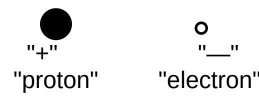
TAKE-HOME EXP. # 6
*The Interaction of Electric Charges**

Please take the following assertions about electric interactions to be true. We'll refine the description a little later.

♦ There are two kinds of charges that can explain all electric phenomena.

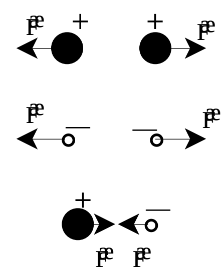
Let's call them "+" and "—", positive and negative. We'll use these "labels" for the charge to take advantage of their coincident use in arithmetic. This is at least one advantage over naming the two kinds of charge "Tom" and "Jerry" or "proton" and "electron". Notice also that the visual symbols are arbitrarily chosen; *any* two symbols can be used.



♦ Like charges ([+,+] or [—,—]) repel each other; unlike charges [+,—] attract each other.

♦ The electric force

a) is proportional to the amounts of both interacting charges,
b) acts along a straight line between the charges, and
c) decreases rapidly as the distance between the charges increases.



We are all essentially blind to electric charge. You cannot see charges on objects; yet they cause the electric force which is the second strongest interaction in the universe. In the gravity interaction, the weakest in the universe, you can usually see the masses that act as the agents of 3rd-law pairs of gravity forces. For example, if you have ever walked near a cliff, you get clear sensory information that the edge is near. If you step over it, your body and the clearly visible Earth will interact freely. However, in reaching for a highly charged object, you don't get any sensory information that you are about to "step off" an electrical cliff.

How can we humans get to see this invisible "charge" stuff more clearly in our imaginations? That's what we'll begin to do in this experiment. We will make electrically charged strips of cellophane tape, and examine how they interact with each other via the long-range electric force.

* The design, approach, and excellence of this experiment is directly owed to Ruth Chabay and Bruce Sherwood, who use it in the first chapter of their truly innovative text *Electric and Magnetic Interactions,* John Wiley, 1995. I first heard of it elsewhere (Arnold Arons), but they carefully developed it into a workable prescription. Any mistakes are due to the present author.

Procedure For This Experiment

The observations will require *an inexpensive generic brand* of "invisible tape", similar to Scotch® brand Magic™ Tape. The latter doesn't work as well as the generic brands in the unusual property we need in this experiment, namely one in which we try to maximize the excess charge on the tape.

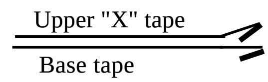
ALERT! Everyone, including me, feels at first like a klutz when handling these tapes. Handling these tapes is easier than learning how to play a musical instrument, but it still takes practice. You cannot learn to play a piano by reading a book, and you cannot experience this without actually doing it. It might feel clumsy, but you'll soon get better at it.

Standard Procedure For Making A Charged Tape:

1. Use a strip of tape about 8 inches or 20 cm long. Fold over a small piece at one end for to make a handle. This page is 8.5 inches wide.

2. Stick a strip of tape with a handle down onto a smooth surface such as a desktop. This base tape forms a standard surface from which to work and generate the tapes to be used. Different surfaces can produce seemingly different effects.

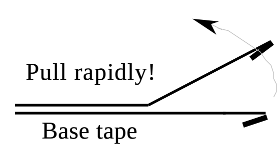
3. ***Every time*** *you use the base tape to make a charged tape, run your fingers or thumb along the tape.* This procedure standardizes the initial charge condition of the base tape by allowing your body to add or subtract any charges required to make the tape neutral.



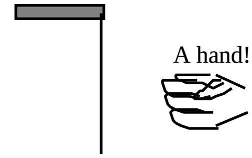
4. Stick another strip of tape-with-handle down *directly on top of the base tape*. Smooth it down with your fingers, again setting the initial charge condition.

5. Write an "X" on the handle portion so you can identify it.

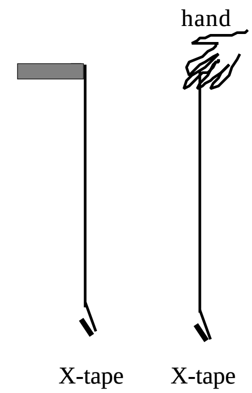
6. Jerk the upper tape very quickly off the base tape, leaving the base tape stuck to the surface.



7. Hang the tape vertically from the edge of a desk. Bring your hand slowly near the hanging tape. When you get close to either side of the tape—don't get close enough to let it touch your hand— you should find an attraction between the strip and your hand . A too-humid day can make this a problem, since the water molecules in the air can be attracted to, and neutralize, the charge on the tape. *If you don't see an attraction to your hand, remake the tape. If you do see an attraction, the tape is charged.* If you need to repeat the procedure, the same piece of tape can be used with the same base tape. Start at Step 2. above.



Observation A: The Effect of Two Similarly Prepared Tapes On Each Other



8. Make another "X" tape in exactly the same way as the previous one. In bringing the second tape near the first one, don't forget that a charged tape is attracted to your hands. Try to keep your hands out of the way. Experiment with various ways of approaching the first tape. For example, it is OK to hold the second tape stretched horizontally, held with a hand at either end, and approach the vertically hanging tape from one side or the other. (If the air is humid, you have to work very fast.)

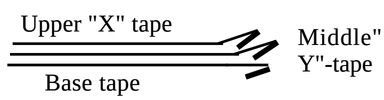
They did repulse each other, didn't they? If not, try it again. Sometimes the first strip off a roll has contamination problems, but repeating the standard procures usually produces results.

Observation B: Making A "Y" Tape And Its Effect On An "X" Tape

9. Stick a strip of tape with a handle down onto a smooth surface such as a desktop. Again, before every time you use the base tape to make a charged tape, run your fingers or thumb along the tape.

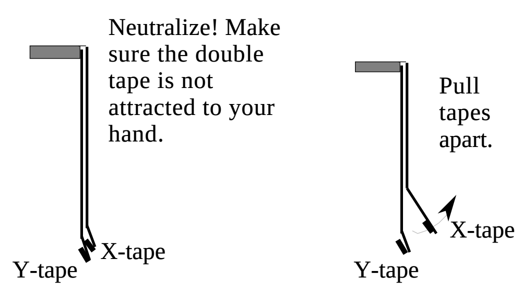
10. Stick another strip of tape-with-handle down *directly on top of the base tape*. Smooth it down with your fingers. *Write an "Y" on the handle portion* so you can identify it.

11. Then stick a third tape-with-handle on top of the combination. Mark the third tape, the one on top, with an "X".



12. *Slowly* lift both tapes together—the Y-tape AND the X-tape together—leaving the base tape stuck to the desktop.

13 Hang the double layer of tape vertically from the edge of the desk and see whether there is any attraction between it and your hand. *If so, get rid of the interaction by holding the bottom of the tape with one hand, and slowly rubbing t**he slick side** with your fingers .*



14. VERY IMPORTANT! CRUCIAL! Check again that the tape pair is no longer attracted to your hand. If it is, repeat the procedure until there is no attraction. IMPORTANT!

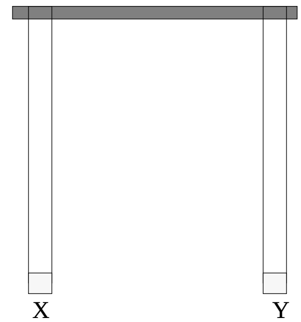
15. Hold onto the bottom of the Y-tape and *quickly* pull the X-tape up and off.

16. Then—not too close to the Y-tape—also hang the X-tape vertically from the edge of the desk.

17. Now repeat the same procedure to make another pair of tapes, so that you have at least two X-tapes and two Y-tapes. Store one of them on a desk edge, and use the other to do the following. Check briefly that they are all charged by moving a finger nearby each.

18. For example, move the 2nd X-tape first toward the hanging X-tape, and note whether there is an attraction or repulsion. Then move it toward the hanging Y-tape, and note the effect there. Record these results on the data sheet.

19. Then do the same set of observations for effects the Y-tape on the two hanging tapes, and recording your observations.



Observation C: Determining the Kind of Charge

Which tape has an excess of electrons, and is therefore charged negatively? Which tape has fewer electrons than a neutral tape, and therefore is charged positively?

There is a kind of "litmus test" that uses a plastic comb or pen, instead of a chemical indicator. In general, plastic material rubbed with hair, wool, or cotton acquires a negative charge. Many observations have shown that if you repeatedly run a plastic comb or pen through or along your hair, or rub it with cotton or wool, the plastic will end up with an excess of electrons, and therefore will have a *negative charge.* The mechanism is still not very clear, but it happens something like the following. Large organic molecules in the plastic and/or your hair break at their weakest bond in such a way that the negatively charged fragments are deposited on the comb and/or the positively charged fragments are deposited on your hair.

It is sometimes said that molecular "ions" are transferred. The word "ion" applied to an atom or molecule simply means that the atom or molecule is charged, that there are not equal numbers of positive and negative charges on the molecule or atom. The number of electrons that an ion has is either more or less than the number of protons present, and the fragment is thus charged either negative (more electrons) or positive, respectively. A similar kind of process occurs with the tapes.

Almost the only materials that can be charged easily by rubbing are those that contain large organic molecules which may have some weak binding energies associated with their structure. It is usually more difficult, but certainly not impossible, to pull single electrons out of atoms or molecules. Glass is one of the few inorganic materials that can be charged easily. When rubbed with silk, glass becomes positively charged. One possible mechanism is that positively charged ions break off the large organic molecules in the silk and are deposited on the glass, or that silk strips single electrons out of the glass. The physics of such surface phenomena are complex, and the subject of continuing research.

But at least one thing is very clear. Only electrons, or larger scale molecular ions can be transferred. It is absolutely certain that you *cannot* remove positive protons from the nuclei of the surface atoms by using these rubbing processes. This would be the equivalent of transmuting matter from one element to another!

The Test. Make an X-tape and a Y-tape, and hang them vertically from the edge of a desk. Rub a plastic pen/comb on your hair, or on wool or cotton, and *slowly* bring it close to each tape. What do you observe?

X-tape: **O** attracted by plastic/rubber object? **O** repulsed by plastic/rubber object?

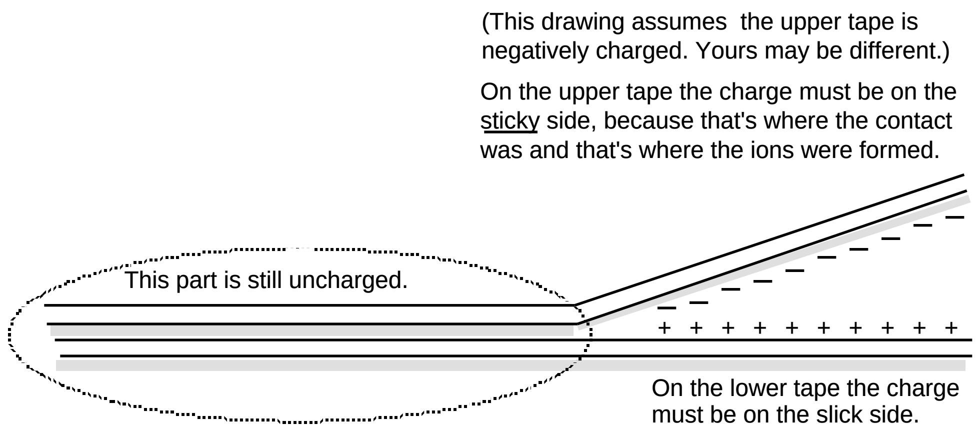
Therefore, X-tape is charged **O** negatively **O** positively .

Y-tape: **O** attracted by plastic/rubber object? **O** repulsed by plastic/rubber object?

Therefore, Y-tape is charged **O** negatively **O** positively .

Informally compare your results with those of some other groups in the class. IMPORTANT! Make sure you agree on the assignment of "+" and "—" labels to your tapes. However, you need to check brands of tape also! Different brands may charge the X- and Y-tapes differently. If you find a disagreement on the assignments and labels with those of another group, it is easy and quick to make the appropriate tapes and check to see what happens.

Where's the Charge Actually Located?



The first "X" tape procedure started with two neutral tapes. Pulling one off the other rapidly probably pulled charged particles off the bottom tape—or equally likely—left some charged particles on the bottom tape.

Either way, if we believe conservation of electric charge, the charge of the base tape must be precisely equal to the charge on the "X" tape, but opposite in sign. The two tapes taken as an isolated system then still have the same zero net charge with which the system started.

The charge doesn't appear to move much on the surface after it is formed. The excess charge is not free to move about, or free to move into the interior of the tape. The medium of the tape does not "conduct" the charge anywhere. The tape would be classified as being a "non-conductor" of electricity. This classification is in contrast to materials which allow excess charge to travel freely. Such materials are classified as "conductors" of electricity. It simply means that the charges are relatively free to move along the surface and sometimes even through the interior volume of the material.

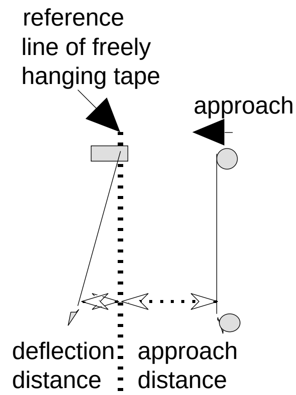
These names—conductor or insulator (non-conductor)—are somewhat misleading because they seem to imply an all-or-nothing proposition, that either a material conducts or it doesn't. That is not true, since the "conduction" varies greatly from material to material, and also can vary as a function of temperature in a given material.

Observation D: What Is The Effect Of The Distance On The Strength (Magnitude) Of The Forces On The Tapes? REPORT YOUR OBSERVATIONS IN THE TABLE AND GRAPH ON THE NEXT PAGE.

It may take 2 or more people to do this observation.

(a) Make two X-tapes. One of the X-tapes can be suspended from a thread or a hair. You can then hold the thread or hair in your hand, or use a piece of tape to attach its upper end to a support, like the desktop.

(b) Move another X tape very slowly toward the vertically hanging X tape BY HOLDING THE TAPE AT BOTH ENDS IN A VERTICAL ORIENTATION. The hanging X tape deflects directly away from the approaching tape, along a straight line imagined between the charged tapes. Make a record of the distance of the deflection of the tape from its initial position. Do this for several approach distances. For example, record the distance at which you first see an effect, and observe the distance of the deflection. Then move to half the first approach distance, and measure the deflection of the hanging tape. Then to half the remaining approach distance, and so on. At each approach location, the hanging tape will exhibit a deflection away from its *original vertical position.*



(c) We know that this is a "rough" and "messy" measurement. For example, both tapes are attracted to your hands—and probably to a ruler. You'll probably have to devise a procedure to keep the ruler, or something, in the background so you can estimate, or later measure against some background, the distance of deflection.

NAME ______________________________ *ID#* ____________________

PARTNERS ____

HAND IN ONLY THIS DATA SHEET

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Record on the above line the brand of tape you used. You will need it when you compare your results.

a) You prepared two X-tapes in exactly the same way. What happened your X-tapes (X-X) interacted?

O attractive interaction **O** repulsion interaction **O** no interaction

b) What happened when your X-Y tapes interacted?

O attractive interaction **O** repulsion interaction **O** no interaction

c) What happened when your Y-Y tapes interacted?

O attractive interaction **O** repulsion interaction **O** no interaction

Explain theoretically why situations a) and c) should have showed repulsive effects.

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Report on Observation D, described on the previous page.

Insert the units of the measurement.

	Approach distance	Deflection distance
1		
2		
3		
4		
5		

Make a rough plot by assigning appropriate scales to the coordinate axes below.