w/ the same + signs), POSITION THE FOIL LEAFS TO MATCH WHAT YOU OBSERVE, and then PLACE MINUS SIGNS in appropriate postiions

You should have 4 total electroscope drawings.

Conclusion:

1. After rubbing the grocery bag and the rubber rod together. What was the net charge on the rod? What was the net charge on the grocery bag?
2. Describe the movement of electrons between your hand and your electroscope when you grounded it at the end of step 1. Describe the movement of electrons between your hand and your electroscope when you grounded it at the end of step 1.
3. Why was it important to ground the electroscope between step 1 and step 2. Why did I never ask you to ground the electroscope after step 3?
4. Describe the movement of electrons between the rubber rod and your hair when you were rubbing them together. What was the net charge on your hair afterwards? Why would this cause your hair to stand up?
5. What do the plus and minus signs in your picture represent?

Table Row Number	Correctness: The row correctly indicates whether the phenomena involves polarization or conduction, and correctly states the net charge of the electroscope. (2 points)	Charge Quantity: The shows the correct number of plus and minus signs in the drawing of the electroscope. (2 points)	Charge Distribution: The picture shows a reasonable distribution of plus and minus signs in the drawing of the electroscope. (2 points)	Total
1				
2				
3				
4				
			Sum	______/24

Lesson Plan – Coulomb's law

Lesson Four (Day 6) – Electrostatics Unit Plan

Time Allotted for this Lesson: 50 minutes. (1 Full period)

Purpose/Rationale

So far in this unit quantitative calculations of electric force have been avoided, to allow for a basic understanding of the electrostatic phenomena first. This lesson attempts to introduce Coulomb's Law by appealing to previously observed phenomena and understanding of Newtonian gravity. Coulomb's allows for students to practice problem solving and algebraic manipulation.

Objectives

- Students will be able to compare and contrast the electric force and gravitational force
- Students will be able to apply Newton's Third Law to electric phenomena
- Students will be able to apply Coulomb's law to solve quantitative electrostatics problems

Standards

PH.1 a) e)

PH.2 a) e)

PH.3 d) e)

PH.4 a)

PH.10 a)

Materials and Resources

Overhead projector, bifilar stand, two suspended conducting balls, a third equally sized conducting ball on a movable insulating stand.

Safety and Classroom Management Issues

Normal classroom procedures apply. Students will be expected to participate in the class discussion.

Procedures

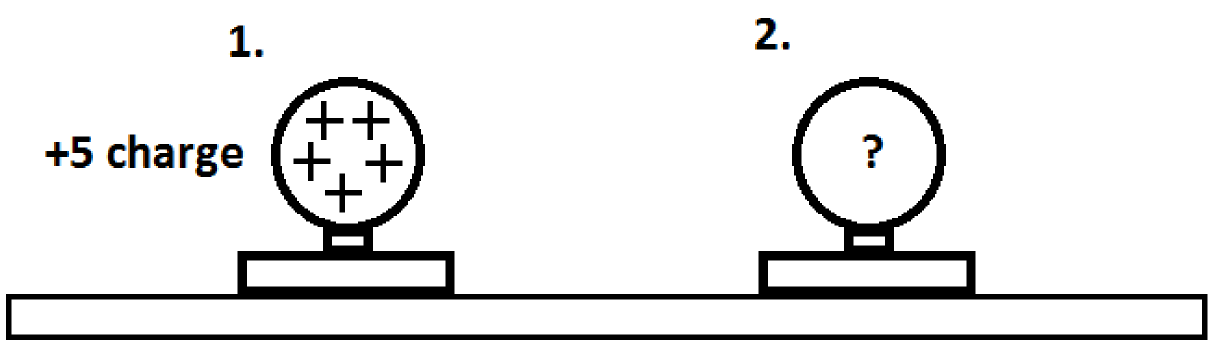
Engage (10+ minutes):

(Day 6 Do Now: Copy down the question on the screen (the explore question)

Students will have a hard time *believing* that the force on two differently charge objects is equal in magnitude, even though they have seen Newton's Third Law in previous problems and units. Appeal to demonstration. Use an overhead projector (this will help provide a dry environment for the experiment). Above the projector set up a bifilar suspension for two aluminum wrapped balls. Initially allow the balls to hang at rest. In their shadow on the project mark there initial position on the grid. Ask students if it likely if the same number of electrons are transferred each time a ball is charged. Charge both balls. Students will be able to see that both balls deflect the same distance on the overhead. Ask students what will happen when another identical conducting ball is touched two a suspended ball. Students should know that this will half the charge. Do so. Still the two suspended ball deflect equally, although a bit less.

Explore (15):

Have students write down answers to the questions regarding the following situation drawn on the board: *Charged conducting sphere (labeled 1 and 2) are attached to insulating hockey pucks that sit on top of a perfectly frictionless air hockey table.*



The following questions are listed in a power point slide for students to work together to answer, students should be aware of the time limit for answering these questions, and should be encouraged to work in pairs:

1) If sphere 2 has a -1 negative charge, which direction will it move?

   Which direction will sphere 1 move?

   Which will have the greater acceleration?

   Will the acceleration be constant?

2) What will change if sphere 2 was given a -10 charge instead?
3) What will change if sphere 2 was given a +5 charge instead?
4) What two things determine the magnitude of the force on the two spheres?
5) What determines the direction of the force on the two spheres?

Though this is the second time in this unit this topic is brought up, some students may still question Newton's Third Law with regards to electrostatics.

Quickly call on different pairs to give their answers, making sure to go over each question thoroughly even if a particular group provides the correct answer.

Explain (10):

At this point students have all the underpinnings necessary to introduce Coulombs Law. In a power point slide present this picture:

$F \gg \textit{magnitue of the Force on either point charge}$

$k \gg \textit{constant which gives the relative strength of the Coulombic Force}$

$Q_1 \gg \textit{the magnitude of the one point charge}$

$Q_2 \gg \textit{the magnitude of the second point charge}$

$d \gg \textit{the distance between the two point charges}$

$$F = ?\frac{?\ \ ?}{?^{?}}$$

Work with the students to fill in the appropriate Question marks with the variables provided. Relate to their experiences from the engage and explore activity.

Provide the constant "k". Carefully introduce the unit for charge, the Coulomb.

Refer back to the hockey puck problem to define d visually.

It is worth emphasizing that this law only applies to static, stationary, point like charges.

Refer to the engage to have students realize that it is experiments that led to the development of the inverse square law, and that the two is result of experimental observation rather than a necessary part of the formula.

Elaborate (15 minutes):

Students may remember from the previous unit on gravity but an example serves to illustrate the relative strengths of the gravitational and electrostatic force. Provide the students both Newton's Universal Law of Gravitation and Coulomb's Law. As a class work to the magnitude of the Coulomb Force between two + 10 nC aluminum wrapped balls 3 cm apart. Then given that each ball has a mass of 10mg, as a class calculate the gravitational force. Make sure that all students are performing the calculation in their calculator.

As a follow up question ask if the *magnitude* of the force would change if one of the aluminum wrapped ball had a -10 nC charge. What would change?

Emphasize that the strength of this force accounts for the structure of all matter.

Students have difficulty realizing the need to convert to C from nC. If there is time it might be useful doing some problems on the board. Have them realize that the need to do so is due to the constant 'k'.

Evaluate:

The Explore questions are collected for a completion grade, and to provide feedback for understanding. A homework is supplied that has students quantitatively using Coulomb's Law in to answer questions.

Students are also assigned a homework assignment to work on over the course of several days. They are provided with a rubric and asked to write three different test questions. The assignment is set to be due the day before the test.

HW Problem Set: Coulomb's Law

Relevant Formulas:

$F = \frac{kQ_1Q_2}{d^2}$ $\quad k = 8.99 * 10^9 \, Nm^2/C^2$ $\quad 1\, nC = 1 \times 10^{-9} C$

1) The fundamental charge, the charge of an electron or proton, is denoted by the symbol e. ($e = 1.602 \times 10^{-19}\, C$). Suppose that a wool rubbed rubber rod touches an aluminum wrapped suspended ball. The ball has a charge of -1.98nC. Approximately how many electrons were transferred from the rod to the ball?

2) Think about what the fundamental charge *e* represents. Not all charges are possible. What is one charge magnitude that is impossible for an object to have?

3) Determine the MAGNITUDE (no signs) electrical force of attraction between two balloons with separate charges of $+3.5 \times 10^{-8}$ C and -2.9×10^{-8} C when separated a distance of 0.65 m.

4) At what distance of separation must two 1.00-microCoulomb charges be positioned in order for the repulsive force between them to be equivalent to the weight (on Earth) of a 1.00-kg mass? Hint: Calculate the weight using g=9.8 m/s^2

	0	1	2	3	points
True/False Question	No effort shown, Incorrect answer, no creativity	Little effort shown, little creativity, Requires little understanding of the material	Moderate effort shown, creativity shown, requires a firm understanding of material	Test Question used = creative, tackles a misconception, requires advanced understanding of material to answer question	
Multiple Choice Question	No effort shown, Incorrect answer, not at least 4 choices, no creativity	Little effort shown, little creativity, Requires little understanding of the material to answer question	Moderate creativity shown, at least one wrong choice is focused on a misconception, requires a firm understanding of material to answer question	Test Question used = creative, more than one wrong choice is focused on a misconception, requires advanced understanding of material to answer question	X2
Quantitative Question	No effort shown, Incorrect answer, no creativity	Little effort shown, little creativity, requires only plugging numbers into a formula to solve	Moderate creativity shown, requires the manipulation of given formula, requires a firm understanding of material to answer question	Test Question used = very creative, tackles misconception, requires the manipulation of given formula, requires advanced understanding of material	X2
				Total	_____/10 (possibility of 15 points)

Lesson Plan – Superposition

Lesson Five(Day 7) – Electrostatics Unit Plan

Time Allotted for this Lesson: 50 minutes. (1 Full period)

Purpose/Rationale

Physics: Electrostatics

Students have difficulty with the superposition of electric forces, both qualitatively and especially quantitatively. To truly understand polarization and the future topic of electric fields it is necessary to the students apply and understand the principle of superposition to a variety of electrostatic problems.

Objectives

- Students will be able to draw individual and net force vectors in electrostatic 1D problems involving superposition
- Students will be able to calculate individual and net forces in 1D electrostatic problems involving superposition both symbolically and numerically.

Standards

PH.2 a) e)

PH.10 a)

Materials and Resources

SmartPals and copies of the problem inserts.

Safety and Classroom Management Issues

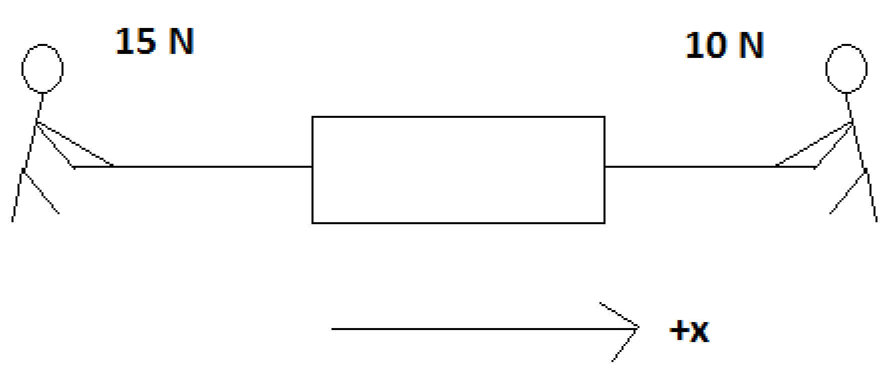
Normal classroom procedures apply. Students will be expected to participate in the class discussion.

Procedures

Engage (<10 minutes):

(Day 7 DO NOW: How can a box move if two people are pulling it at different ends?)

The do now seems rather silly, but it sets the stage to talk about the superposition of forces and the addition of net forces. Working out a problem involving only pushes and pulls on a box first is a useful introduction.

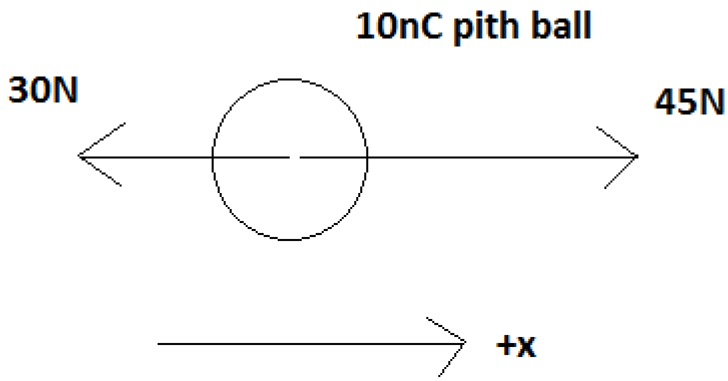


Explore (20 minutes):

Students may have difficulty with fraction addition/subtraction as well as distinguishing from forces caused by negative charges from negative (direction) forces. Using a power point and a couple problems help students work through these difficulties.

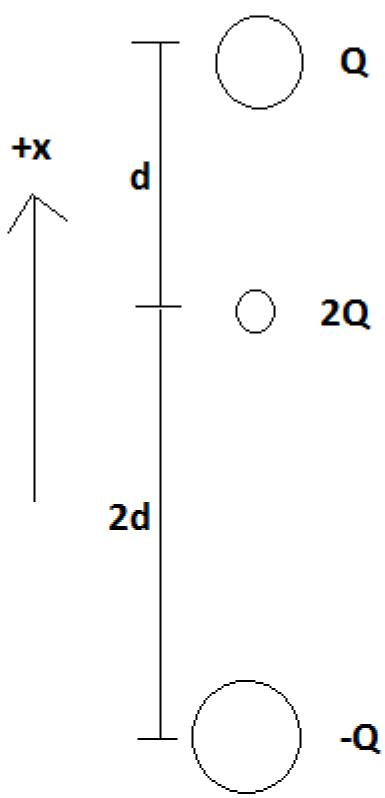
Provide Coulomb's law but not the numerical value of k..

Ask students to solve for the net force on the pith ball.



Many will try to incorporate the charge into the solution. This is an opportunity to emphasize that it is necessary to only look at the force acting on the ball to find the net force acting on it.

Have students work in pairs to solve this problem:



Three charged object sit in a straight line. The top object has a positive charge of Q, the middle object has a positive charge of 2Q, and the bottom object has a negative charge of −Q. One pair of objects is separated by a distance d, the other, by a distance of 2d. Find the net force on the top most object.

Allow students to struggle. Many will be looking for numbers to plug in, but it is important to have students solve problems symbolically. Encourage pairs that do figure it out to explain it to their neighbors. Once a majority have figured out the solution go over it as a class, calling on groups that did not completely finish to answer parts of the solution. Emphasize the important of drawing vectors and determining signs pictorially first.

Explain (<5 minutes):

Take the two problems and show how they apply to polarization problems, and how the principle can be taken to solve problems not involving point charges. (Obviously any attempt of involving calculus is ignored this just serves as a qualitative explanation of phenomena)

Elaborate (25 minutes):

To give students practice using Coulombs Law and superposition a game can be played that rewards the class for participating and answering correctly. Break the students up into groups of four. Each group is given a Smart Pal (essentially a transparent piece of plastic with a white piece of paper behind it to provide contrast). A problem is displayed on the board and the groups work together to solve it. Vary the orientation, the axis, and the number of charges in each problem. Ask for some to be solved numerically and others symbolically. Have students alternate in turns as the writer of the answer. Have students hold up their correct answer to indicate that their team is done.

To encourage a class mentality where different groups are still working towards the same common goal, the instructor should act as the "house." There are four groups working to answer the Coulombs Law questions. Allow each group that gets the correct answer to those questions to have a "guess." Following each Coulombs law question is an unrelated multiple choice question. In my class I used trivial multiple choice questions about myself for fun and to break up the monotony. For each multiple choice question there are four possible answers. If all four groups got the Coulombs law questions correct, then the class is guaranteed to get the multiple choice question correct. Each multiple choice question answered correctly by the class earns the class a point. The fun of the game is that the multiple choice questions are the questions that matter in terms of winning. I set a threshold of points that earns the class extra credit. This motivates the class to work together, answer quickly, and to stay on task.

Evaluate:

The point system allows for a more informal evaluation during the elaborate activity.

For homework assign a 1D problem with several charges and an unusual orientation. Offer EC for a 2D problem of comparable difficulty.

Lesson Plan – Electric Fields

Lesson Five (Day 8-9) – Electrostatics Unit Plan

Time Allotted for this Lesson: 100 minutes. (2 Full period)

Purpose/Rationale

The field concept is introduced as the means by which two charges interact without contact. This field is an abstract idea, though comparisons to gravitational field strength can be made, students will likely doubt its existence and/or its importance. Walking through what the formulas mean through concrete examples and justifying their importance is crucial to understand the *definition* of electric field as a tool, and the *meaning* of the electric field as a hypothesis to explain action-at-a-distance.

Objectives

- Students will be able to draw individual and net force vectors in electrostatic 1D and 2D problems involving superposition
- Students will be able to calculate individual and net forces in 1D electrostatic problems involving superposition
- Students will be able to draw and interpret Electric Field Line diagrams
- Students will be able to differentiate between Field Lines and Field Vectors
- Students will be able to describe a process to measure the Electric Field

Standards

PH.1 a) e)

PH.2 a) e)

PH.3 b) c) d) e)

PH.4 a) b)

PH.10 a)

Materials and Resources

Spring Scale, 500 gram mass, Van de Graaff generator, and aluminum wrapped ball.

Safety and Classroom Management Issues

Normal classroom procedures apply. Students will be expected to participate in the class discussion.

Procedures

Engage (10 minutes):

(Day 8 Do Now: What do you think Newton was talking about?)

Provide a quote on the board:

> 'That gravity should be so innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum and without the mediation of anything else, by and through which this action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers.' – Isaac Newton

Discuss with the class the strangeness of action at a distance. Tell them that Michael Faraday suggested an idea of an Electric field as means by which two charged objects interact without contact.

It helps to turn on the Van de Graff to its effects on a charged ball. After the ball is taken away ask the students if they think there is something still there at that location. Emphasize that Faraday *thought* there was, that it could be measure, and that it was intangible. Explain that Faraday had no direct evidence for the field concept, but that the evidence would follow in later experiments.

Emphasize that writing on the board that Electric Forces are associated with the *objects* that they act on, but the electric field is associated with *locations* in space.

Explore (20 minutes):

Ask the question how you would measure the strength of gravity anywhere in the universe using a spring scale that measures force in Newtons and a mass that is known to be 0.5 kg? Develop the idea among the students that

$$Relative\ Stength\ at\ a\ location\ = \frac{Force\ on\ some\ test\ object}{amount\ of\ force\ causing\ stuff\ in\ the\ test\ object}$$

In the question:

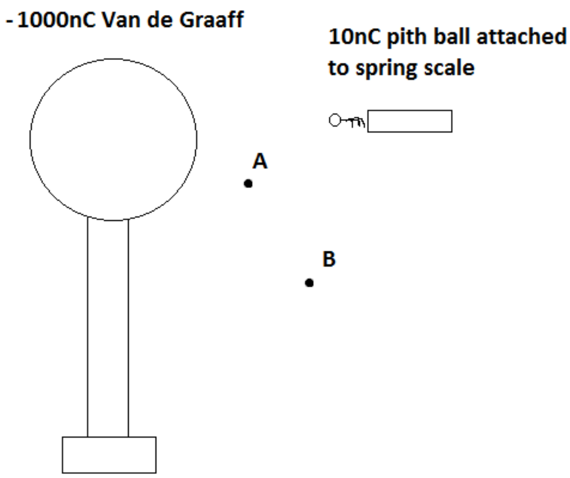
$$Strength\ of\ Gravity\ at\ a\ location = \frac{Reading\ of\ on\ the\ spring\ scale}{mass\ of\ the\ test\ object}$$

Students should recognize through this method by reading the force and dividing out the test mass, the relative "strength" of gravity can be shown. Perform an example to show through this method that the strength of gravity at a specific location in the class room is ~9.81 Newtons of Force/kilogram of mass.

In pairs ask them how they would determine the weight of a 100 kg human (something that is far too large to attach to the spring scale) using the spring scale and the 500 gram mass. At this point the concept of measuring a field will still be abstract. Tell students to write down their suggestion and turn it in as a classwork grade.

Explain (40):

Use this picture to talk about measuring the Electric Field. Carefully define A and B as locations in space and NOT charged objects, this will be a point of confusion. Emphasize that the idea of an electric field is to describe the direction and strength objects will feel.



Ask what would happen to the spring scale at the different locations. Provide "fake scale readings" appropriate to the problem to work out numerical answers. Have the students draw "field" vectors at the locations.

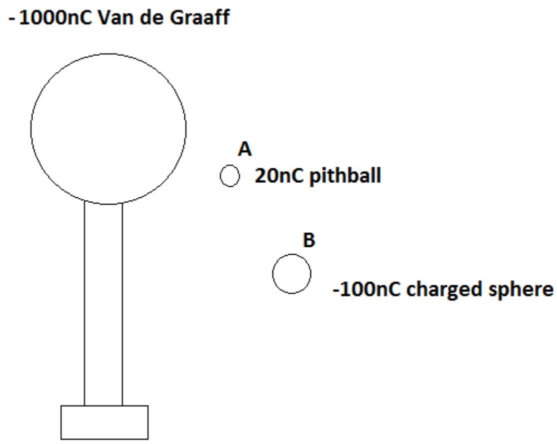
Introduce the equation $E_{at\ a\ location} = \frac{F_{on\ at\ test\ charged\ object}}{Q_{magnitude\ of\ the\ positive\ test\ charge}}$

Explain the meaning of a test charge. Emphasize the field exists whether or not the test charge is at the location. The test charge is only there to measure the strength and direction of the electric field.

Explain that the test charge being positive is only a convention.

Introduce the unit of electric field Netwons per Coloumb (N/C). Compare it to the Newtons per kilogram the students used in the explore activity.

Ask the students to calculate the Force on the charge objects based on already calculated electric field



Introduce the equation

$$F_{on\ any\ charged\ object} = E_{measured\ at\ a\ location} Q_{magnitude\ of\ charge\ on\ any\ object}$$

(Day 9 Do Now: explicitly summarize and describe how to measure the strength and direction electric field anywhere in the universe by using a spring scale and a positive charged ball known to have a charge of 10nC. This will be collected as classwork.)

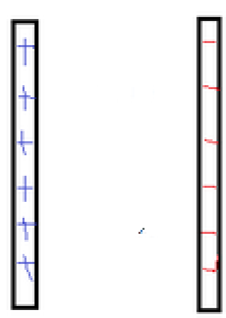
Begin the following day by moving into more quantitative examples where E fields are measure, where E fields are used to calculate force, and where superposition is involved.

Elaborate (30):

Electric field line diagrams can be used to clarify the concept of electric field to some students, but they may serve to further complicate its role. I chose to spend class time introducing the concept and working through examples. It takes at least 20 minutes to justify their purpose. It is important to emphasize that just as when field vectors are drawn, field lines are only a mathematical abstraction, and does not say what the electric field "looks" like. The electric field is immaterial.

Students can be challenged to create their own setup of source charges to draw Electric field lines. Ask students to choose three places on their diagram and describe what electric field vectors would look like.

For homework assign a "parallel plate" setup of charges. See if students can determine on their own from following the rules of drawing diagrams that the E field between two equally charged plates is constant.



An additional homework problem can be given to illustrate the concept of the electric field in a problem worded about polarization.

Evaluate:

The classwork during the Explore activity and the next day's Do Now are collected as classwork. Informally evaluate student understanding as the class works through more difficult quantitative problems involving electric field. It is easy to assign additional problems if necessary. Let students know specifically that similarly shaped problems will appear on the unit assessment.

Lesson Plan – Final Assessment

Lesson Five (Day 10-11) – Electrostatics Unit Plan

Time Allotted for this Lesson: 62 minutes. (1+ Full period)

Purpose/Rationale

A unit assessment serves to tie together the separate ideas of electrostatics. It is an opportunity for students to display their knowledge a series of qualitative and quantitative question about polarization, the fundamental nature of electric charge, and the ideas behind the electric field. An additional day to review these concepts can preface the unit test if the evaluations of student learning show a need for it. The quantitative problems are broken down step by step to clarify exactly what is being evaluated and to provide an easier and fairer means of grading student responses. Most questions were directly covered at some point during class time, but several require the students to apply their understanding in a further way to answer. For example the phenomena of induction was never explained to students, but the extra credit problems asks students to use their understanding of electrostatics to explain what is happening.

At the beginning of the next day the students are given the posttest again as a basis to measuring student growth and understanding.

Raw Score: ____/50

Physics Test - Electrostatics

True and False (1 point each). Write the letter 'T' to indicate the statement is true or 'F' to indicate the statement is false.

1. _____ An object that is electrically neutral most contain more neutrons than protons or electrons
2. _____ Neutral is not a charge type.
3. _____ A positively charged object is an object that has an excess of *positive electrons*.
4. _____ If an atom has an unequal number of protons and electrons, then the atom is electrically charged and referred to as an ion.
5. _____ A single electric field vector provides information about the electric field in more than one location in space.
6. _____ Most metals consist of permanent molecular dipoles which explains their ability to conduct electricity easily.
7. _____ Both conductors and insulators can be polarized.
8. _____ A charged rubber rod is touched against an insulating Styrofoam ball. Some of the charge is transferred to the ball. The charge quickly and uniformly distributes itself across the surface of the Styrofoam.
9. _____ It is possible to charge an aluminum rod by having it rubbed with a material which has a different affinity for electrons.
10. _____ By grounding an object you are completely destroying excess electric charge.
11. _____ Small pieces of paper are lifted by a charged rubber rod, this indicates that the pieces of paper had a net positive or negative electrical charge.

Multiple Choice. (2 point each). Choose one of the five multiple choice options that best answers the question or completes the statement.

12. _____ Upon entering the room, you observe two pieces of tape hanging next to each other. You notice that instead of hanging straight down vertically the pieces of tape seem to be repelling each other. You can conclusively say

A. Both pieces of tape have a negative charge.
B. At least one piece of tape is charged.
C. Both pieces of tape are charged with the same type of charge
D. At least one piece of tape is negatively charged.
E. Both pieces of tape have a positive charge

13. _____ Upon entering another room, you observe two pieces of tape hanging next to each other. You notice that instead of hanging straight down vertically the pieces of tape seem to be attracting each other. You can conclusively say

A. Both pieces of tape have a positive charge.
B. At least one piece of tape is charged.
C. One piece of tape is charged positively and the other negatively
D. At least one piece of tape is positively charged.
E. At least one piece of tape is uncharged.

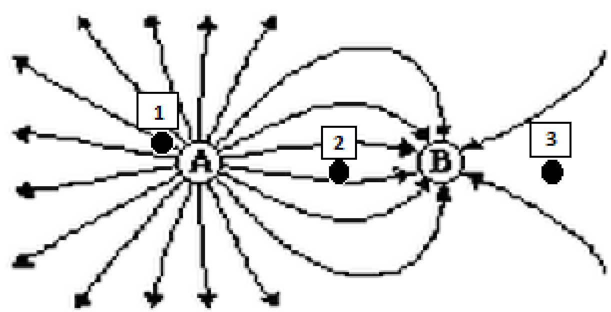
14. _____ Suppose a smaller conducting sphere has a positive 10nC charge. It is brought in contact with a second larger conducting sphere that is initially neutral. After the contact, what is the charge on the larger conducting sphere?

A. 0 nC
B. Between 0 and 5 nC
C. 5 nC
D. Between 5 and 10 nC
E. 10 nC

15. _____Drawn below is an electric field line diagram which describes the electric field around two source charges labeled A and B. Also shown are three locations in space labeled 1, 2, and 3. Determine which of the following statements are TRUE.

I. The magnitude of the charge on A is greater than the magnitude of the charge on B

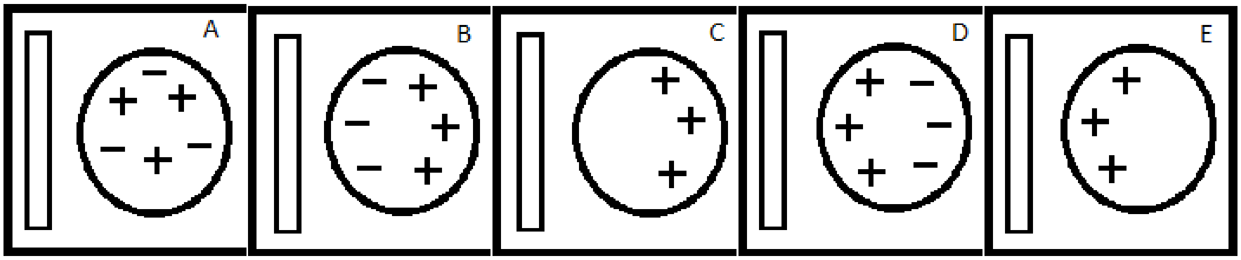
II. The magnitude of the Electric Field ($\vec{E}$) is greatest at 1 and weakest at 3.



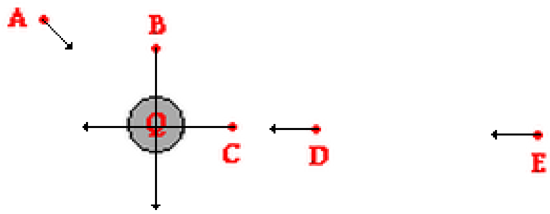
III. A positive test charge placed at 2 would feel a force directed to the left.

A. Only I is TRUE
B. Only I and II are TRUE
C. Only I and III are TRUE
D. Only II and III are TRUE
E. All statement (I, II, and III) are TRUE

16. _____ Which of the diagrams (A, B, C, D, or E) below best represents the charge distribution on a metal sphere when a positively charged plastic tube is placed to the left of the sphere?



17. _____ A <u>negative</u> source charge (Q) is shown. The source charge contributes to a change in the electric field. Various location around the charge are labeled. With an electric field vector indicating the relative strength and direction of the electric field. However, one of the five field vectors has been drawn incorrectly. At which location (A, B, C, D, or E) is the electric field vector ($\vec{E}$) incorrectly drawn?



Problems. Solve the following problems dealing with Electrostatics. Show all work and do not forget to include appropriate units with your answer. Some helpful information:

A shortened Triboelectric Scale

+ Positive

Air
Rabbit Fur
Glass
Human Hair
Wool
Hard Rubber
Polyethylene Teflon

-**Negative**

Relevant Formulas, Constants, and conversions:

Magnitude of the fundamental charge: $e \cong 1.6 \times 10^{-19}\ C$

$k = 8.99 \times 10^{9}\ \frac{Nm^2}{C^2}$ $1nC = 1 \times 10^{-9}C$

$|\vec{E}| = k\frac{|Q_{source}|}{d^2}$ $|\vec{F}| = k\frac{|Q_1 Q_2|}{d^2}$

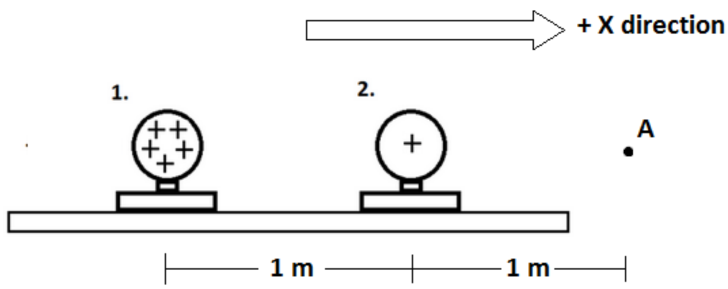
$\vec{E} = \frac{\vec{F}_{on\ positive\ test\ charge}}{q_{positive\ test\ charge}}$ $\vec{F}_{on\ any\ charge} = \vec{E}q_{any\ charge}$

18. (1 point) A negatively charged pith ball has a net charge of $-3.2nC$. How many excess electrons does it have?

19. (2 points)Two charged objects have a repulsive force of 0.080 N. If the charge of one of the objects is doubled, and the distance separating the objects is tripled, then what is the new force?

20. (5 points) Fill in the blanks using the tribolelectric scale and your knowledge of electrostatics: When a glass rod is rubbed with a polyethylene bag. The glass rod becomes _____________ charged. The polyethylene bag becomes _____________. Electrons moved from the _____________ to the _____________. Afterwards the glass rod comes in contact with an aluminum wrapped Styrofoam ball. The ball then becomes ________________ charged.

Consider the scenario drawn below to answer questions 26-34. Two IDENTICAL conducting spheres (labeled 1 and 2) are attached to insulating hockey pucks that sit on top of a perfectly frictionless air hockey table. Sphere 1 has a net charge of **+150nC**. Sphere 2 has a net charge of **+30nC**. They are separated by a distance of **1m**. One meter to the right of sphere 2 is a location in space labeled Point A. To the right, is taken to be the positive x direction.



21. (2 points) **Draw** on the picture provided force vectors on spheres 1 and 2 to indicate the size and direction of the electric force. **Label** the vectors $\vec{F}_1$ (the force on 1) and $\vec{F}_2$ (the force on 2).
22. (1 point) As the spheres move, will their accelerations be constant, increasing, or decreasing?

23. (1 point) As the sphere move, will their velocities be constant, increasing, or decreasing?

24. (2 points) Calculate the electric force acting on sphere 1. Make sure to include units and to indicate the direction of the force.

Refer to the point A. All these questions pertain to before any movement of the spheres. Take all positions to be their present positions.

25. (2 points) **Draw** on the picture provided electric field vectors at point A to indicate the contributions to the electric field from sphere 1 and sphere 2. **Label** the two field vectors as $\vec{E}_1$ and $\vec{E}_2$.
26. (1 point) Calculate the electric field contribution from sphere 1. Make sure to include units and to indicate the direction of the field vector.

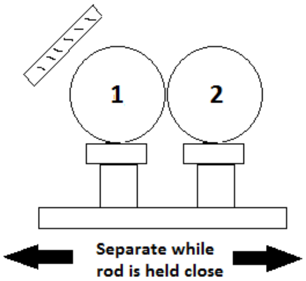
27. (1 point) Calculate the electric field contribution from sphere 2. Make sure to include units and to indicate the direction of the field vector.

28. (1 point) Calculate the net electric at point A using superposition. Make sure to include units and to indicate the direction of the field vector.

29. (2 points) <u>Using the calculation of the Electric Field at point A</u>, Calculate the force on an electron at point A.

30. (7 points) In as step-by step description describe how you would use a spring scale that measures the force in Newton's and an aluminum wrapped Styrofoam ball with a known charge of 10nC to determine the strength and direction of the Electric Field anywhere in the Universe. How that measurement of the electric field and the spring scale then could be used to determine the unknown charge on a different aluminum wrapped pith ball. Use both words and/or pictures to explain your answer. Your answer should be at least 5 sentences in length.

(EC and survey on back)



(3 points) Extra Credit: Two neutral conducting spheres on insulating stands are placed in contact. A negatively charged rod is then brought directly to the left of sphere **1**, but DOES NOT TOUCH either sphere. While the rod is held still, the sphere **2** is moved so that the spheres no longer touch. Then the charged rod is withdrawn.

After the rod is withdrawn, what is the charge state and relative magnitude of the charge on each sphere? Use both words and/or picture to explain your answer.

Survey: Rate on a scale of 1-10. Answering will have NO EFFECT on your grade or my feelings. YOU DO NOT HAVE TO ANSWER. I'm just curious. Answering honestly will just help me write better future tests. Circle the number on the scale that best applies to your opinion.

I found this test to be
(Very Easy) 1 2 3 4 5 6 7 8 9 10 (Very Difficult)

I found this test to be
(Very Unfair) 1 2 3 4 5 6 7 8 9 10 (Very Fair)

I would describe the amount of time I spent studying for this test as
(Very Little Time) 1 2 3 4 5 6 7 8 9 10 (A Huge Amount of Time)

I would describe my understanding of Electrostatics after this unit as
(Very Little Understanding) 1 2 3 4 5 6 7 8 9 10 (Very Strong Understanding)