**PHYS 101 - Measurement and Uncertainty in Scientific Experiments**

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**Worksheet**

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

Jenny Wen Minghui Li

Dang Khoa Nguyen \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*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?

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* + 1. This reading has 3 significant figures.
  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)
     1. 0.1/10.4 = 0.009 ~ 1 x 10-2%
     2. The percentage error of the uncertainty of this measurement is 1 x 10-2%.
  2. 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.
     1. There are supposed to be 4 significant digits there. For the number of significant digits to not be ambiguous, we would write it in scientific notation as **1.040 x 10 g**.

1. Propagation of Uncertainty

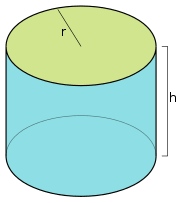
You are asked to measure the volume of a spherical object. Knowing that the volume, V, is related to the radius, R, by , you measure the radius to be 2.2 cm ± 0.1 cm.

* 1. Convert the measurement of the radius to meters and express the radius in scientific notation.
     1. 2.2 cm × 1 m/100 cm = 0.022 m ± 0.001 m
        1. 0.1cm × 1m/100cm = 0.001 m

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* + 1. Scientific Notation: 2.2 x 10-2 m ± 1.0 x 10-3 m
  1. Calculate the volume of the sphere (in cubic meters) using the measured radius and determine the **maximum relative uncertainty**.
     1. V= (4/3) πR^3   
        R= 2.2 x 10-2 m ± 1.0 x 10-3 m   
        V = (4/3) π (2.2)^3  
        **V = 4.46 x 10^-5 m^3**   
        dv/dr = 4πR^2 Δr  
        4π(2.2)^2Δr= 6.08 x 10^-6 m^3  
        6.08 x 10^-6 m^3/4.46 x 10^-5 m^3 = 1.36 x 10^-1 m^3  
        **Maximum relative uncertainty: 1.36 x 10^-1 m^3**

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* 1. 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.  
       
     1. V = πr^2h  
        r = 2.5 cm ± 0.05 cm   
        h = 5.2 cm ± 0.05 cm  
        V = π(2.5)^2 × 5.2  
        **V = 102.1 cm**  
        dv/dr = 2πrhΔr   
        2π(2.5)(5.2)(0.05) = 4.08 cm^3  
          
        dv/dh = πr^2Δh  
        π(2.5)^2(0.05) = 0.981 cm  
        4.08 + 0.981 = 5.061  
        5.061 / 102.1 = 0.05 cm  
        **Maximum relative uncertainty: 0.05 cm**

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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.

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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 | 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 = (10.9+11.3+11.2+11.7+10.6+11.0+13.7+10.9+11.6+11.2) /10 = 11.41cm

Standard Deviation = sqrt (Σ (displacement - average value) ^2 / N)

= sqrt (Σ (displacement - 11.41 cm) ^2 /10) = 0.83

Standard Error = SD / sqrt (N) = 0.83 / sqrt (10) = 0.262 = 26.2%

Percent Error = (SE / average value) \*100 = (0.275/ 11.41) \*100 = 2.29%

* 1. Comment on the “spread” of the data and what it says about the precision of your measurements.
     1. The spread of the data is all seen within the same interval with a standard deviation of 0.83 from the average. There is one outlier being in trial 7 where the value of displacement measured is 13.7. Which is highly out of line with the general spread of the rest of the data. This outlier most likely caused the data to be more skewed to the left.
  2. Identify specific sources of uncertainty in this experiment. Then, suggest some ways to reduce uncertainty and improve the precision.
     1. One specific source of uncertainty of this experiment may come from the procedure of taking the measurement of the displacement. While another way uncertainty can be from the spring launcher itself, where some real-world mistakes in-between trials may reproduce different results. This can be seen exactly in video 4, where the presenter changes the position and angle of the launcher when he went to reset it.   
          
         Some ways to reduce uncertainty and improve precision are to remove human error or human interaction with the experiment. One such improvement can be to make the whole experiment system more ridged, so that the system does not change between trials. To improve the data collection, a more exact form may be adopted. This can be from better equipment, such as Lazer tracking or simply track the cart itself, rather than relying on eyeing the measurement from a yard stick.