# Electrostatics I

## Purpose

To encourage the building of mental models that correspond with physical reality.
To explain the behavior of objects that are charged.
To explain the interaction of charged and uncharged objects.

## Equipment

- 4 Polystyrene rods (white plastic)
- 1 Piece of tissue paper
- 2 Acetate cloths (black)
- 2 Wool cloths (brown or black)
- 1 Sheet of PVC (dark blue)
- 1 Stand for rod that allows rotation (transparent)
- 1 Pith-ball threaded on monofilament
- 1 Chamber (on wood base)
- 1 copper rod & wooden stands
- 1 Iron nail & wooden stands
- 1 acrylic rod (transparent) & wooden stands
- A piece of aluminum foil

Verify that you have all of the equipment listed. Notify your TA if anything is missing.

## Introduction

Please read the preface before your lab section meets. Remember from the preface not to use the words electron, proton or neutron in the reports for electrostatics I and II. Leave aside ideas about the behavior of atoms in bulk materials too. (These ideas won't help you to answer questions in the labs about Electricity either.)

Please recall that 'an observation' is not necessarily the first result that you happen to notice. You may have to repeat something several times before you get a repeatable result that can be correctly called an observation.

Electrostatics apparatus works best when the humidity is low. Results can also be affected by oil on your hands. For best results, handle the apparatus only as much as necessary. It might be a good idea to rinse (and dry!) your hands before beginning.

## Instructions

In physics one, you saw that gravitational interaction is a possible way for objects to interact (that is 'to exert forces on each other). *Tear off small pieces of dry tissue paper and put them on the bench*. You don't need to tear up much paper but the pieces need to be about the size of a letter in this sentence. Clean, dry hands also help!

*Rub a polystyrene rod with a wool cloth*. (Vigorous rubbing doesn't help: the effect is caused primarily by the close contact of dissimilar substances. You get good results if you hold the rod tightly with the wool cloth. Then withdraw the rod from the cloth. Repeat this just a couple of times to charge the rod.)

*Bring the part of the rod that was rubbed near [but not touching] the pieces of paper*. (Keep the bits of paper for something that follows in this lab.) **Write down what you see happening after tearing off small pieces of paper & bringing the rod near them. [1]**

**Is the interaction between a piece of paper and the rod, stronger than the gravitational interaction between the piece of paper and the Earth? Explain why/why not. [2]**

**Are pieces of paper picked up by parts of the rod that weren't rubbed? [1]**

**Might it be possible to explain the interaction of the rod and pieces of paper as a gravitational interaction? Please explain. [2]**

This new interaction between the rod and pieces of paper is not gravitational and so deserves a name of its own. We'll call it an electrostatic interaction. It helps to experience this interaction in more than one way. Do this as follows: *Rub the polystyrene rod with the wool cloth again. Hold the rubbed part of the rod less than 1 cm from your forearm*. Do you feel anything*?* (If not, try rubbing the sheet of PVC on a blank sheet of paper [or inside cover of a book]. Then bring the sheet of PVC close to your forearm.)

Rubbing a rod changes the way that the rod interacts with other objects. In order to describe the new behavior of the rod, we'll say that the rod has become charged. Notice that the word 'charged' is defined by observable behavior of the object that has become charged. This operational definition of the term 'charged', illustrates how scientific terminology arises; the term is just a label for operations that we can do and observations that we can make. Conversely, in science, we avoid the use of words that can't be operationally defined. I won't ask you to think about a mechanism by which an object becomes charged. (This will allow you avoid mentioning sub-atomic particles that can't be observed using apparatus in this lab.)

Since you rubbed the surface of the polystyrene rod, it is reasonable to expect that you charged the surface (rather than the interior) of the rod.

An important feature of the electrostatic interaction that distinguishes it from the gravitational interaction is electrostatic repulsion.

*Rub the sheet of PVC against a blank sheet of paper [or the inside cover of a book]*. (Use the inside cover because it will probably be cleaner than the outside cover. Even minor impurities can change electrostatic behavior.) *You'll need the bits of tissue paper that you used before. Hold the charged PVC sheet horizontally less than 1 cm above the pieces of tissue*. Keep looking for several seconds after the paper initially sticks to the sheet. **What do you see happening? Is repulsion involved? [2]** (If the bits of paper seem to fall from the PVC, you might try holding the PVC vertically before the bits of paper leave the PVC.) There is no need for you to explain this yet.

Another way to see electrostatic interactions involves using stands that rotate. These stands are designed to rotate with very little friction. This makes them quite sensitive but not strong! Please be gentle with them!

*Rub a polystyrene rod with a wool cloth. Put the charged rod on a rotating stand*. (Remember which end of the rod was rubbed.) *Rub another polystyrene rod with the other wool cloth. Bring the charged part of this rod about a centimeter from the charged part of the rod that is on the stand*. **Write the following in the report, filling in the blanks where needed:** Two rods are made of substance X. Both are rubbed with substance Y and then interact by

_____ each other if either of them is free to move. **[1]**

Up to now, we have only distinguished between charged objects and uncharged objects. This only demands the existence of one state-of-charge (that is; 'one type of charge'). We'll see if just having one charge-state still makes sense after the following.

*Rub a third polystyrene rod with an acetate cloth. Bring the charged part of this rod a couple of centimeters from the charged part of the rod that is already on the stand*. **Write the following in the report, filling in the blanks where needed:** One polystyrene rod is rubbed with acetate cloth and another polystyrene rod is rubbed with _____ cloth. The rods _____ each other if either of them is free to move. **[1]**

*Rub a fourth polystyrene rod with the sheet of PVC. Bring the charged part of the polystyrene rod a couple of centimeters from the charged part of the rod that is on the stand*. **Write the following in the report, filling in the blanks where needed:** Two rods are made of polystyrene. One is rubbed with _____ cloth and the other is rubbed with PVC. The rods will _____ each other if either of them is free to move. **[1]**

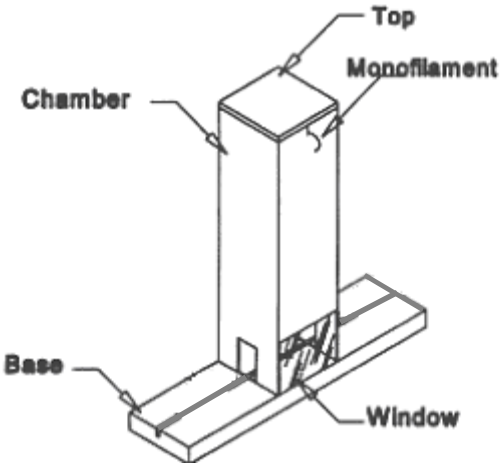
**Is one state-of-charge (or 'one type of charge') sufficient to explain your observations**? **Explain**. **Use observations that you have made in this lab to support your answer. [4]**

Suppose that we have two charged rods and that the rods attract each other. No one has ever found a third charged rod that repels both of the first two. This suggests that there aren't more than two states-of-charge. Benjamin Franklin used the words 'positive' or 'negative'[1] to describe the states-of-charge. (Bear in mind that the names 'positive' and 'negative' are quite arbitrary. He could have called them 'red charge' and 'blue charge' just as easily.) It is important to realize that you can talk about 'positive and 'negative' charge without claiming that these charges have anything to do with sub-atomic particles. When we draw plus or minus signs on a diagram, we are only saying that the region denoted as being 'positive' has different electrostatic properties than a region denoted as 'negative'. (If we simply refer to charged regions of an object then we can avoid mentioning the cause of the charge. Actually, we have already done this: we described the rubbed part of a polystyrene rod as being charged while the interior of the rod was uncharged.)

[1] Actually, Franklin went a bit further and also suggested a mechanism for producing two states-of-charge. His mechanism required the existence of just one variety of charge. For him, 'positive' corresponded to the presence of charge and 'negative' corresponded to its absence. Observations of sub-atomic particles changed his mechanism for producing the two charge states. We now us his words 'positive' and 'negative' to describe the two different kinds of charge that are demanded by the sub-atomic observations.

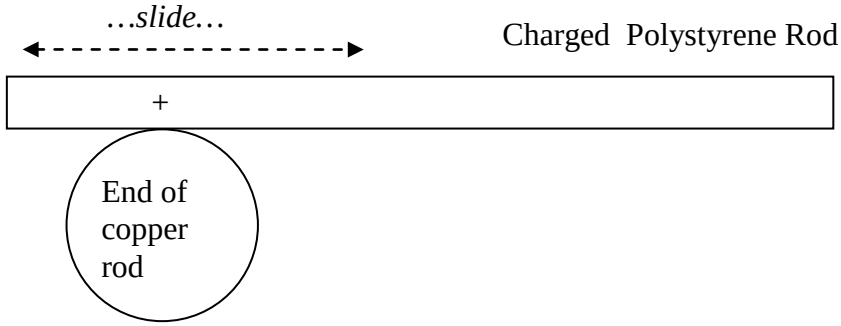
By convention, the state-of-charge acquired by polystyrene when it is rubbed with wool is called 'negative'. The state-of-charge that is acquired by polystyrene when it is rubbed with PVC is called 'positive'.

Let's see if charge can move. A pith-ball is hanging in the (black) chamber. The chamber prevents air-currents from disturbing the pith-ball. The ball is stuck to a piece of monofilament. The monofilament fits into two notches that are cut into the sides of the chamber. *Put the Plexiglas top on the chamber and allow the pith-ball to reach equilibrium.*




*Put the copper rod on the wooden stands Move the copper rod through a rectangular hole in the chamber and point it at the pith-ball.* (Make sure that you can see the pith-ball through the window in the chamber.) This end of the rod should be 2 or 3 mm from the pith-ball. (The gridlines on the base of the chamber are 2 mm apart.) If necessary, change the length of monofilament so that the pith-ball is at the same height as the end of the rod. *Charge a polystyrene rod with a PVC cloth.*

*Touch the charged polystyrene rod against the end of the copper rod that protrudes from the chamber.* No pressure on the polystyrene rod is needed. It helps if you gently slide charged parts of the polystyrene rod against the copper rod. Be careful not to move the copper rod so that it touches the pith-ball.




**Describe how the pith-ball and copper rod interact.** (The interaction might not be simple: if it isn't, focus on the first interaction that happens. Alternatively, you might be able to make the interaction simpler by increasing the distance from the pith-ball to the end of the copper rod from the 3 mm mentioned above.) **What does their interaction tell you about the movement of charge in the copper rod? *Explain*. [3]**

We have just seen that charge that is put in one place doesn't have to stay there indefinitely. In particular, you have shown that charge can move along the copper rod. Substances that allow the free movement of

charge are called conductors. For example, the pith–ball has a conductive coating that allows charge to move onto the pith-ball.[2]

You have an acrylic rod (transparent). Try the same thing with the acrylic rod that you have just done with the copper rod. *Put the uncharged acrylic rod on its wooden stands. Slide one end of the rod into the chamber so that the end of the rod is 2 or 3 mm from the pith-ball. Charge the polystyrene rod again with PVC.* As before, *touch the charged polystyrene rod to* the part of the acrylic rod that protrudes from the chamber. **Is there any effect on the pith-ball? What does this tell you about the charge at the tip of acrylic rod? [1]** Substances that don't allow any movement are called insulators.

Let's develop this a little more. I'd like you to *repeat the previous activity with a charged polystyrene rod, copper rod & pith-ball*. This time, *touch the copper rod with your finger while sliding/touching the copper rod with the charged polystyrene rod*. **Explain why nothing happens. [2]** We describe this by saying that a charged conductor is discharged (or just 'loses its charge') when is touched with another conductor. (In this case, the 'other conductor' is your finger.)

The interaction between charged objects and uncharged objects is very common but is harder to explain. (Actually, much of what follows in this lab is designed to let you address this question.) *Put a negatively charged rod on the rotating stand. Hold the nail close to it*. **Say how the negatively charged rod interacts with the uncharged nail. [1]** Charged objects are attracted to other charged objects that have a different state-of-charge. But you have just seen that a negatively charged rod will attract an object that isn't charged. **What does your observation suggest to you about the presence of any type of charge inside the uncharged nail? [1]** Be careful about this. We obviously can't say that "the uncharged nail is positively charged". **How can we avoid saying this but still explain the interaction? [2]** (Hint: It might help to describe charged regions of the nail rather than saying that the whole nail has any particular charge.)

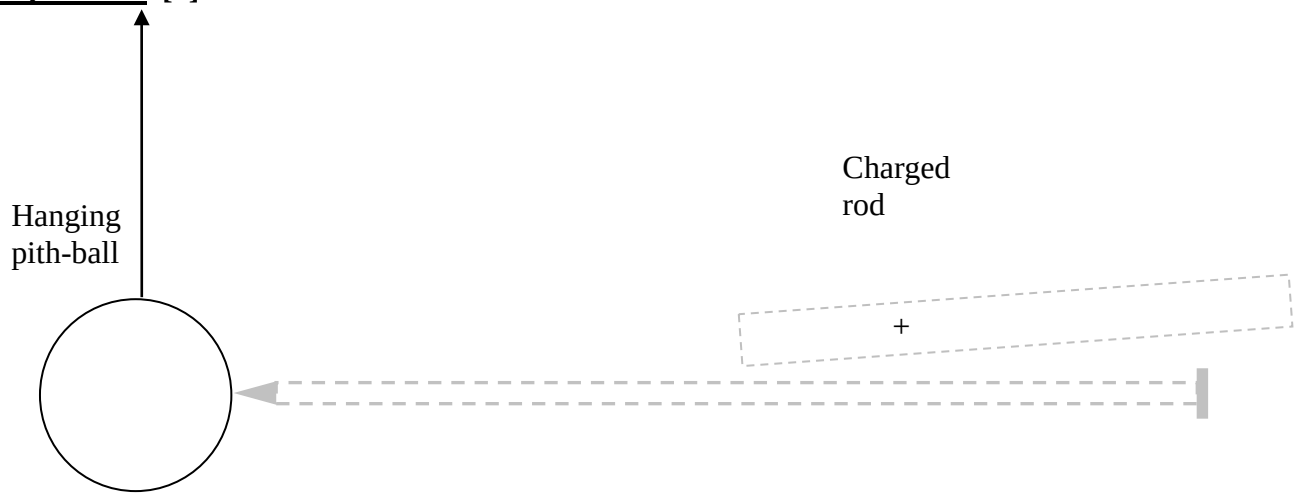
*Now put a positively charged rod on the stand*. **Say how the positively charged rod interacts with the nail. [1] What does your observation suggest to you about the presence of any type of charge inside the uncharged nail? [1]**

Check that the pith-ball is hanging freely in the chamber. *Point the copper rod at the pith-ball as before but now move the rod a bit further into the chamber so that the end of the copper rod touches the hanging pith ball. Charge a polystyrene rod with PVC*. As before, *gently touch/slide the charged polystyrene rod against the end of the copper rod that protrudes from the chamber*. Be gentle and remember that no pressure on the polystyrene rod is needed. *Without touching the copper rod, use its stand to slide the copper rod out of the chamber.*

You'll be drawing a diagram in your report that will include a hanging pith ball, a charged rod and a nail. Please begin the diagram by drawing the hanging pith ball. (Don't include the copper rod used to charge it.) **Include a (single) plus or minus sign in your diagram to indicate the charged region in**

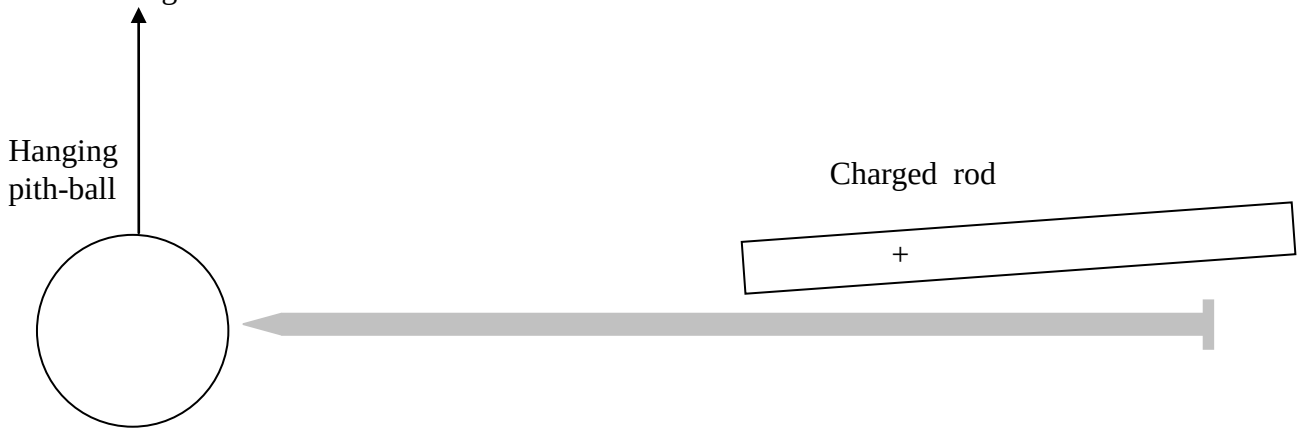
[2] Since we can't observe sub-atomic particles with this apparatus, we can't say if one region of charge moves or if the other stays fixed in place. That is fine for now. I hope that you notice that the movement of either type of charge can be used to explain that a region of charge moves.

**the pith-ball. [1]**




*Put the (uncharged) nail on the wooden stand. Without touching the nail against the pith-ball or without touching the nail with your hand, slide the nail into the chamber and point it at the pith-ball. Keep the nail 4mm from the pith-ball*. (The grid on the bottom of the chamber is 2mm by 2mm.) Allow the pith-ball to come to rest.

*Charge a polystyrene rod with the sheet of PVC. Hold the charged polystyrene rod above and close to* (but not touching) *the part of the nail that protrudes from the chamber*. (In the diagram below, notice that the charged rod overlaps less than half of the nail.) I'm only drawing a single sign in the rod but you probably rubbed a few inches of the polystyrene rod so that the charged region of the rod is probably a few inches long.




**What is the effect on the pith-ball? [1]** You may have to repeat this part several times to get consistent results. It is easy either not to charge the pith-ball, to touch the copper rod while sliding it out of the chamber or get the nail too close to the charged pith ball. Doing any of these, will change the conditions of this experiment so that it will be difficult to explain what is happening.

## Ask your TA to check this last result

**What does the effect on the pith-ball tell you about the type of charge at the tip of the nail? Include the nail and polystyrene rod in the diagram in your report. Draw a single plus or minus sign to denote the type charged region near the tip of the nail. [1]**

Previously in this lab, you put a positively charged rod on a rotating stand and brought an uncharged nail near. You noticed attraction between the positively charged rod and the nail. From this observation, I hope that you inferred that a region of negative charge must have appeared in the nail to account for the attraction. In this case, we have also brought a positively charged rod close to an uncharged nail. If this causes a region of negative charge to appear then **where can the region of negative charge be? Draw a single minus sign on the diagram in your report to denote where you think the region of negative charge is. [1]**

*Now take the charged rod away from the nail.* **Say how the pith-ball behaves long after the charged rod has been taken away? [1]** (You will explain this later.)

Now let's return to explaining the attraction between the uncharged nail and a positively charged rod. We suppose that when a positively charged rod is very far from a nail, no (large) region of charge appears in the nail.

Position of positively charged rod

**Now suppose that the rod is brought close to the nail. Do any charged regions appear? Copy the diagram below into your report. Denote the charged region(s) with two (or fewer) algebraic signs. [2]**

Position of positively charged rod

## Ask your TA to check the previous answer before you go further

Now we can think about how charge in the rod interacts with the charge in the nail. To begin, there is a very important observation to be kept in mind. At the beginning of this lab, you picked up pieces of paper with a charged rod. **Does the distance between charged objects affect the magnitude of electrostatic interactions between them? What relevant evidence have you seen? [2]** We return to the case of the polystyrene rod & (nearby) nail in the diagram above. The positive charge that is fixed in the polystyrene rod will interact with any charge that is induced in the nail. **Compare the forces between the positive charge in the polystyrene rod and;**

- **positive charge in the nail**
- **negative charge in the nail**

**Say if the force is attractive or repulsive in each case. Then compare the magnitudes of the two forces. Explain. [4]**

**Draw a copy of the previous diagram in your report. Draw a force vector that represents the force exerted by the rod on the positively charged region in the nail. Also draw another force vector that represents the force exerted by the rod on the negatively charged region in the nail. [2]**

Now you can explain the interaction of charged and uncharged objects. **Explain how a positively charged rod can attract an uncharged nail. [3]** (Hint: It might help if you consider two things separately. First describe what the charge on the rod does to the nail. Second, consider forces between the charge on the rod and any charged regions that have appeared in the nail.) **How will your explanation differ when a rod with negative charge attracts an uncharged nail? [1]**

Suppose that the charged rod has caused regions of positive and negative charge to appear in a nail. **Why won't the differently charged regions move towards each other? [1] Now suppose that the charged rod is taken away. What will happen to the charged regions in the nail? [1]**

We postponed explaining what happened to a hanging pith-ball long after a charged rod was taken away from a nail that was pointed at the pith-ball. It is now possible to explain that observation. **Explain what happened to charged regions in the nail when the charged rod was taken away from the nail. Explain the effect on the pith-ball**. **[2]**

Notice that the interaction of charged and uncharged objects was explained by using the two kinds of charge that had already been introduced. It wasn't explained by introducing even more fundamental features into the theory (such as introducing a third kind of charge). The fact that we can do this is a characteristic of a good physical theory: a good theory explains many observations using a small number of fundamental statements.

Suppose that someone knows about two states-of-charge that you have called 'positive' and 'negative'. They also know that objects that have the same state-of-charge interact by repelling. **You want to convince this person that uncharged objects don't have a third kind of charge. How would you show this to them? [2]** (Your explanation needs to show this physically using apparatus in this lab. Hint; you can imagine that you have two uncharged nails if you want.)

*Tear small pieces off the piece of aluminum foil and put them on the bench*. The aluminum isn't charged by being torn up! Put a *negative charge on a polystyrene rod. Hold the rod over the pieces of aluminum*. **Explain why the foil is attracted (at first) by the charged rod. Consider any charge that exists in the neutral foil. [4]** (Hint: It might help to recall that aluminum is a metal and charge can separate in it. You will have to think about the interaction between any charge that has separated in the aluminum and the charge on the charged rod.) **Would a positively charged rod attract the foil too? Why? [2]**

Now explain the repulsion of some pieces of aluminum after they hit the charged rod. (If you didn't notice any repulsion, then tear up smaller pieces of foil.) Recall that rubbing the rod charges the surface of the rod. **Why are small pieces of aluminum repelled by the charged rod after they have touched it**? **[2]**

***Remember leave the apparatus as it was when you arrived.***
***Ask your TA to check your apparatus before you turn in your reports.***
Throw away torn bits of paper and aluminum foil.

# REPORT

NAME:_____ Course & Section: _____
*Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.*

Write down what you see happening after tearing off small pieces of paper & bringing the rod near them.

_____**[1]**

Is the interaction between a piece of paper and the rod, stronger than the gravitational interaction between the piece of paper and the Earth? Explain why/why not.

_____

_____**[2]**

Are pieces of paper picked up by parts of the rod that weren't rubbed?

_____**[1]**

Might it be possible to explain the interaction of the rod and pieces of paper as a gravitational interaction? Please explain.

_____

_____**[2]**

What do you see happening? Is repulsion involved? (There is no need for an explanation at the moment.)

_____

_____**[2]**

… fill in the following:

Two rods are made of substance X. Both are rubbed with substance Y and then interact by

_____ each other if either of them is free to move. **[1]**

… fill in the following:
One polystyrene rod is rubbed with acetate cloth and another polystyrene rod is rubbed with

_____ cloth. The rods _____ each other if either of them is free to move. **[1]**

… fill in the following:

Two rods are made of polystyrene. One is rubbed with _____ cloth and the

other is rubbed with PVC. The rods will _____ each other if either of them is free to move.

**[1]**

Is one state-of-charge (or 'one type of charge') sufficient to explain your observations? Explain. Use observations that you have made in this lab to support your answer.

_____

_____

_____

_____ **[4]**

Describe how the pith-ball and copper rod interact. What does their interaction tell you about the movement of charge <u>in the copper rod?</u> *Explain*.

_____

_____

_____

_____**[3]**

Is there any effect on the pith-ball? What does this tell you about the charge at the tip of acrylic rod?

_____**[1]**

Explain why nothing happens.

_____

_____

_____**[2]**

Say how the negatively charged rod interacts with the uncharged nail.

_____**[1]**

What does your observation suggest to you about the presence of any type of charge inside the uncharged nail?

_____**[1]**

How can we avoid saying this but still explain the interaction?

_____

_____

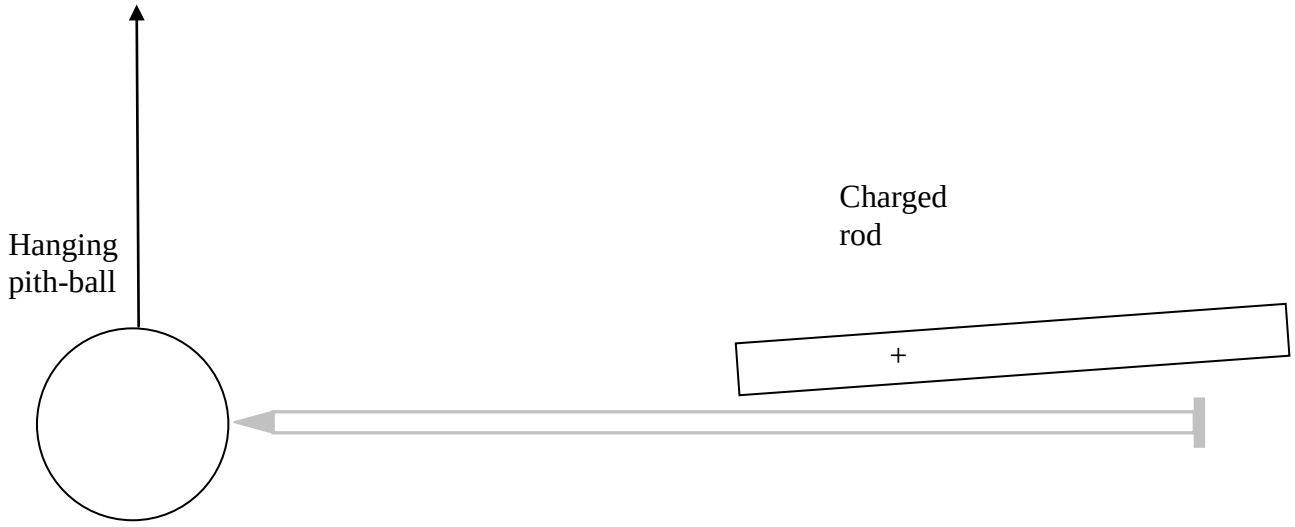
_____**[2]**

Say how the positively charged rod interacts with the nail.

_____**[1]**

What does your observation suggest to you about the presence of any type of charge inside the uncharged nail?

_____**[1]**




Include a (single) plus or minus sign in your diagram to indicate the charged region <u>in the pith-ball</u>. [1]

What is the effect on the pith-ball?

_____**[1]**

What does the effect on the pith-ball tell you about the type of charge at the tip of the nail? Draw a single plus or minus sign (on the diagram above) to denote the type charged region near the tip of the nail.

_____**[1]**

…where can the region of negative charge be? Draw a single plus or minus sign (on the diagram above) to denote where you think the region of negative charge is.

_____**[1]**

*Now take the charged rod away from the nail.* Say how the pith-ball behaves long after the charged rod has been taken away? (You will explain this later.)

_____**[1]**

Now suppose that the rod is brought close to the nail. Do any charged regions appear? Denote them with two (or fewer) algebraic signs on the following diagram.


Position of positively charged rod

**[2]**

Does the distance between charged objects affect the magnitude of electrostatic interactions between them? What relevant evidence have you seen?

_____

_____**[2]**

Compare the forces between the positive charge in the rod and;

- positive charge in the nail
- negative charge in the nail

(Say if the force is attractive or repulsive in each case. Then compare the magnitudes of the two forces, giving a reason for your answer.)

_____

_____

_____**[4]**

…draw two force vectors on the previous diagram. One should represent the force exerted by the rod on the positively charged region in the nail. Another should represent the force exerted by the rod on the negatively charged region in the nail.

**[2]**

Explain how a positively charged rod can attract an uncharged nail.

_____

_____

_____**[3]**

How will your explanation differ when a rod with negative charge attracts an uncharged nail?

_____

_____**[2]**

Why won't the differently charged regions move towards each other?

_____**[1]**

Now suppose that the charged rod is taken away. What will happen to the charged regions in the nail?

_____**[1]**

Explain what happened to charge in the nail when the charged rod was taken away from the nail. Explain the effect on the pith-ball.

_____

_____**[2]**

You want to convince this person that uncharged objects don't have a third kind of charge. How would you show this to them? (Your explanation needs to <u>show</u> this physically using apparatus in this lab.)

_____

_____**[2]**

Explain why the foil is attracted (at first) by the charged rod. Consider any charge that exists in the neutral foil.

_____

_____

_____

_____

_____**[4]**

Would a positively charged rod attract the foil too? Why?

_____

_____**[2]**

Why are some <u>small</u> pieces of aluminum repelled by the charged rod after they have touched it?

_____

_____

_____

_____**[2]**