Name: ___________________________________

Partner(s): ________________________________

1225 Section: _______

Desk # _____________

Date: _________________

Electrostatic Interactions

(This lab is adapted from *Electric and Magnetic Interactions,* Chabay and Sherwood, 1995)

Purpose

Part 1: To investigate the basic aspects of electrostatic interactions through seven short exercises.
Part 2: To estimate the number of deficit electrons on the surface of a positively charged tape.

Introduction and Theory

Electrostatic interactions have the following basic properties:

- There are two kinds of charge, called "+" and "−",
- Like charges repel, unlike charges attract.
- The electrostatic force:
    - is proportional to the amounts of both charges,
    - acts along a line between the charges, and
    - decreases rapidly as the distance between the charges increases.

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

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

Apparatus

"invisible" tape, thread, box of electrostatic demo toys.

 Saved: 9/9/22, printed: 9/9/22

Preparing a base-tape:

- Use a strip of tape about 20 cm or 8 inches long (about as long as this paper is wide). Shorter pieces are not flexible enough and longer pieces are difficult to handle.
- Fold over one end of the strip to make a non-sticky handle:

- Stick a strip of tape with the handle down onto a smooth flat surface like a desk.
- Smooth this base tape down with your thumb or fingertips.

This base tape 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 slowly across the base-tape.
- Stick another tape with a handle down on top of the base tape.
- Smooth the upper tape down well with your thumb or fingertips.
- Write "U" (for Upper) on the handle of the upper tape.
- Quickly pull the "U tape" up and off the base tape, leaving the base tape stuck to the desk.

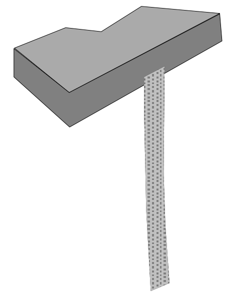
Note 1:U-tapes can be re-used again by following the above procedures to recharge them.
Note 2:Please do not leave any tape stuck to your desk!

Part 1

Exercise 1 Initial observations of a U-tape.

Why does invisible tape 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 mentioned 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.

(a) Hang the U tape vertically from the edge of the desk, and bring your hand near the hanging tape. Describe what happens to the tape:



(b) Bring your hand towards the other side of the tape and observe what happens. Does it matter which side of the tape you approach?

☐ Yes ☐ No

Exercise 2 Is there an electrostatic interaction between two U-tapes?

(a) Does the force follow "like charge repel"

Prediction: If U-tapes are electrically charged, how would you predict two U-tapes to interact with each other?

☐ repel ☐ attract ☐ not interact at all

Why? (If you say "like charges repel", you need to explain why they have like charges.)

Observation: Prepare a second U tape and bring it near the hanging U tape. You may need to practice keeping your hands out of the way. Describe what happens:

We continue our investigation to decide whether the interaction between two U-tapes is electrostatic by checking the direction and the strength of the interaction:

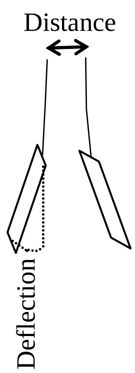
(b) Does the force act along a line connecting the objects

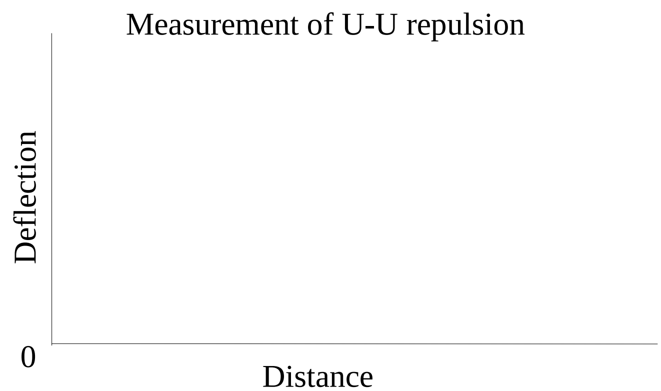
Suspend a U-tape from a thread. Hold the thread in your hand. Approach the suspended U-tape from various directions with another U-tape. Does the force act along a line connecting the two tapes?

☐ Yes ☐ No

(c) Does the force decrease rapidly as the distance between the two tapes increases

Move a U-tape very slowly toward a hanging U-tape. Observe the deflection of the hanging tape from its original position, at several distances – for example, the distance at which you first see repulsion, half that distance, etc. Make a rough graph of the deflection as a function of the distance between the two tapes, where the deflection of the tape from vertical is a measure of the strength of the repulsive interaction (see graph below).





Does the force decrease rapidly as the distance between the two tapes increases? ☐ Yes ☐ No

(d) Does the force depend on the amounts of both charges?

Making a weaker U-tape: Make a fresh U tape and stick it to the desk's edge. Hold its bottom end with one hand and slowly rub the thumb of your other hand along its non-sticky side. This action decreases the charge and creates a weaker U-tape. Now make observations and answer following questions:

How is the interaction between the weaker U-tape and your hand compared to a fresh U-tape with your hand?

☐ stronger ☐ weaker ☐ same as before ☐ no interaction

How is the interaction between the weaker U-tape with a fresh U-tape compared to a fresh U-tape with a fresh U-tape?

☐ stronger ☐ weaker ☐ same as before ☐ no interaction

How is the interaction between the weaker U-tape with another weaker U-tape compared to a fresh U-tape with a weaker U-tape?

☐ stronger ☐ weaker ☐ same as before ☐ no interaction

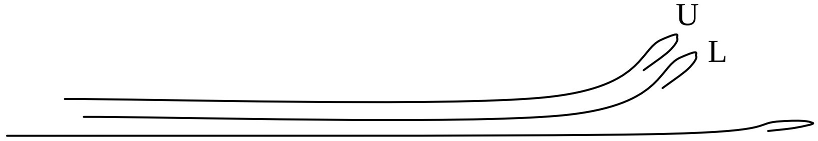
To conclude, does the force depend on the amounts of both charges? ☐ Yes ☐ No

Exercise 3 Observations of L- and U-tapes

How could you prepare a tape that has an electric charge unlike the charge of a U-tape? Try to think of a way before reading the next paragraph.

Preparing an L-tape: (a reproducible way of making a tape with a charge that is unlike the U-tape)

- Run your finger slowly across the base-tape.
- 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, and smooth it down well.
- Write "U" (for Upper) on the handle of this tape.
  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 (leaving the base-tape stuck to the desk).
- Get rid of any interaction of the pair to your hand by slowly rubbing the slick side with your fingers or thumb. *Check that the double layer of tape is no longer attracted to your hand.*
- Quickly separate the L and U-tape.

Before making any observation, do you expect L-tape and U-tape have like charges or unlike charges? Why? (Hint: before and after separating the L-tape and U-tape, what was the total charge on the pair?)

Make two L-tapes and two U-tapes. Make sure that all tapes are active.

What interaction do you observe between an L-tape and a U-tape?

☐ Attraction ☐ Repulsion ☐ No interaction

What interaction do you observe between two L-tapes?

☐ Attraction ☐ Repulsion ☐ No interaction

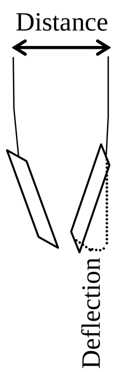
Are the interactions consistent with the statement: "Like charges repel; unlike charges attract"?

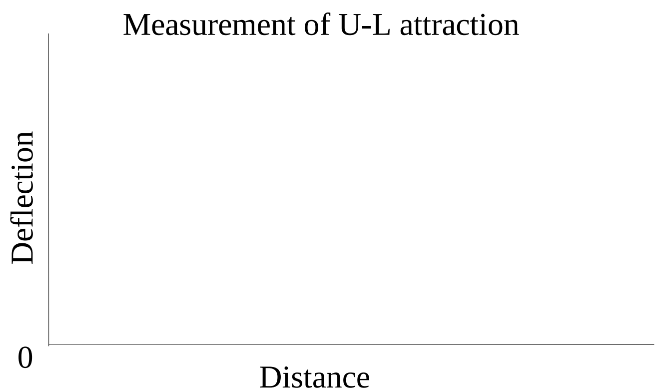
☐ Yes ☐ No

Exercise 4 Distance dependence of force between a U-tape and an L-tape

Move a U-tape very slowly toward a hanging L-tape. Observe the deflection of the L-tape from the vertical at several distances, measured from L-tape's original position – for example the distance at which you first see a deflection, at half that distance, etc. Note that you can't really go all the way to 0 distance!

(a) Make a rough graph of the strength of the attractive interaction as a function of the distance between the two tapes. Note that there is a difference between "U-L attraction" graph and "U-U repulsion" graph. (Hint: you should have a shorter curve for the attraction. Mark the reason on the graph.)





(b) Does the force decrease rapidly as the distance between the tapes increases? ☐ Yes ☐ No

Exercise 5 Interactions of U- and L-tapes with uncharged objects

Observe the interactions of U- or L-tape with uncharged objects (hand, paper, metal, plastic, etc.) Summarize the interactions observed below.

Did you find any uncharged object non-interacting with the U- or L-tape?
☐ Yes ☐ No

Did you find any uncharged object repelling the U- or L-tape?
☐ Yes ☐ No

You may be wondering why both charges are attracted to uncharged objects. We will investigate the physics behind this phenomenon in Exercise 8.

Exercise 6 Determining the sign of U-tapes and L-tapes

Charged objects, such as your 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-tapes are positively or negatively charged, we can use the fact that if you run a plastic comb or pen repeatedly through your hair or rub it with cotton or wool, the plastic ends up having a negative charge and therefore repels electrons.

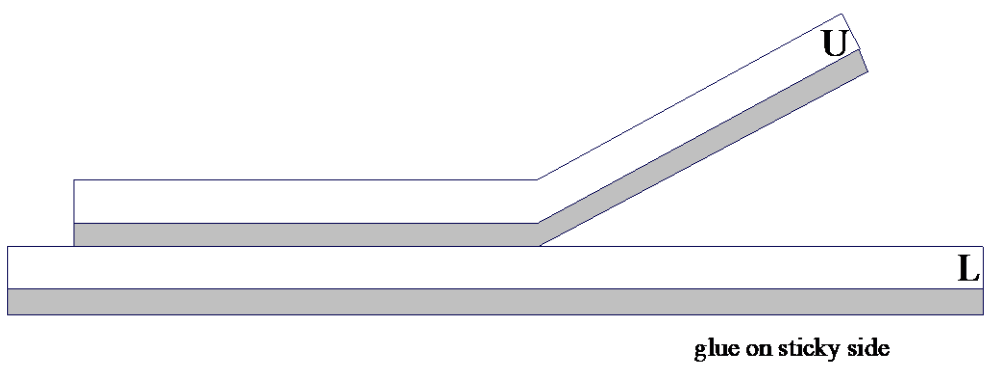
(a) Prepare a U-tape and an L-tape and hang them from your desk. Test them with your hand to make sure that they are both charged. Charge a plastic pen or comb and bring it close to each tape. Record your observations.

(b) What can you conclude about the sign of the electric charge on:

the U-tape? ☐ Positive ☐ Negative

the L-tape? ☐ Positive ☐ Negative

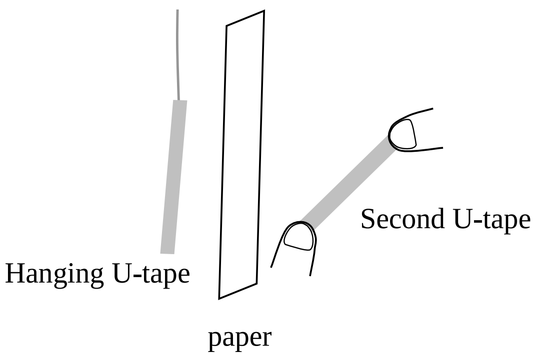
(c) On this side view of a U-tape being pulled up off an L-tape, draw minus signs (−) where a surface has become negatively charged (by gaining negatively charged particles (electrons or negative ions) or losing positive ions). Draw positive signs (+) where a surface has become positively charged (by gaining positive ions or losing negatively charged particles). Place the – and + symbols on the surfaces where they actually are!



Exercise 7 Interaction through a piece of paper

The presence of matter between two charged objects does not affect the electrostatic interactions between them. Intervening matter does not "screen" or "shield" charged objects from each other, just as your desk does not "screen" or "shield" a book from gravitational interactions with the earth.

Have a partner hold a piece of paper close to, but not touching, a hanging U-tape. Bring a second U-tape toward the hanging tape from the other side of the paper as shown below.



(a) Can you observe an interaction occurring right through the intervening paper?

☐ Yes ☐ No

This can be difficult, because the paper interacts with the hanging tape, which masks the interaction due to the other tape.

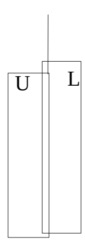
To increase the sensitivity of the experiment, move the second U-tape rhythmically toward and away from the paper, as though you were pushing a swing. This should allow you to build up a sizable swing in the hanging tape because you are adding up lots of small interactions.

(b) Using rhythmic movements, are you able to observe an interaction through the intervening paper?

☐ Yes ☐ No

Exercise 8 An electric dipole

Make a long electric dipole by sticking a U-tape and an L-tape together side-by side. Hang the dipole from a thread, as shown below.



(a) Approach the dipole from different directions with a U tape and then an L tape. Describe the behaviour of the dipole.

(b) To summarize, the dipole is attracted to

☐ U-tape ☐ L-tape ☐ Both U and L tapes

(c) In Exercise 5, you should find many things that attract both U and L tapes. Explain why it is so.

Part 2 Estimating of the number of electrons on the surface of a charged tape

We will use the apparatus we have to estimate the number of electrons on the tapes we used. Assume we know the mass of the tapes and the constants g, k and q_e.

We will use pieces of tape of width 1.9 cm and length 20 cm. It is known that such a piece of tape has a mass of 0.25 g and the charge of one electron is 1.60×10^{-19}C.

Following steps will help you to devise the experiment.

1. Given a ruler to be the only tool, in what order will you approach the final answer? (Which quantity will you find first, and then which one second, which one third, etc.) Number the quantities by the order and write a short note and/or an equation to explain how you will get the quantity.
   (Hint: You will need to use Coulomb's law and for static equilibrium: $\sum \vec{\mathbf{F}}_{\mathbf{external}} = \mathbf{0}$.)

   ☐ Number of electrons

   ☐ Coulomb force between tapes

   ☐ Charge on the tape

   ☐ Distances between tapes

   ☐ Deflection angle from vertical

2. Should we use tapes of like charges or unlike charges? Why?

3. Should we find the number of deficit electrons (missing electrons) on a U-tape, or the number of excess electrons on an L-tape? Why?

4. To apply Coulomb law to the tapes, what big assumption must you make regarding the tapes?

5. We cannot solve for the two charges from the Coulomb force and the distance unless we make another major assumption (1nC and 6nC will give same force as 2nC and 3nC): what is it?

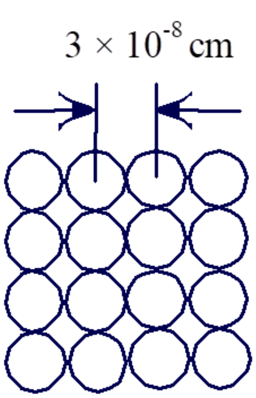
Data

Draw a picture of your set up below, and record the data (with uncertainties) on the picture, in ink. Draw a FBD for one of the tapes on the right.

Have your instructor check your answers before moving on.

Calculations: (No uncertainty is needed. Keep the result to proper sig. figs.)

Conclusion:



Compare to the number of surface molecules: Assume that the distance between the centres of adjacent molecules on the surface of the tape is 3×10^{-8}cm and the molecules are positioned side by side, as in the diagram, use the length and width of the tape to estimate the number of surface molecules.