Introduction to Measuring What You Can't See.

Content Discussion and Activities

PHYS 104L

1 Goal

The goal of this week's activities is to gain some insight into the challenge of measuring the characteristics of something you cannot see or touch. You will perform two measurements using techniques similar to those devised for actual situations where scientists wanted to measure a characteristic for something that couldn't be easily seen directly.

2 Introduction

We have seen that a key aspect of the scientific method is making measurements on physical systems. Measurements allow one to develop models and then, most importantly, test those models by having the model make a prediction on a previously unstudied system and making measurements to test those predictions. In both developing models and testing models, measurements play a key role.

In the situations you have previously faced in lab, you have been able to directly measure the quantity of interest during experiments or activities. If you wanted to know the mass of an object, you put the object on a triple beam or electronic balance and measured the mass. If you wanted to know the width of a washer, you held the washer and measured it using a meterstick or Vernier caliper. If you needed to measure the time a bowl took to sink, you watched the bowl and measured the time as you viewed it. In these situations, you could directly see or interact with an object such that the desired measurement was fairly straightforward. Not all physical systems are like this. There are many situations where the quantity you want to determine a value for cannot be directly measured. The object may be a great distance away (like a distant star) or so large we can't easily work with it (measuring the radius of the earth) or so small that we cannot directly see or hold it (atomic scale distances or masses). If we want to know the mass of a proton, it is challenging to grab a single proton and put it on an electronic balance to get a value. We still want to be able to determine a value, and have that value based on actual measurements, but the methodology may well need to entail more than just a single direct measurement. Today's activities will highlight two such techniques actually used to make extremely important determinations of physical quantities for objects we could not, at the time, directly see or hold; the size of the nucleus and the charge on a single electron.

3A Discussion - Measuring an area when you can't see it.

You may be familiar with the atomic model where an atom is comprised of a small central positively charged nucleus, made up of protons and neutrons, with negatively charged electrons orbiting around the outside of the nucleus. In the early 1900's, an alternative model of the atom, the "plum pudding" model, was generally accepted. In this model, rather than a small central nucleus, the atom was pictured as a (relatively) large sphere of positive matter (the pudding) with negative charges spread throughout it (the plums). One way of testing the plum pudding model would be to measure the region of an atom over which the positive material was distributed to see if it was about the same as the size of the atom or not. The only problem was that, at that time, one could not visually inspect something at the atomic size scale. One needed another way to try and measure the size of the positive charge distribution for an atom.

One idea for doing so relied on the knowledge that charged particles interact with each other. If somebody was to "fire" a proton or other positively charged particle at an atom, it can interact with the positive charge distribution of the atom and be repelled and deflected from its original path. Even though one could not see the atoms or the charged particles being fired at them, by looking at how many projectiles were deflected and how they were deflected, one could determine knowledge of the size of the positive charge distribution for the atom.

In the following activity, you will use a simplified version of this idea to measure the area of a dime without actually being able to pick up a dime, measure its diameter, and then directly calculate the area by knowing the area of a circle is $A = \pi R^2$. You will, instead, use an alternative method similar to how scientists were able to investigate the size of the nucleus. After completing the activity, you will directly measure the area and see how your direct result compares with the alternative method.

3B Activity – Measuring the area of a dime

1.) You should have a paper with a 10 cm by 10 cm empty square outlined. Use a pen or pencil to make at least 50 small but clearly visible dots, randomly spread throughout the square. You don't want to have them UNIFORMLY spread out but rather just RANDOMLY scattered throughout the box. The dots should be as small as possible such that you are still able to clearly see them. Double check by counting the actual number of dots and record that number on your activity sheet.

2.) Once your square of dots is ready, ask the instructor for a "dime sheet". The "dime sheet" is a paper with a 10 cm by 10 cm square with several actual sized dimes pictured on it. Count the number of pictured dimes and record that number on your activity sheet.

3.) Place the "dime sheet" under the "dot sheet" such that the outlines of the square edges are lined up. Circle every dot that happens to lie on a dime and put a half circle around any dots that partially landed on a dime (the dot would have been on a dime edge).

4.) Count and record the number of circled dots counting half circled dots as ½.

5.) Calculate the fraction of dots that are circled. This ratio would be the number of circled dots divided by the total number of dots.

6.) This fraction is related to the area of the square covered by the dimes. Specifically, this ratio should also be equal to the total area of pictured dimes divided by the total area of the square. Knowing this ratio and the total area of the square, calculate the total area of pictured dimes.

7.) The area of a single dime should just be the total area of pictured dimes divided by the number of pictured dimes. Calculate and record this value on the activity sheet. You have now calculated the area of a dime, using the randomly placed dots in the square, without actually touching and directly measuring the size of any one dime.

8.) Once you have finished step 7, return the "dime sheet" to the instructor and pick up an actual dime. Use the calipers to measure the diameter of the dime. Record this value. Using this measured diameter, calculate and record the radius of the dime. Finally, calculate and record the area of the actual dime. Be sure and include units and have your units match those used for the squares in steps 1-7. Turn in your Blanks Square Sheet with circled dots with your data sheet.

9.) Calculate and record the %Error in your alternative method (the first one) determined value for the area of a dime. The %Error is the difference between your experimental value and the actual value divided by the actual value and multiplied by 100.

$$\%Error = \left(\frac{Experiment - Actual}{Actual}\right) * 100$$

4A Discussion – Millikan's Oil Drop Experiment

A second historical example of measuring something you cannot see was completed in 1909 by Robert Millikan to determine the charge of a single electron; the elementary unit of charge. Again, one was interested in the amount of charge associated with a single electron, however, the experimenter did not have the capability to conveniently isolate a single electron, inspect it and or measure the charge on that single electron. The atomic model at the time did realize that the net charge on an object was determined by the relative number of protons and electrons the object was made of. If there were more electrons, the object would have a negative net charge and if it had more protons, it would have a positive net charge. As a result, it was expected that the net charge for negatively charged objects could only come in integer numbers of electrons. If an object had 5 extra electrons, then its net charge would be 5 times the charge of a single electron. If the object only had 3 extra electrons, then its net charge would be 3 times the charge of a single electron. There would be no way to have an object with a net charge of 2.5 or 5.5 times the charge of an electron or any other non-integer multiple of the charge of an electron.

For the Millikan Oil Drop experiment, a slick experimental method was employed to allow the experimenter to measure and determine the net charge on a single oil drop. However, since Millikan was not able to directly count how many electrons and protons were on the drop so he could know the number of excess electrons, it wasn't straightforward to calculate the charge on a single electron. The problem, then, was how to determine the charge on a single electron if you are only able to measure the total charge and not count the number of electrons that net charge is due to.

In this activity, you will again simulate a process addressing just this problem. You will have a set of 10 identical containers, none of which you will be allowed to open, each of which has a different number of identical objects in it. One of the containers is labeled with an "E". This is the "empty" container, it has none of the objects in it. Actually, you will notice that this container has something in it. To make it difficult to guess how many objects are in a given container, in addition to the identical objects, each container has the same number of washers in it and those washers will be treated as part of the container. Your goal for this activity is to collect data and do calculations to determine the mass of an individual object in the containers without being able to directly count how many objects are in each container.

4B Activity – The "Milli-cans" experiment

1.) At your table, there should be a set of ten "Milli-cans", one of which is labeled as being the "empty" one. Measure and record the mass of the "empty" can.

2.) Measure and record the mass of each of the other nine "Milli-cans".

3.) Calculate the total mass of objects in each of the other nine "Milli-cans" by subtracting the mass of the "empty" can from the total mass of a can. Record these masses on the activity sheet.

4.) The reason different cans have a different total mass of objects is that different cans have different numbers of objects. The differences in masses should occur in integer increments of mass of a single object, the quantity we are interested in determining. To do this, you will try to determine what the largest "increment" of mass is that divides evenly into the total mass values for each can. As a first step, reorder the ten total mass values listing them largest down to smallest in the appropriate place on the activity sheet. The smallest value will be zero for the empty container then the other nine non-zero values.

5.) Calculate the difference between adjacent total masses and record these differences. Since you have ten different total mass values, there will be nine differences that you calculate.

If you were lucky each integer number of objects would be part of the sample (1 object, 2 objects, 3 objects, 4 objects…..) in which case all the mass differences would be due to a single extra object and we would expect all the differences to be about the same. The average of those differences would be our best estimate for the mass of an individual object. You, however, don't know how many extra objects make up the difference between adjacent total masses; it could be 2, 3, 4 or even more. Hopefully, there will be at least one case where the difference in mass is due to a single object. Notice, this would be the smallest difference we would see.

6.) Look at your nine difference values and identify what looks to be the smallest difference between adjacent masses. We will expect this increment to be roughly the mass of a single object as the smallest mas difference should be due to just one more object in the can. You should also find that the other differences are roughly integer multiples of this amount. Using this knowledge as a guide, start with the smallest total mass and identify how many objects are likely in each of the containers. Record these values on the activity sheet.

7.) Now, for each of the nine non-empty containers, calculate a value for the mass of an individual object by taking the total extra mass and dividing by the number of objects you believe are in the container. Record these nine values on the activity sheet. They should all be fairly similar, although likely not exactly the same.

8.) Perform statistics calculations to calculate the average, standard deviation, standard error and associated error for these nine values. Record the statistics values on your activity sheet.

9.) Finally, using the average and associated error, list your result and corresponding range for the determined mass of an individual object in the "Milli-cans". You would be 95% confident that the actual mass you are trying to determine is within that range, and yet, you still don't know what the objects are and have not even seen them.

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Activity Data Sheet

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Activity 3B

Total Number of Dots in the Square ______________________

Number of dimes pictured in the "dime sheet" _________________________

Number of dots on dimes ___________________________________

Fraction of dots on dimes __________________________________

Calculated Total Area of pictured dimes __________________________

Determined Area of a single dime _________________________________

Directly Measured Diameter of an Actual Dime _____________________________

Calculated Radius of an Actual Dime _______________________________

Calculated Area of an Actual Dime ____________________________________

%Error for the alternative method Area __________________________________

Activity 4B

Color of Milli-cans set ___________________ Mass of the "Empty" can __________________

Total Mass of Can (grams)	Total Mass of Objects in Can (grams)

Total Mass Objects (g)	Differences (g)	# of objects difference is due to	Believed # of objects in the "Milli-can"	Mass of an individual object value (g)
0	XXXXXXX	XXXXXXX	0	0

Statistics Calculations Values:

Average Mass of Individual Object ______________________________________ grams

Standard Deviation in Mass Values _______________________________________ grams

Standard Error on the Average ____ grams

Associated Error on the Average ____ grams

Properly Rounded Result ____ grams

Properly Rounded Range ____ grams

Explain how you determined the values for the number of objects each difference was due to (the third column on the second table for this activity).