PHYS 11A Lab - General Physics: Mechanics

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Lab #1 – Measurement and Uncertainty

Names:
_Santiago_Bermudez_, _Merabuddin_Niazi____

Objective Statement: Describe your objective for this lab in a few sentences, and state any hypothesis formed ahead of doing the experiment. We are getting creative here, as you are working with what you have at home. Did you decide to compare the densities of 3 different types of beans? Or are you comparing the density of you and your roommate? Just make sure you choose 2 or more relatively cylindrical objects to compare. Remember this is a physics class… it's okay to call your roommate a "cylinder".

In this lab, we are going to learn about uncertainties in our measurements and learn about the process of proper measurement taking. Here, we want to learn about propagation of errors as well as how to use derivatives in certain formulas like density and volume to help us measure how uncertain we are about our measurements. We decided to compare the densities of a soda can and a paint gallon. We hypothesized that if the paint is used to harden into a plastic-like layer on walls, unlike soda, then it would be more dense.

First some theory and an introduction to error propagation: The density of a sphere

To determine the density of a sphere we will need to know its mass and its volume, since density is mass divided by volume. We will want to use an equation for density that depends on the mass of the sphere and its diameter. List your equation below:

Density = mass(g)/volume(cm^3), The volume of a sphere is (4/3)π r^3

So, we get: **Density of a sphere =** $\frac{mass(g)}{\frac{4}{3}\pi r^3}$

What measurements must you take in order to get the data necessary to complete your calculation?

If possible, we would need to figure out the mass of the sphere. Even if we don't have a device that can measure mass, we just need to figure out the weight and convert weight into mass. Mass is equal to weight divided by gravity. We would also need to figure out the diameter of the sphere. We can try placing a ruler nearby or wrapping a string around the sphere to measure the diameter.

We write the uncertainty associated with those measurements as δx and δy, where x and y are your measurements (aka variables). In our example, what are the uncertainties? List them below:

δx : Uncertainty with Volume

δy : Uncertainty with Mass

Complete the following error propagation formula for your case:

$$\delta f = \left[\left(\frac{\partial f}{\partial x} \delta x \right)^2 + \left(\frac{\partial f}{\partial y} \delta y \right)^2 \right]^{\frac{1}{2}}$$

Complete the 2 partial derivatives:

$$\frac{\partial f}{\partial x} = \frac{\partial D}{\partial V} = -\frac{m}{v^2}$$

$$\frac{\partial f}{\partial y} = \frac{\partial D}{\partial M} = \frac{1}{V}$$

Report out your final equation representing the propagated error for density.

$$\delta D = \left[\left(\frac{\partial D}{\partial V} \delta V \right)^2 + \left(\frac{\partial D}{\partial M} \delta M \right)^2 \right]^{\frac{1}{2}}$$

Error propagation in practice: The density of a "cylinder"

What objects are you comparing in this experiment? How cylindrical are they? Justify your choices.

The objects that we are comparing in this experiment are a soda can and a gallon of paint container. The soda can is pretty cylindrical except for the top and bottom, which are curved inward a bit. The paint gallon container is almost perfectly cylindrical from top to bottom. We decided to go with a soda can, as it would be easy to measure its dimensions and mass. The paint gallon is quite a bit heavier, but still simple to measure nonetheless.

Measure the "cylinders" mass M, diameter D, and height H. Since you have very limited equipment at home you might be using very creative methods for measurements. Give very detailed estimates for your uncertainties, δM, δD, and δH with explanations.

The scale we had was used to measure the weight and mass of people, so we decided to weigh 12 full soda cans and divide by 12 to get the result for one soda can. This allows us to spread the uncertainty of mass over 12 cans. So we used a scale to weigh 12 soda cans and got an average of 4.6 kilograms with the uncertainty being δM = 0.1 kg for the 12 cans. Please note that the scale only goes to the tenths place after the decimal, so we could be a tenth of a kilogram off. If we divide by 12 to get the mass of one can, we get 383.33 grams of mass for a single soda can and δM = 8.33 grams. The height was 12.4 cm with our accuracy being limited to tenths of a centimeter. This gives us δH = 0.1cm. The diameter of a soda can was determined to be about 6.7 cm and we measured this by placing a can on its side and placing a flat stick on top to help find its diameter by a ruler. Again we are limited to tenths of a centimeter, so we get δD = 0.1cm. For the paint gallon, we measured it to be 5.1 kilograms. δM = 0.1kg for the gallon as that was the limit of our scale. The height was 19.6cm and easily determined with a ruler. We believe our uncertainty for the height to be δH = 0.1cm The diameter was 16.8cm with δD = 0.1cm.

Use propagation of error to **obtain a formula** for $\delta\rho$, and calculate values for ρ and $\delta\rho$ for all your objects.

$$\text{p(Density)} = \frac{mass}{volume} = \frac{mass}{\pi r^2 h}$$

$$\delta p = \left[\left(\frac{\partial p}{\partial V} \delta V \right)^2 + \left(\frac{\partial p}{\partial M} \delta M \right)^2 \right]^{\frac{1}{2}}$$

$$p_{soda} = \frac{383.33}{\pi 3.35^2 (12.40)} = 0.87 \frac{g}{cm^3}$$

$$\delta p = \left[\left(-\frac{M}{V^2} \delta V \right)^2 + \left(\frac{1}{V} \delta M \right)^2 \right]^{\frac{1}{2}}$$

For the soda can:

$V = \pi\, 3.35^2 (12.40)$ or about $437.18\ cm^3$

$M = 383.33$ grams

$\delta V = 10\, cm^3$

$\delta M = 8.33$ grams

$$\delta p_{soda} = \left[\left(-\frac{383.33}{(437.18)^2} 10 \right)^2 + \left(\frac{1}{437.18} 8.33 \right)^2 \right]^{\frac{1}{2}}$$

$$\delta p_{soda} = 0.03 \frac{g}{cm^3}$$

$$p_{paintgal} = \frac{5100}{\pi 8.4^2 (19.6)} = 1.2 \frac{g}{cm^3}$$

For the paint gallon:

$V = \pi\, 8.4^2 (19.6)$ or about $4344.7\ cm^3$

$M = 5.1$ kilograms or 5100 grams

$\delta V = 50\, cm^3$

$\delta M = 0.1$ kilograms or 100 grams

$$\delta p_{paintgal} = \left[\left(-\frac{5100}{(4344.7)^2} 50 \right)^2 + \left(\frac{1}{4344.7} 100 \right)^2 \right]^{\frac{1}{2}}$$

$$\delta p_{paintgal} = 0.03 \frac{g}{cm^3} \text{ or } 3 * 10^2 \frac{g}{cm^3}$$

<u>Conclusion</u>: Summarize your findings (**including relevant numbers, uncertainties, etc.**), and compare them to your objective statement/hypothesis.

We found that $p_{soda} = 0.87 \pm 0.03 \frac{g}{cm^3}$ and that $p_{paintgal} = 1.2 \pm 3 * 10^2 \frac{g}{cm^3}$. As it turns out, our hypothesis was correct. We were first concerned that the volume of the two objects in question would skew our results, but remembered that density is mass divided by volume. What this may imply is that the results we got would be proportional if we decided to fill up a gallon with soda and another with paint and decided to compare the two. We were also concerned about significant figures, especially for the paint gallon's measurements, but had help from the "Experiments in Physics" notebook.