

Experimental Uncertainty

Name _____ ID _____ TA _____

Partners _____

Date _____ Section _____

Use “grams” and “centimeters” for this experiment so that you can easily compare with the reference values.

- **Measurements of densities**

➤ Description of object 1

Object 1: Material \Rightarrow _____ & Shape \Rightarrow _____

➤ Reference value of density: \Rightarrow _____ g/cm³

Please label the dimensions, such as height, radius, width, etc.

	Mass (g)	Dimension 1 (cm)	Dimension 2 (cm)	Dimension 3 (cm)
Measurement 1				
Measurement 2				
Measurement 3				
Average				
Standard Deviation				

Average Volume of the Object (Use the average values): $V =$ _____

Average Density [average value of mass \div average volume]: $D =$ _____

➤ Error propagation

$S_1 =$ _____ ; $S_2 =$ _____ ;

$S_3 =$ _____ ; $S_4 =$ _____

S_D (Uncertainty of density) = _____

Experimental data for the density: [D (average) \pm S_D (uncertainty)]: _____ \pm _____ ()

Units for density \Rightarrow

Question: Is the reference value of the density satisfied within the standard deviation?

➤ Description of object 2

Object 2: Material ⇨ _____ & Shape ⇨ _____

➤ Reference value of density: ⇨ _____ g/cm³

Please label the dimensions, such as height, radius, width, etc.

	Mass (g)	Dimension 1 (cm)	Dimension 2 (cm)	Dimension 3 (cm)
Measurement 1				
Measurement 2				
Measurement 3				
Average				
Standard Deviation				

Average Volume of the Object (Use the average values): $V =$ _____

Average Density [average value of mass ÷ average volume]: $D =$ _____

➤ Error propagation

$S_1 =$ _____; $S_2 =$ _____;

$S_3 =$ _____; $S_4 =$ _____

S_D (Uncertainty of density) = _____

Experimental data for the density: [D (average) ± S_D (uncertainty)]: _____ ± _____ ()
Units for density ⇨

Question: Is the reference value of the density satisfied within the standard deviation?

➤ Description of object 3

Object 3: Material ⇨ _____ & Shape ⇨ _____

➤ Reference value of density: ⇨ _____ g/cm³

Please label the dimensions, such as height, radius, width, etc.

	Mass (g)	Dimension 1 (cm)	Dimension 2 (cm)	Dimension 3 (cm)
Measurement 1				
Measurement 2				
Measurement 3				
Average				
Standard Deviation				

Average Volume of the Object (Use the average values): $V =$ _____

Average Density [average value of mass ÷ average volume]: $D =$ _____

➤ Error propagation

$S_1 =$ _____; $S_2 =$ _____;

$S_3 =$ _____; $S_4 =$ _____

S_D (Uncertainty of density) = _____

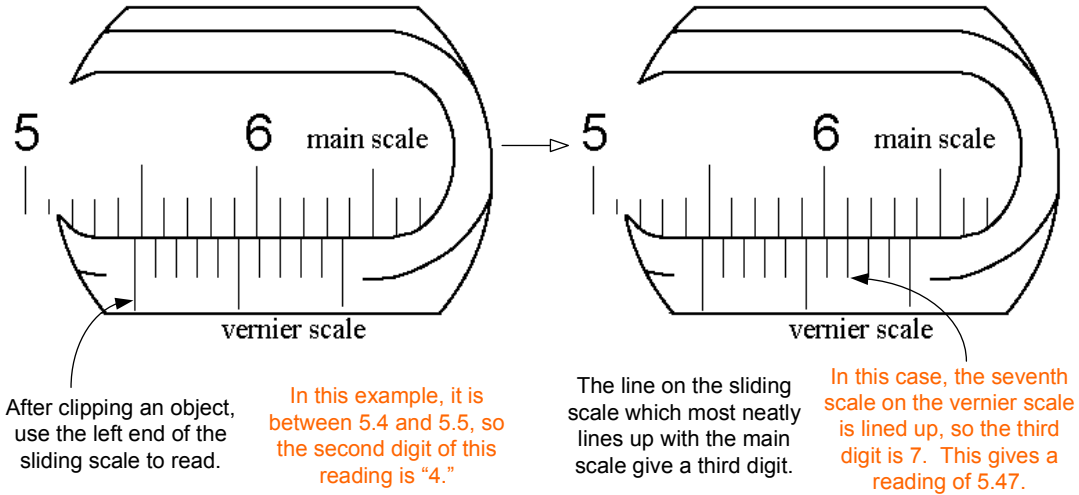
Experimental data for the density: [D (average) ± S_D (uncertainty)]: _____ ± _____ ()
Units for density ⇨

Question: Is the reference value of the density satisfied within the standard deviation?

<i>Reference values of densities</i>	
Copper: 8.93 g/cm ³	Lead: 11.3 g/cm ³
Nickel: 8.8 g/cm ³	Wood: (0.25 – 1.0) g/cm ³
Iron (Steel): 7.8 g/cm ³	Aluminum: 2.7 g/cm ³
Brass: (7.5 – 8.5) g/cm ³	Silver: 10.5 g/cm ³

Appendices

- **How to use a caliper**



- **How to use the formula of Standard Deviation**

The equation of standard deviation is given as

$$\text{Standard Deviation} = \sqrt{\frac{1}{N-1} \sum_i (x_i - x_m)^2}$$

where N is the number of data, x_i is the i -th datum, and x_m is the average value of data. For example, here is a set of data.

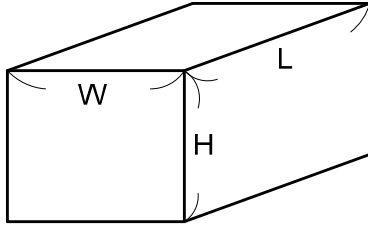
x_i	x_1	x_2	x_3
Values of data	4.56	4.37	4.61

In this case, the number of data is 3, so $N = 3$. The average is $(4.56 + 4.37 + 4.61)/3 = 4.51$. Namely, $x_m = 4.51$. Now, if we calculate the standard deviation, we have

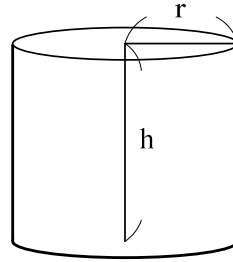
$$SD = \sqrt{\frac{1}{3-1} [(4.56 - 4.51)^2 + (4.37 - 4.51)^2 + (4.61 - 4.51)^2]} = 0.126 \Rightarrow 0.13.$$

The final format of this data is: **4.51 ± 0.13** [units].

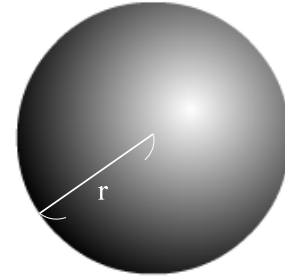
- **How to calculate volumes**



$$V = L \times W \times H$$



$$V = \pi r^2 h$$



$$V = \frac{4}{3} \pi r^3$$

- **How to calculate the error propagations**

S_M , S_L , S_W , S_H , S_h , and S_r are the standard deviation of each dimension. M , L , W , H , h , r , and D are the average value of each dimension.

Cube or rectangular solid

$$S_1 = \frac{(M + S_M)}{L \times W \times H} - D \quad (\text{Uncertainty of the density with standard deviation of the mass})$$

$$S_2 = \frac{M}{(L + S_L) \times W \times H} - D \quad (\text{Uncertainty of the density with SD of the length})$$

$$S_3 = \frac{M}{L \times (W + S_W) \times H} - D \quad (\text{Uncertainty of the density with SD of the width})$$

$$S_4 = \frac{M}{L \times W \times (H + S_H)} - D \quad (\text{Uncertainty of the density with SD of the height})$$

$$S_D = \sqrt{S_1^2 + S_2^2 + S_3^2 + S_4^2} \quad (\text{Total uncertainty of the density})$$

Cylinder

$$S_1 = \frac{(M + S_M)}{\pi r^2 h} - D \quad S_2 = \frac{M}{\pi (r + S_r)^2 h} - D \quad S_3 = \frac{M}{\pi r^2 (h + S_h)} - D$$

$$S_D = \sqrt{S_1^2 + S_2^2 + S_3^2}$$

Sphere

$$S_1 = \frac{(M + S_M)}{\frac{4}{3} \pi r^3} - D \quad S_2 = \frac{M}{\frac{4}{3} \pi (r + S_r)^3} - D$$

$$S_D = \sqrt{S_1^2 + S_2^2}$$