**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
   1. 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 sig figs

* 1. 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)

0.1/10.4 \* 100 = 0.96%

* 1. 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.

4 sig figs

1.040×101 g

1. 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 , you measure the radius to be 2.2 cm ± 0.1 cm.

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

Radius (R):

2.2/100 = 2.2×10−2 m (or 0.022 m)

Uncertainty (ΔR):

0.1/100 = 1.0×10−3 m (or 0.001 m)

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

Volume (V):

4/3×π×(0.022)3 =4.46×10−5 m3

maximum relative uncertainty:

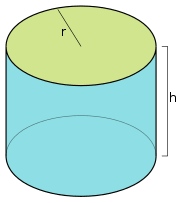
dV/dR = 4πR2

ΔV=4πR2ΔR

R=0.022m and ΔR=0.001m

ΔV = 4π × (0.022)2 × 0.001 = 6.082×10−6 m3

Maximum relative uncertainty is given by: ΔV/V = 13.64%

* 1. You now calculate the volume of a cylindrical object. The height is measured to be 5.20 cm ± 0.05 cm and the radius is measured to be 2.50 cm ± 0.05 cm. Calculate the volume and the **maximum relative uncertainty** of the volume calculation.

Volume:

r=2.5cm=0.025m h=5.2cm=0.052m

V=πr2h = π × 0.0252 × 0.052 = 1.021×10−4 m3

Δr=0.05cm=0.0005m Δh=0.05cm=0.0005m

ΔV=V√((Δr/r)2 + (Δh/h)2) = 2.266×10−6m3

Maximum Relative uncertainty: ΔV/V = 2.22%

1. Statistical Errors

*Watch “Video 4 – Ramp Experiment” before doing these exercises*

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.** *If you use Excel or some other program to automate these calculations, please include the Excel file or a screenshot of your work.*

DATA:

|  |  |  |
| --- | --- | --- |
| Trial | End position (cm) | Displacement (cm) |
| 1 |  | 37 |
| 2 |  | 31 |
| 3 |  | 32 |
| 4 |  | 29 |
| 5 |  | 33 |
| 6 |  | 27 |
| 7 |  | 32 |
| 8 |  | 35 |
| 9 |  | 32 |
| 10 |  | 24 |

Sum=37+31+32+29+33+27+32+35+32+24 = 312

Average Value = Sum/Number of elements = 312/10 = 31.2

Calculate (X-AverageValue)2:

* (37−31.2)2=33.64
* (31−31.2)2=0.04
* (32−31.2)2=0.64
* (29−31.2)2=4.84
* (33−31.2)2=3.24
* (27−31.2)2=17.64
* (32−31.2)2=0.64
* (35−31.2)2=14.44
* (32−31.2)2=0.64
* (24−31.2)2=51.84

Sum (X-AverageValue)2 = 127.6

Variance = Sum/number of elements = 127.6/10 = 12.76

Standard Deviation = √Variance = √12.76 = 3.57

Standard Error = Standard Deviation/√Number of elements = 3.57/√10 = 1.13

* 1. Comment on the “spread” of the data and what it says about the precision of your measurements.

A graph with a line

Description automatically generated

Most data points lie within a range of ±3.57 units from the mean. There is some spread in the data; it is not excessively wide relative to the range of values. A standard error of 1.13 relative to the mean of 31.2 signifies that if this experiment were repeated multiple times, the average of the sample means would typically vary by about ±1.13 from the true population mean. While the data has some inherent variability, the precision in estimating the population mean using this sample is good.

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

Sources of Uncertainty:

1. Variations in Spring Compression
2. Frictional Forces
3. Initial Positioning of the Cart
4. Measurement Technique with the Ruler
5. Environmental Factors

Ways to Reduce Uncertainty and Improve Precision:

1. Standardize Spring Compression: Use a mechanical or digital gauge.
2. Minimize Friction: Regularly maintain the ramp and cart’s wheels. Use lubricants if necessary and ensure the ramp surface is smooth and clean.
3. Improve Cart Positioning: Use a fixed mechanical stop to place the cart at the exact starting position every time.
4. Enhance Measurement Accuracy by Using a digital measuring device or a more precise ruler (e.g., one with finer divisions).
5. Control Environmental Conditions: Experiment in a controlled environment with constant temperature and humidity. Ensure that the ramp is perfectly leveled and stable.
6. Increase the Number of Trials