Measuring and Comparing Densities

In this lab you will measure the densities of various objects made of different materials using several of the tools and pieces of equipment you may need in future labs. You will also calculate the uncertainty in your density measurements using the techniques of error propagation.

Equipment: Ruler, calipers, digital balance, triple-beam balance, block of wood, metal or glass sphere, metal cube, metal cylinder (various metals)

Procedure:
Read the "Equipment User Guide" in the Supplements subfolder of the Labs folder on Canvas. For all the following questions, show your work on the space below the table on the last page.

Part A – Wooden Block

1. Use your ruler to measure the length ℓ, width w, and height h of your wooden block. Also measure the mass m of your block using both the digital balance and the triple-beam balance. Record all of these values in the table below and <u>include uncertainties</u>.
2. What is the volume V of your block (formula and result)? Use the maximum variation method or the method of quadrature to propagate your uncertainties into an uncertainty for V.
3. What is the density of your block? Remember that $\rho = m/V$, use whichever mass measurement you think is "best" (with justification) and again propagate your uncertainties to obtain $\delta\rho$.

Part B – Metal or Glass Sphere

1. Use the calipers to measure the diameter D of your sphere (you may need to check with your instructor to ensure you're taking the measurement correctly). Also use the digital balance to record its mass. Include uncertainties.
2. What is the volume V of your sphere (formula and result)? Propagate your uncertainties.
3. What is the density ρ of your sphere (with propagated uncertainties)?
4. Find a table of densities online and decide what metal or material the sphere is made of (it probably isn't very exotic or expensive!). Calculate the absolute and percent errors between your measured density and that in the table.
5. Is your result consistent with that in the table?

Part C – Metal Cube

1. Repeat Part B for your cube of side length L. What are its volume and density (including uncertainties)? What material is it, and what is the percent error in the density? Is your measurement consistent with the table?

Part D – Metal Cylinder

1. Repeat Part B for your cylinder of diameter D and height h. What are its volume and density (including uncertainties)? What material is it, and what is the percent error in the density? Is your measurement consistent with the table?

© 2022 Project Caliper. All rights reserved.

Measuring and Comparing Densities

Analysis:

1. Compute the percent uncertainties in the dimensions of the block. What trend do you notice? Do larger measurements have larger or smaller percent uncertainties? Can you explain why this trend is so?
2. How many times bigger is the absolute uncertainty of the block's length as compared to the absolute uncertainty of the sphere's diameter? Call this ratio r. One might expect that this would mean that the length's percent uncertainty would be r times bigger than the diameter's percent uncertainty, and yet this is not what is observed. Can you explain why this is so?
3. How many times bigger is the volume percent uncertainty for the block as compared to the sphere? Earlier you found r, the ratio of absolute uncertainties between the ruler and the calipers. Given that $V = \ell wh$, we might expect that the percent uncertainty in the block of wood's volume would be r^3 times bigger than the percent uncertainty in the sphere's volume. Why **isn't** the block's percent uncertainty r^3 times bigger than the sphere's percent uncertainty? Can you explain what is going on?

DATA TABLES

	Wooden Block		Sphere	Metal Cube	Metal Cylinder
Mass m (g)	214.4g	254.6g	28.2g	66.4g	103.4g
δm (g)	0.05	0.05	0.05g	0.05g	0.05g
Length ℓ (mm)	85mm			20.24mm	
$\delta\ell$ (mm)	0.5mm			0.005mm	
Width w (mm)	35mm				
δw (mm)	0.5mm				
Height h (mm)	195mm				42.95mm
δh (mm)	0.5mm				0.005mm
Diameter D (mm)			18.96mm		19.12mm
δD (mm)			0.005mm		0.005mm
Volume V (cm^3)	580cm^3		3.517cm^3	8.291cm^3	12.332cm^3
δV (cm^3)	13cm^3		0.02cm^3	0.006cm^3	0.014cm^3
Density ρ (g/cm^3)	0.47g/cm^3		7.90g/cm^3	8.01g/cm^3	8.38g/cm^3
$\delta\rho$ (g/cm^3)	0.11g/cm^3		0.06g/cm^3	0.01g/cm^3	0.01g/cm^3

© 2022 Project Caliper. All rights reserved.

Measuring and Comparing Densities

	Wooden Block	Sphere	Metal Cube	Metal Cylinder
Material?		Iron	bronze	bronze
Theoretical density ρ_{th} (g/cm^3)		7.874 g/cm^3	8.73 g/cm^3	8.13 g/cm^3
Error E_ρ (g/cm^3)		−0.026 g/cm^3	0.72 g/cm^3	0.35 g/cm^3
% Error $\%E_\rho$		−0.33%	8.25%	4.01%
Consistent?		Yes	Yes	Yes

Scratch Work:

Volume of block (in terms of ℓ, w, h): $(l \times w \times h)$

Volume of sphere (in terms of D): $\frac{4}{3} \times \pi \times \left(\frac{D}{2}\right)^3$

Volume of cube (in terms of L): L^3

Volume of cylinder (in terms of D and h): $\pi \times \left(\frac{D}{2}\right)^2 \times h$

δV for block (in terms of $\ell, w, h, \delta\ell, \delta w, \delta h$): $(l + \delta l)(w + \delta w)(h + \delta h) - (l \times w \times h)$

δV for sphere (in terms of $D, \delta D$): $\frac{4}{3} \times \pi \times \left(\frac{D + \delta D}{2}\right)^3 - \frac{4}{3} \times \pi \times \left(\frac{D}{2}\right)^3$

δV for cube (in terms of $L, \delta L$): $(L + \delta L)^3 - L^3$

δV for cylinder (in terms of $D, h, \delta D, \delta h$): $\pi \times \left(\frac{D + \delta D}{2}\right)^2 \times h - \pi \times \left(\frac{D}{2}\right)^2 \times h$

© 2022 Project Caliper. All rights reserved.