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PHYS 101 - Measurement and Uncertainty in Scientific Experiments

Worksheet

Complete the worksheet as a group and turn in a single document with your names.

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Show all work and calculations to receive full credit! You may use additional sheets.

1. Significant Figures
   a. Suppose you are measuring the mass of a pendulum bob on an electronic mass balance. The mass balance reads "10.4 g". How many significant figures does this reading have?

   3 significant figures

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   b. What is the relative uncertainty of this measurement, expressed as a percent error? (recall that the precision of an electronic instrument is usually equal to the smallest difference it can detect, 0.1 g in this case)

   precision = .1 g

   Percent error = .1 x 100 = $\boxed{10\%}$

   2/3: relative uncertainty is .1g/10.4g then times 100% to convert

c. Suppose you measure the mass with a more precise electronic mass balance, that can measure mass with a precision of 0.01 g. If the mass balance reads "10.40 g", how many significant digits are there? Write this value so that the number of significant digits is not ambiguous. precision = .01g

1 2 3 4
10.40 g

all are known as precison is .01g

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$\boxed{\text{4 Significant figures} \quad 1.040 \times 10^{1} g}$

2. Propagation of Uncertainty

You are asked to measure the volume of a spherical object. Knowing that the volume, V, is related to the radius, R, by $V = (4/3)\, \pi R^3$, you measure the radius to be 2.2 cm ± 0.1 cm.

a. Convert the measurement of the radius to meters and express the radius in scientific notation.

radius = $2.2\cancel{cm} \times \frac{1\ m}{100\cancel{cm}} = 0.022\ m = 2.2 \times 10^{-2}\ m$

2/2; but should write with only one power of ten (2.2±0.1)*10^-2 m

$0.1\cancel{cm} \times \frac{1m}{100\cancel{cm}} = 1\times10^{-3}m$

$\boxed{\text{radius} = 2.2\times10^{-2}m \pm 1\times10^{-3}m}$

b. Calculate the volume of the sphere (in cubic meters) using the measured radius and determine the **maximum relative uncertainty**.

$V = \frac{4}{3}\pi R^3$ Volume = $V_{best} \pm \Delta V$

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$\frac{4}{3}\pi(2.2\times10^{-2}m)^3$

$= 4.46\times10^{-5}\ m^3$

$\Delta V(R) = \frac{dV}{dR}\Delta R$ $\Delta R = 1\times10^{-3} m$

$\boxed{\text{Volume} = 4.5\times10^{-5}m^3 \pm 6.1\times10^{-6}m^3}$

$\left(\frac{4}{3}\pi\right)\left(\frac{d}{dR}R^3\right)$

$= \frac{4}{\cancel{3}}\pi \cancel{3} R^2$

$= 4\pi R^2$

$= 4\pi(2.2\times10^{-2}m)^2 \cdot 1\times10^{-3}m$

$= 6.08\times10^{-6}\ m^3$

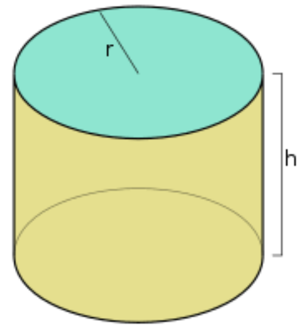
maximum relative uncertainty = $\left|\frac{\Delta V}{V}\right|$

$= \left|\frac{6.1\times10^{-6}\ \cancel{m^3}}{4.5\times10^{-5}\ \cancel{m^3}}\right| = \boxed{1.4\times10^{-1}}$

c. You now calculate the volume of a cylindrical object. The height is measured to be 5.2 cm ± 0.05 cm and the radius is measured to be 2.5 cm ± 0.05 cm. Calculate the volume and the **maximum relative uncertainty** of the volume calculation. $V = \pi R^2 h$

$R = 2.5cm \pm 0.05\ cm$

$h = 5.2cm \pm 0.05cm$



Volume = $V_{best} \pm \Delta V$

$\pi (2.5cm)^2 (5.2cm)$

$= 32.5\pi\ cm^3$

$= 102.1\ cm^3$

$\Delta V = \frac{dV}{dR}\Delta R + \frac{\Delta V}{dh}\Delta h$

$\pi h \frac{d}{dR}(R^2)$ $\quad$ $\pi R^2 \frac{d}{dh} h$

$= \pi h 2R\Delta R + \pi R^2 \Delta h$

$= \pi(5.2cm)2(2.5cm)(0.05cm) + \pi(2.5cm)^2(0.05cm)$

$\pi\ 1.3cm^3 + \pi\ .3125\ cm^3$

$= 5.07cm^3$

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$\boxed{\text{Volume} = 1.0 \times 10^2 cm^3 \pm 5.1\ cm^3}$

maximum relative uncertainty $= \left|\frac{\Delta V}{V}\right|$

$= \left|\frac{5.1\ cm^3}{1 \times 10^2 cm^3}\right| = \boxed{5.1 \times 10^{-2}}$

3. Statistical Errors

Watch "Video 4 – Ramp Experiment" before doing these exercises

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Your use a compressed spring to launch a wheeled cart up an inclined ramp (see video). We wish to know how far the cart is launched up the ramp, and this displacement can be measured using the ramp's built-in ruler. The starting position of the cart is measured, and the displacement is then the difference between the starting and ending positions. To determine the precision of this measurement, you repeat and record your measurements 10 times.

Use the data to report an **average value** of the displacement and calculate the **standard deviation** and **standard error** in this value. Convert your standard error to a **percent error.** <u>If you use Excel or some other program to automate these calculations, please include the Excel file or a screenshot of your work.</u>

DATA:

Trial	End position (cm)	Displacement (cm)
1	44.1	10.9
2	44.5	11.3
3	44.4	11.2
4	44.9	11.7
5	43.8	10.6
6	44.2	11.0
7	46.9	13.7
8	44.1	10.9
9	44.8	11.6
10	44.4	11.2

Average Value = 11.4cm

Standard Deviation = 0.870cm

Standard Error = 0.275cm

Percent Error = 2.41%

From prelab lecture:

$$\text{percent error} = \frac{\delta x}{\bar{x}} \times 100 = \frac{\text{Standard error}}{\text{Average}} \times 100$$

$$= \frac{.275}{11.4} \times 100 = 2.41\%$$

a. Comment on the "spread" of the data and what it says about the precision of your measurements.

The data has a fairly small spread of measurements, with a couple of outliers such as trials 4 and 7. These measurements have a high precision, with a standard error of 0.275cm.

b. Identify specific sources of uncertainty in this experiment. Then, suggest some ways to reduce uncertainty and improve the precision.

When looking at the ruler, a major source of uncertainty is that the cart moves too quickly for it's final position to be seen for certain by human eyes. This precision can be improved by using a camera to record each run, and pausing once the apex is reached to make sure the displacement is measured as accurately as possible. A second possible source of uncertainty is that one person was running the experiment. This means that the setting up of the experiment, data recording, and measurements are all done without anyone double checking. This can be fixed by having multiple people run the experiment, especially as a second set of eyes on the ruler to ensure it is as precise as possible.