Name: ___________________________________

Partner(s): ________________________________

1118 section: _______

Desk # _____________

Date: _________________

Electrostatic Interactions

(This lab is adapted from Chapter 1of Electric and Magnetic Interactions, Chabay and Sherwood, 1995.)

(All questions that you need to answer are in italics. Answer them all!)

Purpose

The purpose is to investigate the basic aspects of electrostatic interactions via a series of short exercises.

Introduction and Theory

Electrostatic interactions have the following basic properties:

- There are two kinds of charges called positive charge (+) and negative charge (–).
- Like charges repel and unlike charges attract.
- The electrostatic force
  - increases rapidly as the distance between the charges decreases,
  - acts along a line between the charges,
  - is proportional to the amounts of both charges, and
  - obeys the superposition principle.

In these experiments, you will investigate these basic aspects of electrostatics using "invisible" tape to make electrically charged objects in a reproducible manner. You will attempt to explain these basic interactions using these three fundamental physical principles:

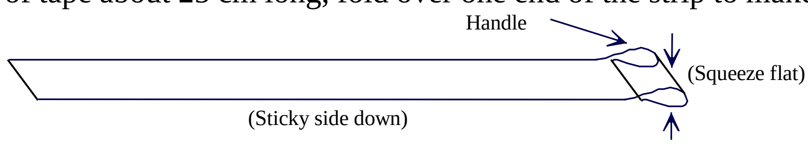
- **Conservation of charge**: The net charge of a closed system does not change,
- **Coulomb's law**: $|F| = \frac{k|q_1 q_2|}{r^2}$,
- **The superposition principle**: The net electrostatic force on a charged object is the vector sum of the individual electrostatic forces acting on the object.

Apparatus

"Invisible" tape, thread, stand. Note: Please do not leave any tape stuck to your desk.

Preparing a Base-tape

- Get a strip of tape about 25 cm long, fold over one end of the strip to make a non-sticky handle:



- Take the strip of tape with the handle and stick it onto a smooth flat surface (such as a desk).
- Smooth this tape down with your thumb or fingertips. This is our base tape. It provides a standard surface to work from. Without this base tape, you may get different effects on different kinds of surfaces.

Preparing a U tape

- Run your finger along the base tape that is on the desk.
- Stick another piece of tape (about 15 to 20 cm long, also with a handle) on top of the base tape. (Shorter pieces are not flexible enough, and longer pieces are too unwieldy.)
- Smooth the upper tape down well with your thumb or fingertips.
- Write "U" (for Upper) on the handle of the upper tape.
- With a quick motion, charge the tape by jerking the U tape up and off the base tape leaving the base tape stuck to the desk. Faster tearing results in a stronger charge.

Note: U tapes can be reused again and again by following the above procedure.

Exercise 1 Initial observations of a U tape

Why does invisible tape frequently stick to your hand when you pull a strip off the roll? Is this due to electrostatic interactions? Here we will see if invisible tape exhibits the properties of electrostatic interactions listed earlier. If so, we can conclude that the tape becomes electrically charged when we pull it off another piece of tape, and we can study the behaviour of pieces of tape as a concrete example of electrostatic interactions.

Make a U tape as described above. Hang the U tape vertically with a thread from the stand. Bring your hand near the hanging U tape. *Briefly describe what happens.*

Does it matter which side of the tape you approach? *Yes* *No*

If U tapes are electrically charged, *how would you expect two U tapes to interact with each other? Would you expect them to repel each other, attract each other, or not to interact at all? Make a prediction and briefly state your reason*[1].

Prepare a second U tape. Hold the tape horizontally and bring it near the hanging U tape. *Describe what happens.*

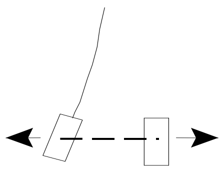
[1] Avoid circular reasoning like "They will repel because they have like charges, and they should be like charges because they repel."

Exercise 2 Is the interaction between U tapes electrostatic?

To decide whether the interaction between two U tapes is electrostatic, we will check the criteria for electrostatic interactions:

Criteria 1: Does the force act along a line connecting the objects? (Not all forces act along a line joining the two objects, e.g., electromagnetic force.)

Suspend a U tape from a thread. Hold the thread in your hand, or hang it to the stand. Approach the suspended tape from various directions with another U tape.

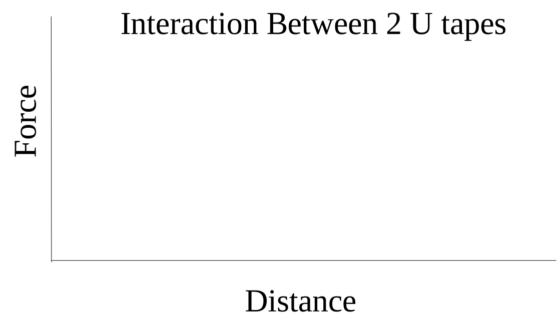


Does the force act along a line drawn from one object to the other as shown in the figure below?

Yes No

Criteria 2: Does the force increase rapidly as the distance between the tapes decreases?

Move a U tape very slowly toward the other hanging U tape. Observe the deflections of the tapes from the vertical at several distances (where you first see a deflection, half that distance, etc.). The magnitude of the deflection is a measure of the strength of the interaction force. *Make a rough graph of the strength of the interaction as a function of the distance. Scale the "Distance" axis in* cm.



Criteria 3: Does the force depend on the amounts of both charges?

Prepare two U tapes. Note the interaction between them. Now **partially** "neutralize" one of the U tapes (by running your finger over part of its length on the non-sticky side) and compare the interaction to the one before you neutralized one of the U tapes.

The interaction between the two tapes is stronger. weaker. the same.

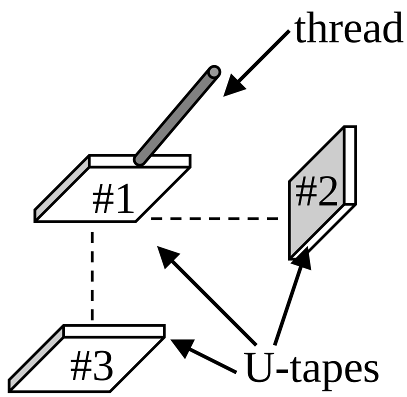
How does the partially "neutralized" U tape interact with your hand, compared to before you neutralized it? The interaction is stronger. weaker. the same.

How do two partially "neutralized" U tapes interact with each other, compared to only one tape "neutralized"? The interaction is stronger. weaker. the same.

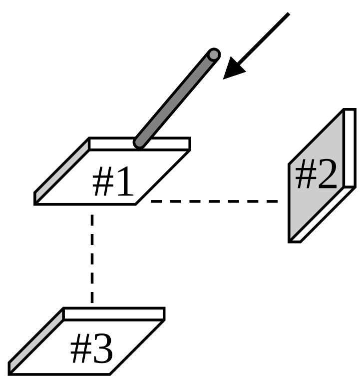
To conclude, does the force depend on the amount of charge on each tape? Yes No

Criteria 4: Does the superposition principle apply?

Prepare 4 U tapes about the same lengths. Hang the first one (#1) with a thread from the stand. Hold #2 and # 3 U tapes close to the hanging #1 tape as in the diagram below (looking from above). *In which direction does #1 U tape move? Draw an arrow below to show #1 U tape's motion.*



Draw below in where you would place #4 U tape so that #1 U tape hangs straight down again.



Try the tape placement that you drew above. *Were you able to have the hanging U tape hang straight down? Yes No*

Draw the three electrostatic forces acting on #1 U tape and mark them as $\vec{F}_{21}$, $\vec{F}_{31}$ and $\vec{F}_{41}$ on the diagram above.

Give an equation between these 3 forces: ____.

Does this equation agree with the superposition principle? Explain.

Exercise 3 Observations of L and U tapes

How could you prepare a tape that might have an electric charge unlike the charge of a U tape? Try and think of a way before reading the next paragraph.

Preparing an L tape
(a reproducible way of making a tape whose charge is unlike the charge of a U tape)

- Run your finger along the base-tape that is on the desk.
- Stick another tape with a handle down on top of the base tape, and smooth it down well.
- Write "L" (for Lower) on the handle of this tape.
- Stick another tape with handle down on top of the L tape.
- Write "U" (for Upper) on the handle of this tape.
- Smooth the upper tape down well with your thumb or fingertips
- You now have three layers of tape on the desk: a base tape, an L tape, and a U tape.
- Slowly lift the L tape off the base tape, bring the U tape along with it (and leaving the base- tape stuck to the desk).
- Check to see whether there is attraction between the double layer of tape and your hand. If there is, get rid of these interactions: hold the bottom of the tape and slowly rub the slick side with your fingers or thumb. *Check that the tape is no longer attracted to your hand.*
- Hold onto the handle of the L tape and quickly pull the U tape up and off.

Follow the procedures above and you get one L tape and one U tape. Before you bring them together, answer the following questions:

Just before the L tape and U tape are separated, what is the total charge on the pair? ______

After the L tape and U tape are separated, what is the total charge on the pair? ______
(Hint: Conservation of Charge.)

Do you expect the L tape and U tape to have like charges or unlike charges? Explain your reasoning.

Now, bring the tapes together. What type of interaction do you observe between an L tape and a U tape?
Attractive *Repulsive* *No interaction*

Make another set of U and L tapes. What interaction do you observe between two L tapes?

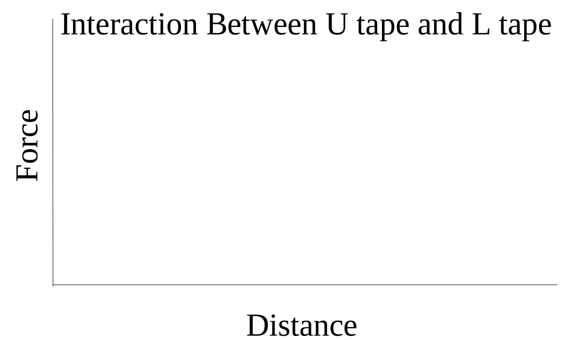
Attractive *Repulsive* *No interaction*

Is the interaction pattern that you observed consistent with "Like charges repel; unlike charges attract"?
Yes *No*

Exercise 4 Distance dependence of force between U and L

Move a U tape very slowly toward a hanging L tape. Observe the deflections of the tapes from the vertical at several distances. (For example the distance at which you first see a deflection, at half that distance, etc.) *Again, make a rough graph of the deflection of the tapes as a function of the distance between the two tapes. The deflection of the tapes from the vertical is a measure of the strength of the interactions.*

This U-L graph has a subtle difference from U-U graph you drew on Page 3. (Hint: If the tapes are touching, you can no longer measure the strength of the interaction.)



Exercise 5 Determining the sign of the charges on U and L tapes

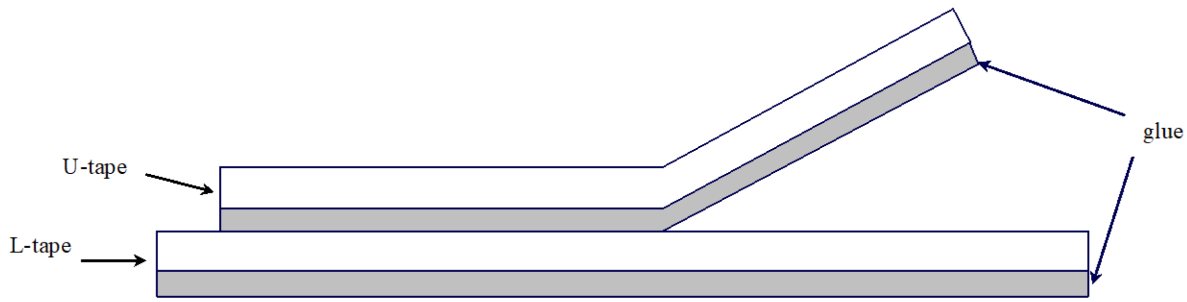
Charged objects, such as invisible tape, are negatively charged if they have more electrons than protons, and positively charged if they have fewer electrons than protons. To determine if U and L tapes are positively or negatively charged, we can use the fact that if you rub a plastic rod (obtained from the front desk) or a plastic pen repeatedly against your hair, the plastic ends up having a negative charge and, therefore, repels electrons.

Prepare a U tape and an L tape, and hang them from your desk. Test them with your hand to make sure that they are both charged. Charge a plastic pen or comb and bring it close to each tape.
Record your observations below.

What can you conclude about the sign of the electric charge on the U tape? On the L tape?

Charge on U tape: ____________________. *Charge on L tape:* ________________________

Below, on the side view of a U tape being pulled up off an L tape, draw minus signs where a surface has become negatively charged (by gaining negatively charged particles (electrons or negative ions) or losing positive ions). *Draw plus signs where a surface has become positively charged (by gaining positive ions or losing negatively charged particles). Be careful! Place minus and plus signs only on the surfaces they actually are on.*



Exercise 6 Interactions of charged tapes with uncharged objects

We saw that although our hand is neutral, it can attract both U and L tapes. Is that the case for other uncharged objects (paper, metal, plastic, etc.)?

Make a U tape and an L tape and hang them far apart. Bring an uncharged object close to each tape, *observe the interactions and record them in the table below. For the last two rows, find two other objects from the "electrostatic toy box", making sure they are uncharged.* (See Page 3 for how to un-charge or neutralize an object.)

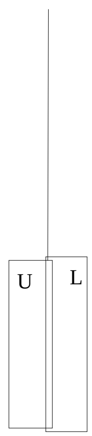
	U tape	L tape
Paper (this handout)		
Metal weight		
Plastic ruler		

Summarize the interactions of charged tapes with uncharged objects:

You should find that most neutral objects attract both U and L tapes. Why does this happen? Can we say that there are electrostatic force between a positive or negative charge and a "neutral charge"? To answer these questions, let's move on to the last exercise.

Exercise 7 Interaction between a charge and an electric dipole

Make a long electric dipole by sticking a U tape and an L tape together **side-by side** as shown below, overlapping them only enough to hold them together. Hang the dipole from a thread.



(a) Approach the dipole with a U tape from different directions. *Describe the behaviour of the dipole. Give details of when the tape is a few centimeters away, and when the tape is really close.*

(b) *What is the type of interaction between the dipole and the U tape? Attractive. Repulsive.*

(c) *When we approach the U tape to the dipole, U-side of the dipole should be repelled and L-side of the dipole should be attracted, but in the end we only see attraction. Explain why.*

(d) *Describe what will happen when you bring an L tape close to a dipole from various directions.*

(e) *Explain in one sentence why your hand (that contains many H_2O molecules) and other uncharged objects attract both U and L tapes.*

Remove all the tape stuck to your desk, as you could lose marks for not doing so. Put the roll of tape and the strings back in the box at the instructor's desk. Don't throw empty tape dispensers away – they will be re-filled.