Name ______________________________ School ______________________________ Date __________

Coulomb's Law

Purpose

To observe the effect of the electrostatic force on light-weight charged objects.
To experimentally determine the charge on a sphere small sphere acting as the bob of a pendulum.

Equipment

Virtual Electrostatics Lab PENCIL

Explore the Apparatus/Theory

Open the Virtual Electrostatics Lab on the website.

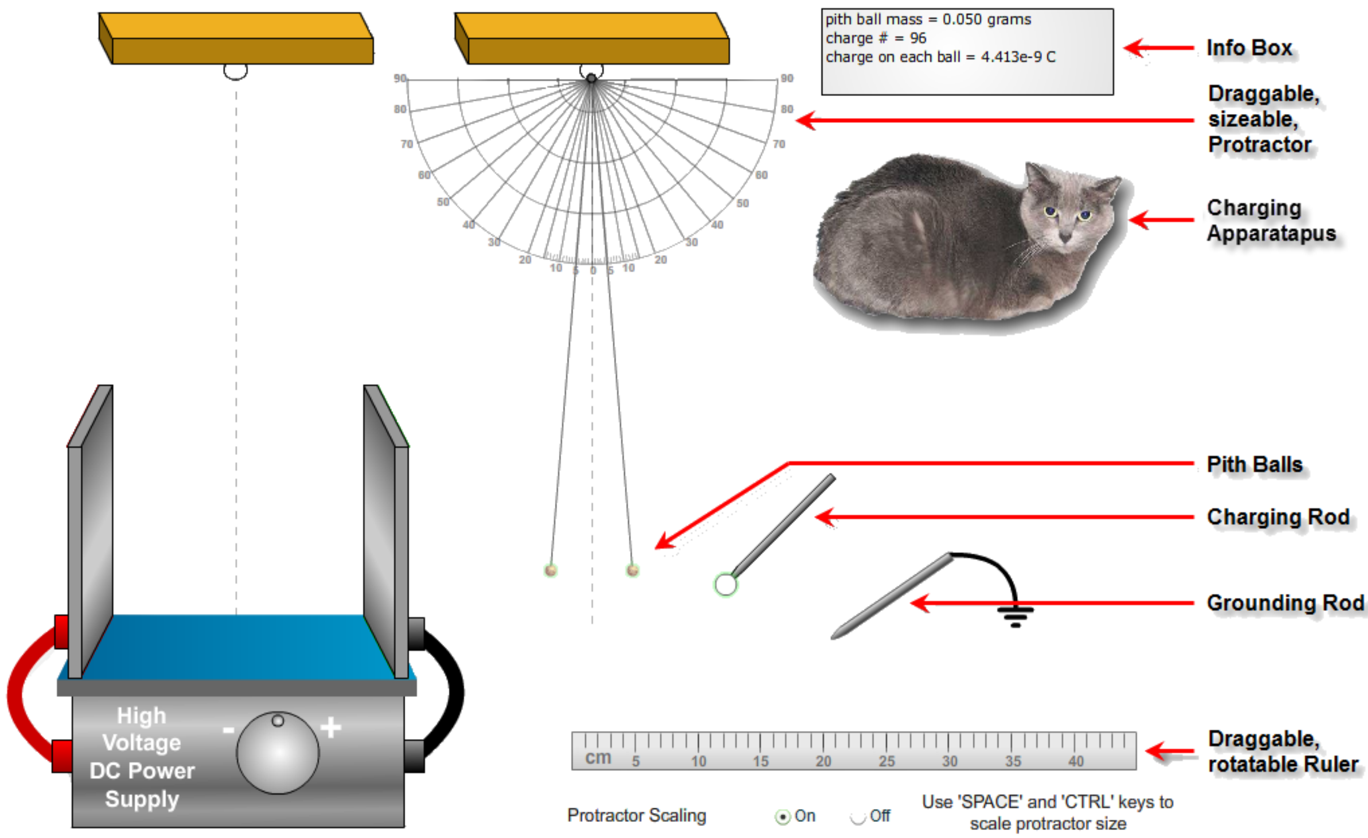

Figure 1

In this lab you'll observe a typical large-scale manifestation of the forces between electrically charged objects. We'll pit the force of gravity against the electrostatic force to determine the amount of charge on each of a pair of small identical spheres – pith balls.

The operation of the Virtual Electrostatics Lab is very simple. A certain amount of charge is acquired by a charging rod when this rod is rubbed against the charging cat which has volunteered to take part in this experiment. Part of this excess charge is passed on to two initially neutral conducting pith balls which then share it equally.

The pith balls are immediately forced apart by the Coulomb repulsion between them. They swing back and forth, gradually slowed by air resistance, until they are in static equilibrium as shown in Figure 1. If there was just one ball present its excess charge should be a spherically symmetrical surface charge. Because they are similarly charged – both negative – conductors placed near one another their excess charge would actually be skewed outward away from one another. To minimize the effect of this the balls have been made very small. The balls will be considered small enough relative to their separation distance that the redistribution of charge on them is insignificant. We'll assume that the charge on each ball takes on a spherical distribution. So why does that matter?

$$F = k\frac{q_1 q_2}{r^2}$$ Coulomb's Law

In Coulomb's Law, r is the distance between the charges, q_1, and q_2. But our pith balls have charges spread all over their surfaces. So the force is actually the sum of all the forces between all the individual charges – electrons and protons – and each pair has a different r. Fortunately, if the (excess) charge is distributed evenly on a spherical surface, the force is the same as if the charge was all located at the center of each sphere. So r is just the distance between the centers of the pith balls.

We now want to find to find the charge on one of the pith balls. Since they're equally charged – they have an equal number of excess electrons – we'll just call the charge on either ball, q.

Your goal is to find q, (in Coulombs.)

So how's that going to happen? Let's try out the apparatus first to get a clearer idea of what's going to happen.

Figure 2 shows how the apparatus looks at start up. Refer to Figure 1 for terminology. The parallel plates that are omitted from the figure are not used in this lab.

1. Notice that the charge number and charge on each ball in the info box both read zero. The charge number is a reference number that you'll record for grading purposes. It's meaningless otherwise. The charge on each ball is initially zero since they are initially uncharged. **(Take a screenshot for the methodology section of the lab report).**
2. Click anywhere on the charging rod. Keeping an eye on the info box, drag the rod so that the ball on its end moves across the cat. The more you drag it across the cat the more the charge # increases. The ball is fully charged when the number reaches 120. Try it.
3. Drag the charging rod until the charging ball touches the tip of the grounding rod. Poof. Back to zero. You can also move the grounding rod to touch the charging ball to discharge it.
4. Recharge the rod to a charge # > 50. Now drag it until it its ball touches either of the pith balls. Some charge has now been transferred. The pith balls equally share it.
5. You're going to need to know the **deflection angle, θ,** between either ball and the vertical. That's what the protractor is for. Move your pointer over the protractor until the pointer changes to a hand (or whatever). Click and drag it up near where the strings are tied and release. It should snap in place. **(Take a screenshot for the lab report).**

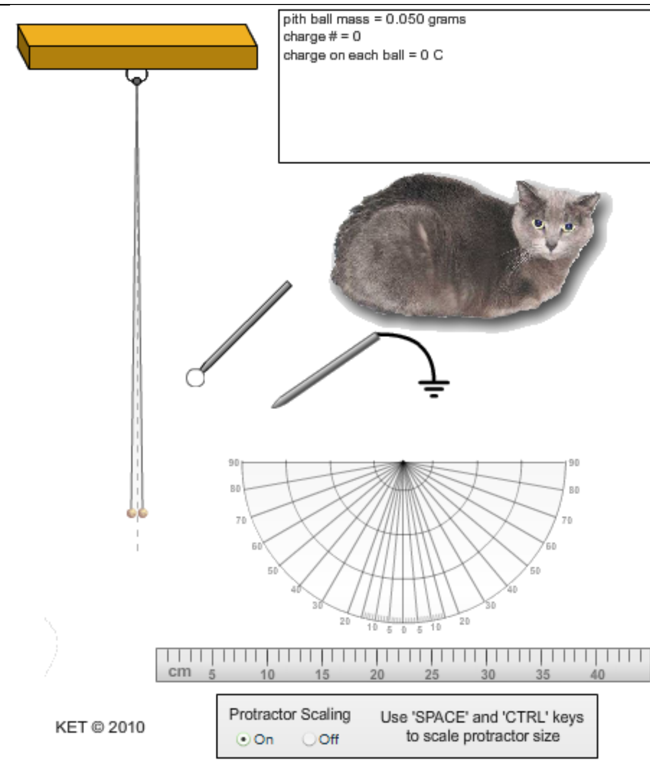

Figure 2

Hold down the space bar until the curved edge of the protractor almost reaches the pith balls. You should now be able to read the angle between either string and the vertical line at 0°. This deflection angle is the angle you'll be using in your calculations. You can shrink the protractor back down with the <CTRL> key and drag it out of the way when you don't need it.

Note: You can right-click or <CTRL>-click (Mac) to zoom in at any time. But while zoomed in you can't drag anything.

6. To measure the separation between the centers of the balls, click on the ruler, **somewhere to the left of 35 cm**, and drag it to a convenient place beneath the pith balls. You'll want to measure the distance between their centers when taking data. **(Take a screenshot for your lab report)**
7. You may also want to measure the length of the pendulum – the distance from the tie-off point to the center of a pith ball. Clicking to the right of 35 cm and dragging up or down will rotate the ruler. You can then align it with the string.

Finding the charge, q on a pith ball

Apparently the angle, θ, between the strings is important and we haven't discussed why, so let's have a look at that.

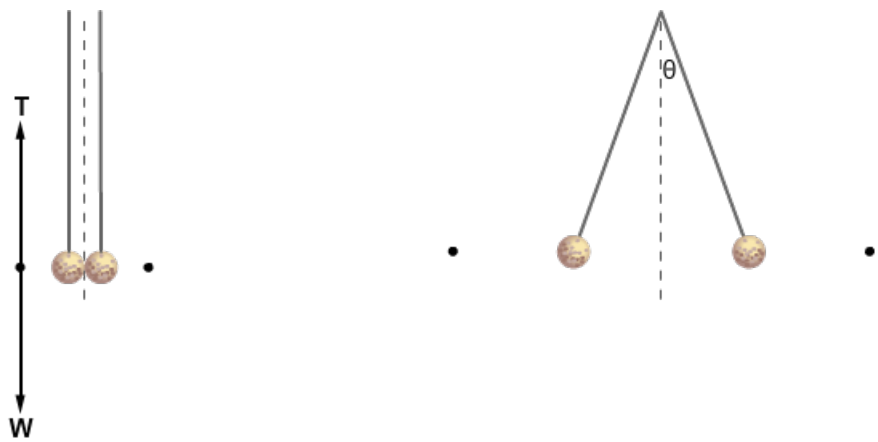

Figure 3 **(3a)** **(3b)**

In figure 3 you see two pairs of pith balls hanging from strings. Beside each ball is a dot where you'll draw force vectors to create a free body diagram, FBD. In each FBD the balls will be in equilibrium. This means that

$$\Sigma\overrightarrow{F_x} = 0 \text{ and } \Sigma\overrightarrow{F_y} = 0$$

In figure 3a the pith balls are side-by-side and the strings are vertical. (This is impossible with this apparatus since the strings are attached at a point, but that won't be an issue since we aren't concerned with their behavior at this angle.) The vertical orientation of the strings could indicate one of two things. The balls could be oppositely charged. But we'll never see that case since our pith balls can only be neutral or negatively charged.

1. What then can you say about the charges on the pith balls in Figure 3a?

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2. Each pith ball is hanging at rest. What are the two (external) forces acting on, say, the left ball in Figure 3a?

   Strong nuclear, weak nuclear, friction, gravity (its weight), electrostatic, tension, air resistance (Circle two)

3. How do the magnitudes and directions of these two forces compare? (They are not accelerating.)

   The forces are _______________ and _______________.

4. Draw a FBD for the right-hand ball in Figure 3a using the dot provided. Use the same scale as the FBD on the left ball. USE A PENCIL.

In figure 3b the balls have been equally charged. Both are hanging at the same angle, θ either side of the vertical line.

5. Keeping the same scale, add a weight vector to the right ball's FBD. (Ignore the weight of the excess electrons.)
6. The ball is in equilibrium, so there still must be an equal upward force. In figure 3a that force was the tension force. But the tension is no longer acting in the upward direction. It's now acting in a direction of θ degrees relative to the vertical. The upward force is the y-component of the tension, $\mathbf{T_y}$. Draw this vector and label it T_y. Be careful with your scale.

7. You now have T's y-component. From it you can draw the actual tension vector, T. Carefully add it to the FBD.
8. Explain how you knew how long the vector T should be.

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9. Add the angle θ to your FBD.
10. You now have T and T_y on your FBD. Clearly there is a horizontal component of T, T_x. Add that to your figure. Draw it with its tail starting at the dot. Again, be careful with your scaling.

We now have W, T, T_y, and T_x in our FBD. Are all these forces acting on the pith ball? Not exactly. We have some redundancy. T is the vector sum of T_x and T_y. So T has actually been replaced by its components.

11. Draw a "≈" through the T vector to indicate that we can ignore it now.
12. Look at our remaining three vectors. Does our FBD indicate that the ball is in equilibrium? __________
13. What type of force, missing from our FBD, is keeping the ball in equilibrium?

    Strong nuclear, weak nuclear, friction, gravity (its weight), electrostatic, tension, air resistance (Circle one)
14. Add that force vector to your FBD and label it F_e. Draw it with its tail starting at the dot. Again, be careful with your scale.
15. Draw the matching FBD for the left ball.

Your sole task is to determine the charge on either pith ball and compare it to the value given in the info box. Here are some guidelines and suggestions.

- Charge up the pith balls to start. Use a large charge for best results.
- The forces involved are gravity (weight), W, the string tension, T, and the Coulomb force, F_e. Forces that are not horizontal or vertical will need to be resolved into correctly-labeled components.
- Record any data you take in the data table provided. You may add to the table.
- Explain your method in words, referring to labeled figures. (You supply the figures.) (Item 1 below.)
  For clarity's sake, refer to the right-hand ball in your discussion.
- Clearly show your calculations using the proper variable terminology. (Item 2 below.) Define any variables that you create. E.g., F_e: electrostatic force between pith balls
  Wait as long as possible before replacing your variables with numbers. (See Ex.)

Ex. a = 2.5 m/s^2, V_o = 12 m/s, V_f = 22 m/s, t =?	
Wrong $2.5m/s^2 = \frac{22^m/_s - 12^m/_s}{t}$, etc.	Right $a = \frac{v_f - v_o}{t}$, $t = \frac{v_f - v_o}{a}$, $t = \frac{22^m/_s - 12^m/_s}{2.5m/s^2}$ = 4.0 s

Table 1 Charge on a Pith Ball (you may not actually need all of these values)

$k = 9.0\times10^9$ N m²/C²

mass of a pith ball (from lab info box), m = ___________ kg

charge # = ____

accepted value for charge on one pith ball (info box), Q_a = ___________ C

experimental value for charge on one pith ball, Q_e = ___________ C

separation between centers of pith balls, r = ___________ m

length of the pendulum, L = ___________ m

deflection angle of a pith ball from the vertical, θ = ___________ °

1. Explain your method in words, referring to labeled figures. (You supply the figures.)	

2. Clearly show your calculations using the proper variable terminology. Include the calculation of percentage error for your value of the charge on a pith ball.

3. What do you feel was the major source of error? Why?

4. Is the assumption that the charge distribution is spherical most inaccurate for small or large r's? Explain.