Measurement

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Objectives

The purpose of this experiment is to acquaint the student with basic principles of using measurement instrumentation and to help the student become familiar with several measuring devices used in physics and apply them to measuring length (I) and mass (m). From these measurements, volume (V) and density (ρ) can be calculated. Particular emphasis will be given to the use of the vernier scale and the reporting of percent error.

Theory

In physics, it is essential that proper care is taken to ensure that correct, accurate measurements of physical quantities are made. The field of classical mechanics puts observations in terms of three fundamental quantities: length, mass, and time. Our standard unit of length measurement in the international system is the meter (m), and it is exactly defined as the distance that a beam of light can travel in 1/299,792,458th of a second (s). Common fractional units of length based on the meter are the centimeter (cm; 1/100th of a meter) and a millimeter (mm; 1/100th of a meter). Our standard unit of mass measurement is the kilogram (kg), and it is exactly defined as the mass of a platinum-iridium alloy kept at the Bureau of Weights and Measures near Paris. A common fractional unit of mass based on the kilogram is the gram (g; 1/100th of a kilogram).

If an object of unknown composition is under study, measurements of the physical dimensions and mass of the object can be used to determine its composition. The volume of the object can be calculated using the equations V = (I)(w)(h) for rectangular solids, $V = \pi r^2 h$ for cylinders (where r is the radius of the cylinder and h is the height of the cylinder), and $V = (4/3)\pi r^3$ for spheres (where r is the radius of the sphere). From the volume calculation (taking care to observe correct significant figure notation), and from a measurement of mass, we can determine the density of the unknown object using the equation $\rho = m/V$. A comparison of this calculated density to known material densities can be used to approximate the object's composition.

Procedure

The mass of a silver colored and brass colored cylinder were measured using a square pan digital balance, and the mass was recorded in units of grams. Additionally, the mass of a sphere, rectangular solid, and irregular solid were measured in grams using the square pan balance, while the mass of three small wires (a silver colored wire, a shiny copper wire, and a burnt copper wire) were measured in grams using the round pan balance. The square pan balance allowed for a mass measurement precision of 0.1 g, while the round pan balance allowed for a mass measurement precision of 0.01 g.

The diameters of each of the cylinders and wires were measured in centimeters using a vernier caliper, as was the diameter of the metal sphere, and the length, width, and height of the rectangular solid. The caliper allows for a measurement precision of 0.01 cm. The length of the wires was measured in centimeters using a metric ruler, with a precision of 0.05 cm.

Two methods for measuring the volume of the irregular solid were used, one in which the irregular solid was allowed to displace a known quantity of water, the other in which the physical dimensions of the outer cylinder and the physical dimensions of the inner cylinder were measured using the vernier caliper. A volume calculated from the dimensions of the inner cylinder can be subtracted from a volume calculated from the dimensions of the outer cylinder to give the total volume of the irregular solid.

Data

Table 1: Mass Measurements

Object	Mass	
Silver Cylinder	12.7 g	
Brass Cylinder	76.8 g	
Silver Wire*	0.79 g	
Shiny Copper Wire*	0.39 g	
Burnt Copper Wire*	0.45 g	
Sphere	28.3 g	
Rectangular Solid	44.8 g	
Irregular Solid	119.9 g	

* Measured using a round-pan balance

Table 2: Object Diameters

Object	Diameter	
Silver Cylinder	1.60 cm	
Brass Cylinder	1.28 cm	
Silver Wire	0.20 cm	
Shiny Copper Wire	0.09 cm	
Burnt Copper Wire	0.10 cm	
Sphere	1.90 cm	
Irregular Solid Outside	1.92 cm	
Irregular Solid Cavity	0.93 cm	

Table 3: Object Lengths

Object	Length
Silver Cylinder	2.31 cm
Brass Cylinder	6.81 cm
Silver Wire**	9.20 cm
Shiny Copper Wire**	8.70 cm
Burnt Copper Wire**	10.20 cm
	1.27 cm,
Rectangular Solid	2.55 cm,
	5.00 cm
Irregular Solid Outside	6.07 cm
Irregular Solid Cavity	4.74 cm

** Measured using a metric ruler

Calculations

The volume of the rectangular solid can be calculated using the equation V = (l)(w)(h), and for the data collected in this lab, V = (1.27 cm)(2.55 cm)(5.00 cm) = 16.2 cm³. The volume of the cylinders and wires can be calculated from V = $\pi r^2 h$, and for the data collected in this lab for the silver cylinder, V = (3.14)(1.60 cm/2)²(2.31 cm) = 4.64 cm³. For the sphere, V = (4/3)) πr^3 , and for the data collected in this lab, V = (4/3)(3.14)(1.90/2 cm)³ = 3.59 cm³. The remaining volumes calculated from the data can be found in Table 4 in the Results section.

Results

Table 4: Object Volumes	
Object	Volume
Silver Cylinder	4.64 cm ³
Brass Cylinder	8.76 cm ³
Silver Wire	0.29 cm ³
Shiny Copper Wire	0.07 cm ³
Burnt Copper Wire	0.08 cm ³
Sphere	3.59 cm ³
Rectangular Solid	16.2 cm ³
Irregular Solid (Displacement Method)	14 cm ³
Irregular Solid (Calculated)	15 cm ³

Table 5: Object Densities

Object	Density		
Silver Cylinder	2.74 g/cm ³	2.74x10 ³ kg/m ³	
Brass Cylinder	8.77 g/cm ³	8.77 x10 ³ kg/m ³	
Silver Wire	2.7 g/cm ³	2.7 x10 ³ kg/m ³	
Shiny Copper Wire	6 g/cm ³	6 x10 ³ kg/m ³	
Burnt Copper Wire	6 g/cm ³	6 x10 ³ kg/m ³	
Sphere	7.88 g/cm ³	7.88 x10 ³ kg/m ³	
Rectangular Solid	2.77 g/cm ³	2.77 x10 ³ kg/m ³	
Irregular Solid*	8.0 g/cm ³	8.0 x10 ³ kg/m ³	

*Used average volume of two methods

Table 6: Obje	ct Composition	Approximations
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Object	Material	% Error
Silver Cylinder	Aluminum	3.7 %
Brass Cylinder	Brass	1.2 %
Silver Wire	Aluminum	0 %
Shiny Copper Wire	Unknown	Unknown
Burnt Copper Wire	Unknown	Unknown
Sphere	Steel	1.3 %
Rectangular Solid	Aluminum	2.6 %
Irregular Solid	Steel	2.6 %

Questions

1. In measuring the length and diameter of a cylinder, which dimensions should be measured more carefully? Why?

We should measure diameter more carefully. When making a volume calculation, the radius of the cylinder is squared. Any error in the diameter measurement is propagated through twice in the volume calculation.

2. What is the volume in cubic millimeters of the largest cylinder you measured? What is the volume in liters? What is the mass in kilograms?

The largest cylinder that was measured was the brass cylinder. It has a volume of 8.8 x 10^3 mm³, which is also equal to 8.8 x 10^{-3} L. Its mass in kilograms is 7.68 x 10^{-2} kg.

3. A thin circular sheet of copper has a diameter of 30.0 cm and a thickness of 1.00 mm. Find the mass of the sheet in grams.

The volume of the sheet can be found using the equation for the volume of a cylinder. V = $(3.14)(15.0 \times 10^{-2} \text{ m})^2(1.00 \times 10^{-3} \text{ m}) = 7.10 \times 10^{-5} \text{ m}^3$. Plugging this into the density equation, 8.9 x $10^3 \text{ kg/m}^3 = \text{m}/(7.10 \times 10^{-5} \text{ m}^3)$. Therefore, the mass of the sheet is 0.60 kg, or 600 g.

Conclusions

Accurate measurement is essential for observations of physical phenomena. The fundamental units of length and mass are the meter and kilogram, respectively. Using instruments designed to correctly measure these quantities, we were able to make low error calculations of volume and density for several objects of previously unknown composition. Proper attention was given to significant figures, as our measurement devices were known to have finite and specific values of precision. With the exception of two materials, our observed errors were less than 10%, which we consider to be within the range of acceptable error for this lab. A possible explanation for the "unknown" designation that we had to assign to two of our objects is that our density tables from the text are not comprehensive enough to account for the materials these objects may be comprised of.

References

University Physics, 12th Edition, Young and Freedman, Pearson/Addison-Wesley, 2007.