THE INTERACTIONS OF ELECTRIC CHARGES

In this lab you will examine experimentally the basic aspects of electric interactions.

The basic properties of electric interactions

Electric interactions have the following basic properties:

- There are two kinds of charge, called "+" and "-".
- Like charges repel, unlike charges attract.
- The electric 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.

You need a simple, inexpensive, reproducible method of producing electrically charged objects so that you can further explore the properties of electric interactions. A possible material is "invisible tape" such as Scotch® brand Magic™ Tape. You may have noticed that invisible tape frequently sticks to your hand when you pull a strip off the roll. If this behavior is due to electric interactions, then this tape may be a suitable experimental material.

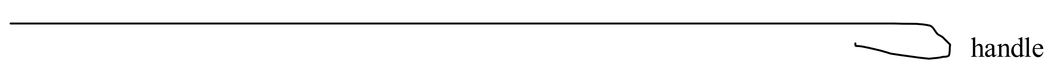
You will be using very simple apparatus, yet your experiments will raise fundamental questions about the nature of the electric interactions of atoms and molecules.

Is invisible tape electrically charged?

You will see whether invisible tape exhibits the properties of electric interactions in the list above. If it does, we can conclude that the tape becomes electrically charged when we strip it off of another piece of tape, and you can study the behavior of pieces of tape as a concrete example of electric interactions.

1. Preparing a “U” 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:



Prepare a U tape as follows:

- Stick a strip of tape with a handle down onto a smooth flat surface such as 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 get different effects on different kinds of surfaces.)
- 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.
- With a very quick motion, pull the U tape up and off the base tape, leaving the base tape stuck to the desk.

Your hand and a U tape

Hang the U tape vertically from the edge of the stand, and bring your hand near the hanging tape.

In the box provided, write a brief description of what happens:

Does it matter which side of the tape you approach?

If the tape is in good condition and the room is not too humid, you should find that there is an attraction between the hanging strip and your hand when you get close to either side of the tape.
If you don't see an attraction, re-make the tape. You can re-use the same piece of tape by again sticking it down on the base tape and then pulling it off, using the same procedure as before.

2. Two U tapes: Repulsion or attraction?

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? Circle yourprediction, and briefly state your reason, in the box below:

Prediction:

attraction repulsion no interaction

Reason:

Prepare a second U tape in exactly the same way (remember to write U on the handle). Bring it near the hanging U tape. Since the hanging tape is attracted to your hands, try to keep your hands out of the way. For example, you might approach the vertically hanging tape with the other tape oriented horizontally, held by two hands at its ends.
Describe what happens:

3. Direction of force

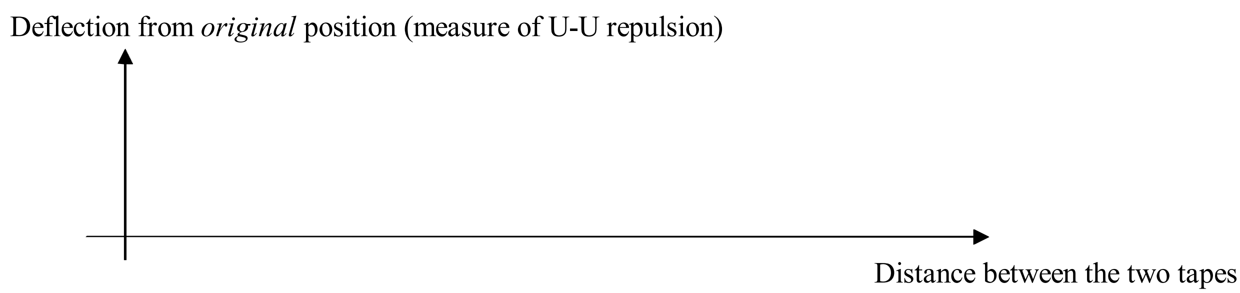
We are told that electric forces between two objects act along a line drawn from one object to the other. This may sound a little obvious; perhaps you can't think of a force that acts at an angle to the line between two objects. Let's see what happens with our tapes.

Suspend a U tape from a thread or a hair. Hold the thread or hair in your hand, or use a short piece of tape to stick the upper end of the thread or hair to the stand. Approach the suspended tape from various directions with another U tape.

Do you find that the force does indeed act along a line drawn from one object to the other? Explain your reasoning.

4. Two U tapes: Effect of distance

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 very rough graph of the strength of the repulsive interaction as a function of the distance between the two tapes (you can't really go all the way to 0 distance!). The deflection of the tape away from its *original* vertical position is a measure of the strength of the interaction.



Note: The real world is messy

You may have noted several difficulties in making accurate measurements of displacement versus distance. For example, the tapes are both attracted to your hand, as well as repelling each other. If you tried to use a ruler, you may have found that the tapes are attracted to the ruler, too. For now, we'll settle for rough observations, but keep these difficulties in mind.

5. Effect of amount of charge

You may have already discovered that if you handle a U tape too much, it no longer repels another U tape. Next we will learn a systematic way for getting this to happen.

Making a tape not interact

Make sure you have an active U tape. Hold onto the bottom of the U tape and slowly rub your fingers or thumb back and forth along the *slick* side of the tape. Describe the changes in how this U tape interacts with your hand and with another U tape:

With Hand	With another U tape

So we have a way of making a tape not interact with other ordinary objects, which will be useful in the future. If the U tape was electrically charged, as we suppose, then by running a finger along the slick side we have apparently "neutralized" it—it now appears electrically neutral (uncharged).

Decreasing the Amount of charge.

Let's partially neutralize a U tape and see what happens:

Prepare two charged U tapes. Hang one of them from the stand, and note how strongly the other tape repels it. *Partially* neutralize one of the tapes by running your finger along the length of the slick side of the tape, being careful that your finger touches only a portion of the width of the tape. Again observe how strongly the two tapes repel.

What is the effect of this partial neutralization? Circle your observation:

weaker repulsion	stronger repulsion	no effect

6. Unlike charges

So far you should have observed that two U tapes repel each other, that the force acts along a line between the tapes, that the strength of the repulsion decreases as the tapes get farther away from each other, and that the strength of the interaction depends on the amount of charge on the tape. These observations are consistent with the hypothesis that the U tapes are electrically charged, and that all U tapes have like electric charge.

How could you prepare a tape that might have an electric charge UNLIKE the charge of a U tape? Think of a plan considering the fact that **charge cannot be created or destroyed:** In an extremely wide variety of experiments, no one has ever observed electric charge to be created or destroyed. These results are summarized by the important principle called "conservation of charge": the net charge of the universe, or of any closed system, cannot change. By a closed system we mean any region through whose boundaries charged particles neither enter nor leave. Also, consider that you start with neutral tapes.

Outline your plan below.

Making an "L" tape

Here is a reproducible procedure for making an "L" tape, whose charge is unlike the charge of a U tape:

- Stick a new strip of tape, with a handle at one end, down onto a base tape that is stuck down on the desk. Smooth it down with your thumb or fingertips, and write L on its handle. Then stick another strip with a handle on top of the L tape, smooth it down, and write U on its handle.

- *Slowly* lift the L tape, bringing the U tape along with it (and leaving the bottom base tape stuck to the desk). Hang the double layer of tape vertically from the edge of the stand (handles down) and see whether there is attraction between it and your hand. *If so, 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 pair is no longer attracted to your hand.* THIS IS IMPORTANT!

- Hold onto the bottom tab of the L tape and *quickly* pull the U tape up and off. Hang the U tape vertically from the edge of the stand, not too close to the L tape!

- Repeating exactly the same procedure, make another pair of tapes so that you have at least two U tapes and two L tapes. Before separating the tapes from each other, *remember to run your finger along the slick side of the tape pair to get rid of interactions with your hand.*

If an L tape is indeed electrically charged, and its charge is unlike the charge on a U tape, what interaction would you *predict* between an L tape and a U tape?

Prediction:	attraction	repulsion	no interaction
Reason:			

Make sure that both the U tape and the L tape are active (attracted to your hand). What interaction do you *observe* between an L tape and a U tape?

What interaction would you *predict* between two L tapes?

Prediction:	attraction	repulsion	no interaction
Reason:			

What interaction do you *observe* between two L tapes?

Summarize the interactions you have observed between U and L tapes:

L-U	U-U	L-L

Is this pattern of interactions consistent with the statement: "Like charges repel; unlike charges attract"?

7. Summary conclusions: U and L tapes

Summarize your observations and try to conclude, at least tentatively, whether U and L tapes are electrically charged. In the table below, state very briefly what you observed:

Property	Experimental observations of U and L tapes
There are two kinds of charges; like charges repel; unlike charges attract	U-U: L-L: U-L:
Electric force is proportional to amount of: change	U tape and partially neutralized U tape
Electric force acts along a line between charges	U-U:
Strength of interaction decreases rapidly as distance between charges increases	U-U:

Tentative conclusion

If all of your observations of U and L tapes are consistent with description of the electric interactions between charged objects, you can therefore *tentatively* conclude that:

- U and L tapes are electrically charged, and have unlike charges.

What kind of charge is on the 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. Are U tapes positively or negatively charged? How can we tell? Charging a comb or pen gives us a "litmus test."

1. Charging a plastic object by rubbing

Prepare a U tape and an L tape, and hang them from your stand. Test them with your hand to make sure they are both charged. Rub a plastic pen on your hair, and bring it close to each tape. You should observe that one of the tapes is repelled by the pen, and one is attracted to it. What do you observe?

How a plastic comb or pen becomes charged

It is known that if you run a plastic comb or pen repeatedly through or along your hair, or rub it with cotton or wool, the plastic ends up having a *negative* charge and so repels electrons. Large organic molecules in the plastic and/or your hair break at their weakest bond in such a way that negative ions (negatively charged fragments) are deposited on the comb and/or positive ions (positively charged fragments) are deposited on your hair. A similar process occurs when you separate one tape from another.

It is probably significant that almost the only materials that can be charged easily by rubbing are those that contain large organic molecules, which can be broken fairly easily. It is typically more difficult to pull single electrons out of atoms or molecules, although we cannot rule out the possibility of stripping a single electron out of a molecule.

One of the few inorganic materials that can be charged easily by rubbing is glass (which consists of silicon dioxide). Glass becomes positively charged when rubbed with silk. It |may be that positive ions break off the large organic molecules in the silk and are deposited on the glass, or that silk strips single electrons off of glass.
Molecular breakage or electron transfer provides a rough explanation of why tapes and combs get charged, but such details as to why the comb rather than your hair becomes negative are the subject of continuing research by physicists and chemists. Part of the complexity of these phenomena is due to the fact that they are *surface* phenomena. The special nature of intermolecular interactions at the surface of a solid are generally less well understood than those in the interior. Moreover, unless one takes extraordinary precautions, real surfaces are always "dirty" with various kinds of (possibly charged) contaminants, which further complicates any prediction about the effect of rubbing, which may remove or deposit charged contaminants.

One thing is certain: you *cannot by rubbing remove nuclei from inside the surface atoms nor remove protons from inside the nuclei of the surface atoms.* Removing protons would amount to transmuting one element into another! The nucleus is buried deep inside the atom, and the protons are bound tightly in the nucleus. So the only charged objects that can be transferred by rubbing are positive or negative ions, or electrons.

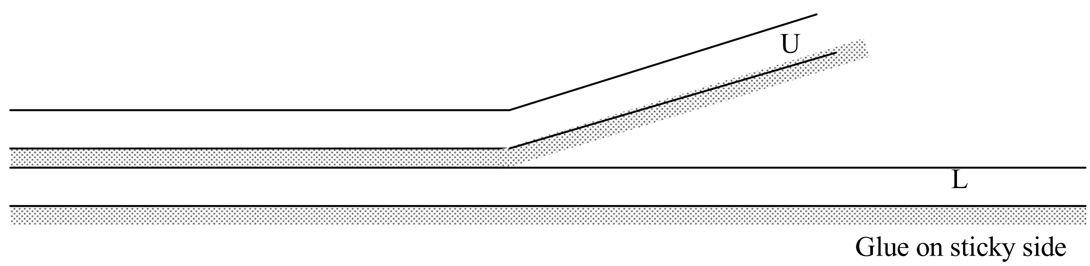
2. Determining the charge on U and L tapes

Now that you know that the plastic was negatively charged, what can you conclude about the sign of the electric charge on U tapes? On L tapes?

sign of U tape:	sign of L tape:

Be *sure* to compare your results with those of other groups! Make sure you ail agree on the assignment of "+" and "-" labels to your tapes.

Here is a side view of an upper tape (U) being pulled up off a lower tape (L). Place -'s wherever a surface has gained negatively charged particles (electrons or negative ions) or lost positive ions and therefore has become negatively charged. Place +'s wherever a surface has gained positive ions or lost negatively charged particles (electrons or negative ions) and therefore has become positively charged. BE CAREFUL: Place -'s and +'s only on the appropriate upper or lower surfaces where they actually are for your tape!



Amount of charge separation: Rubbing a surface, or separating two surfaces, can lead to separating ions (charged fragments) from some molecules or transferring individual electrons. The electric attractions (chemical bonds) inside a molecule are very strong, and even if a charged fragment is pulled away from a surface, the newly charged surface exerts a strong attraction for the lost fragment which may pull it back. As a result, in the tape experiments only a very small fraction of the molecules in the surface gains or loses one electronic charge). But since electric forces are much larger than gravitational forces, even this small excess charge is sufficient to make the tapes repel or attract each other strongly.

Interactions with Neutral objects - Polarization

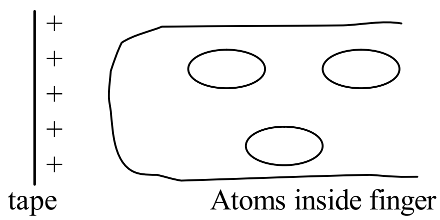
Polarization:

A dipole has a net charge of zero, but its positive and negative charges are separated by some distance. Some molecules are permanent dipoles (e.g., water, HCl); the bonding is such that the centers of positive charge and centers of negative charge are separated. It is also possible to “induce” a dipole by bringing an external charge close to the object. The centers of positive and negative charge are shifted due to the interaction with the external charge. This dipole will last only as long as the charged object is nearby. An atom or molecule is said to be “polarized” when its charges are shifted due to the influence of an external charge. In an insulator, with no mobile charges, there still can be this polarization due to the shift within the atom or molecule. In a conductor, e.g., metals or ionic solutions, with mobile charges, there is polarization as the mobile charges shift position under the influence of the external charge. The difference is that in an insulator there is polarization thought the material, in a conductor, the charges build up on the surfaces and there is no polarization in the interior.

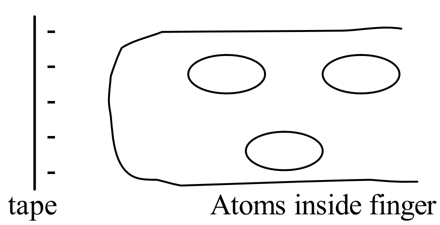
Why your hand attracts charged tapes:

A charged tape moves toward neutral objects such as your hand. All atoms and molecules are polarized by external charges. Unless the external charge is just a few atomic diameters away, the shift in the electron cloud is typically so tiny that it can't be seen in a picture. But if all the molecules in your hand are polarized even very slightly by a charged tape, the tiny interactions with the huge number of molecules can add up to an observable effect.

Consider atoms or molecules inside your finger. Explain carefully, in detail, what happens when you bring your hand near a *positively* charged tape. Be rigorous in your reasoning. You must take into account *all* the electric interactions between the tape and a molecule, not just some of them! Draw and label all relevant force vectors.



In the diagram below, show what happens when your hand interacts with a negatively charged tape. Again, be sure to take into consideration *all* of the electric interactions.



Determining the charge of an object using polarization

Earlier you used a plastic pen rubbed on hair or cloth as a test device to enable you to determine the charge on U and L tapes. In the light of what we now know about polarization of neutral matter, we are now in a position to suggest a conclusive and foolproof procedure for determining the charge of an object.

1. Attraction

Val and Cary were working together, and they had a negatively charged tape hanging from the stand. They rubbed a wooden pencil on a wool sweater and brought it near the tape. The tape swung toward the pencil. Cary said that this showed that the pencil had been charged positively by rubbing it on the wool. Val wasn't sure that they'd really proved that.
Is Cary right? If so, briefly explain why. If on the other hand you think Val's doubts are well founded, briefly explain why.

Different materials do behave differently when rubbed. For example, rubbing plastic with hair or cloth charges the plastic negatively, but rubbing glass with silk charges the glass positively. There is no simple rule that predicts whether two materials will get charged when rubbed together, nor which of the two objects will become positively charged.

2. Repulsion

Can a charged object repel a neutral object? Why or why not? Draw diagrams to help you make your point.

3. A conclusive test for charge

Suppose you have charged tapes hanging from the stand, and you know which ones are positively charged and which are negatively charged. Someone hands you an object whose charge is not known (but if it is charged, the charge is big enough for you to detect). How would you determine unambiguously whether the object is charged positively, negatively, or is neutral? Write out an explicit experimental procedure, and explain each step.

In the light of these procedures, review your critique of Val'sand Cary's reasoning on the preceding page. Make sure that your critique is consistent with the procedures you have outlined here. Make corrections to your earlier discussion if necessary.

Charging and discharging

We say an object is "charged" when its net charge is not zero. You produced charged tapes by stripping them off other pieces of tape. You charged a pen by rubbing it on your hair. In both these cases, some kind of rubbing or pulling resulted in the removal of one kind of charged particle from a surface that was originally neutral, leaving an excess of the other kind of charge behind. In both cases, you started with a neutral object.

However, if you already have a charged object, we ought to be able to use it to produce other charged objects.

1. Charging by contact

In a demonstration, I'll bring a rubber rod, which is charged by rubing on a fur, up to and touch a small metal piece which is connected to a metal rod and a hinged movable metal arm (an electroscope). If the metal becomes charged, the metal arm is deflected from the metal rod since the charge is distributed on the rod and arm.

Now the rubber rod is recharged and brought close to the electroscope but not touching.
What happens to the metal arm? How does the charge on the electroscope compare to that on the rubber rod?

A lucite rod is rubbed on plastic wrap. This is now brought close to the elctroscope which is still charged from contact with the rubber rod. What now happens to the metal arm? What does this say about the charge on the lucite rod?

I now touch the metal top of the electroscope with my finger. What happens to the metal arm?

Charging and discharging with the body

If you exercise on a hot day, you sweat, and your body becomes coveted with a layer of salt water. Even in a cool when you are not moving, there is still a thin layer of salt water covering your skin, salt water is a conductor, so you have a conducting film all over the surface of your skin.

When you touch a negatively charged metal surface, this film allows excess electrons on the metal surface to be partially neutralized by positive ions from your skin. Similarly, a deficiency of electrons on the metal surface would be partially neutralized by negative ions from your skin. This nearly neutralizes the charge on the metal surface, because the original amount of charge is now spread out over a much larger area.

Now it is clear why touching a charged piece of metal with your finger seems to "discharge" the metal, leaving it nearly (but not quite) neutral.

Discharging and "grounding": Touching a charged object is a pretty effective way to discharge the object. An even better way to discharge an object is to "ground" it by making a good connection to the earth or ground (typically through a water pipe that goes into the ground). This spreads charge throughout a huge region, essentially completely neutralizing a small object

2. Charging by induction

Next, we will use these effects to charge a piece of metal in an indirect way.
Here are the steps I will follow:

(1) Touch the electrosope to make sure it is not charged.
(2) Rub the rubber rod on fur to charge it.
(3) Bring a rubber rod close to the electroscope, but not touching.
(4) *While holding the rod near the electroscope, touch* the metal of the electroscope with my finger.
(5) Move my finger away from the electroscope, *then* move the rod away from the electroscope.

Is the electroscope charged? If so, how will I determine the sign of the charge?

What charge does the electroscope have?

Make a "comic strip" of diagrams illustrating the process I just carried out. Make sure you have the sign of the charges right. In each diagram show charge distributions, polarization, movement of charges, etc. In each frame explain what happens with a few well chosen words.

1 Rod close to electroscope	2 Finger touches electroscope (rod still close)
3 Remove finger (rod still close)	4 Remove rod

This process is called "charging by induction" because the entire metal becomes an induced dipole when it is polarized by the external charge. Charging by induction makes it possible to charge a metal without touching the external charge to the metal.