Laboratory 2. Measurement of Density

Comments to the Instructor

This laboratory is much like Laboratory 1 in that its purpose is to introduce the concepts of measurement. This laboratory introduces the students to the vernier caliper and to the laboratory balance. Because there are usually more laboratories to do in a semester than time permits, it may be necessary to choose between Laboratory 1 and Laboratory 2 or else do both of them in one period.

It is important to note that the metal cylinders should not be perfectly machined or the variations in the measurements of length and diameter when using the vernier caliper will be so small that the point to the laboratory may be lost.

In addition to the general ideas about the measurement process contained in this laboratory, the concept of density is introduced. The student is asked to compare his results with the known density of the material from which the cylinder is made. There is enough variation in the density of a given type of metal that the instructor really should make an accurate determination of the density of the actual cylinders used by the students if a really good test of the student's accuracy is desired.

Most of the questions that were given for a post laboratory exam for Laboratory 1 are appropriate for a post laboratory exam for this laboratory also.

Post Laboratory Exam Questions

1. If an object of total mass M and total mass V has its mass distributed uniformly the density ρ is given by (a) MV (b) M/V (c) V/M (d) $1/2\ M\ V^2$ **Answer (b)**
2. The vernier calipers described in the laboratory are capable of measurements which are accurate to the nearest (a) 0.001 mm (b) 0.01 mm (c) 0.1 mm (d) 1 mm. **Answer (c)**
3. Any device that is used to determine thickness, the diameter of an object, or the distance between two surfaces, is called a (a) vernier (b) caliper (c) balance (d) rivet. **Answer (b)**

4. A scale used to interpolate between marked scale divisions is called a (a) vernier (b) caliper (c) balance (d) rivet. **Answer (a)**

5. The zero correction of a vernier caliper (a) is always positive (b) is always negative (c) is always zero (d) can be positive, negative, or zero. **Answer (d)**

6. A uniform sphere of iron ($\rho = 7.85\times10^3$ kg/m^3) has a radius of 0.0500 meters. Its mass is (a) 4.11 gm (b) 41.1 gm (c) 4.11 kg (d) 0.411 kg **Answer (c)**

7. When calculating the standard error this laboratory suggests one should keep in the result (a) always two decimal places (b) always two significant figures (c) only one significant figure (d) three significant figures **Answer (c)**

A series of measurements of the mass, length, and diameter of a cylinder are made. The results of those measurements are:

Mass--46.9, 47.2, and 47.4 g

Length--3.15, 3.17, and 3.18 cm

Diameter-- 1.52, 1.49, and 1.50 cm

Consider the measurements above in answering question 8 through 10.

8. Based on these three measurements of the mass, 68.3% of the measurements of the mass of the cylinder (in grams) should fall in the range (a) 47.17 ± 0.20 (b) 47.30 ± 0.10 (c) 47.17 ± 0.15 (d) 47.17 ± 0.25 **Answer (d)**

9. The standard error (in grams) for the mass measurements is (a) 0.20 (b) 0.10 (c) 0.15 (d) 0.25 **Answer (c)**

10. Use Equation 4 in Laboratory 2 to calculate the standard error α_ρ of the value of ρ determined from these measurements. The result for α_ρ is (a) 0.20 (b) 0.10 (c) 0.15 (d) 0.25 **Answer (b)**

Pre-Laboratory Assignment

1. A cylinder has a length of 3.23 cm, a diameter of 1.75 cm, and a mass of 65.3 grams. What is the density of the cylinder? Based on its density, of what kind of material might it be made? Material is likely to be: **Brass** (Show your work.)

   $\boldsymbol{\rho = (4M)/(pd^2L) = =(4)(65.3)/(3.14)(1.75)^2(3.23) = 8.41\ g/cm^3}$

2. Figure 2-4 shows a vernier caliper scale set to a particular reading. What is the reading of the scale? Reading = **2.22** cm

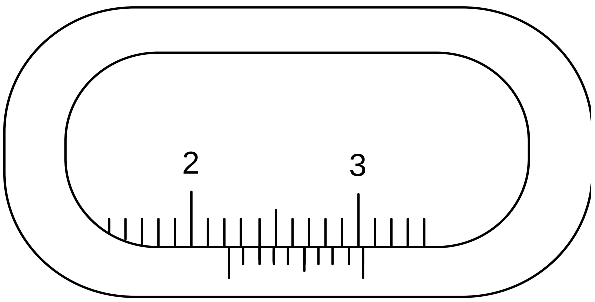

Figure 2-4. Example of a reading of a vernier caliper.

3. The caliper in Figure 2-5 has its jaws closed. If the caliper has a zero error what is its value? Is it positive or negative? Error = **−0.03** cm

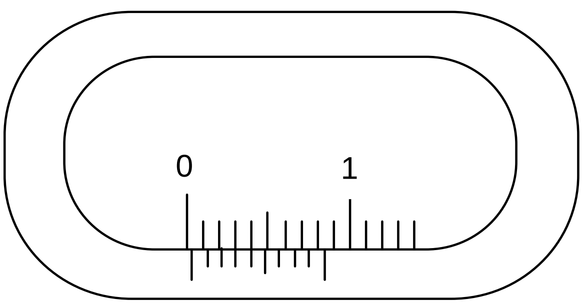

Figure 2-5. Vernier caliper with its jaws closed. Does it have a zero error?

4. A series of four measurements of the mass, length, and diameter are made of a cylinder. The results of these measurements are:

   Mass - 20.6, 20.5, 20.6, and 20.4 grams

   Length - 2.68, 2.67, 2.65, and 2.69 cm

Diameter - 1.07, 1.05, 1.06, and 1.05 cm

Find the mean, standard deviation, and standard error for each of the measured quantities and tabulate them below. Keep only *one* significant figure in each standard error and then keep *decimal places* in the mean to coincide with the standard error.

$\overline{M}$ = **20.53 g** σ_{n-1} = **0.096 g** α_M = **0.05 g**

$\overline{L}$ = **2.673 cm** σ_{n-1} = **0.017 cm** α_L = **0.009 cm**

$\overline{d}$ = **1.058 cm** σ_{n-1} = **0.0096 cm** α_d = **0.005 cm**

Calculate the density and the standard error of the density using Equations 3 and 5. Keep only *one significant figure* in the standard error and then keep *decimal places* in the density to coincide with the standard error.

ρ = **8.82 g/cm^3** α_ρ = **0.09 g/cm^3**

5. **Since the second digit to the right of the decimal is the significant digit in the standard error it is the first uncertain digit. Thus there are three significant digits in the value of *r*.**

Laboratory Report

Mass Data and Calculations Table

	M_1 (g)	M_2 (g)	M_3 (g)	M_4 (g)	$\overline{M}$ (g)	$\overline{M}$ (kg)	σ_{n-1}(kg)	α_M (kg)
Aluminum	**63.99**	**63.96**	**64.15**	**64.11**	**64.05**	**0.06405**	**0.00092**	**0.00005**
Brass	**68.31**	**68.40**	**68.46**	**68.47**	**68.41**	**0.06841**	**0.00073**	**0.00004**
Iron	**63.74**	**63.73**	**63.87**	**63.89**	**63.81**	**0.06381**	**0.084**	**0.00004**

Zero Reading of the calipers 0.00 cm

Length Data and Calculations Table

	L_1 (cm)	L_2 (cm)	L_3 (cm)	L_4 (cm)	$\bar{L}$ (cm)	$\bar{L}$ (m)	σ_{n-1}(m)	α_L (cm)
Aluminum	**8.03**	**8.02**	**8.04**	**8.04**	**8.033**	**0.08033**	**0.000096**	**0.00005**
Brass	**4.14**	**4.13**	**4.14**	**4.13**	**4.135**	**0.04135**	**0.000058**	**0.00003**
Iron	**2.96**	**2.95**	**2.95**	**2.95**	**2.953**	**0.02953**	**0.000050**	**0.00003**

Diameter Data and Calculations Table

	d_1 (cm)	d_2 (cm)	d_3 c(m)	d_4 (cm)	$\bar{d}$ (cm)	$\bar{d}$ (m)	σ_{n-1} (m)	α_d (m)
Aluminum	**1.91**	**1.90**	**1.91**	**1.91**	**1.908**	**0.01908**	**0.000050**	**0.00003**
Brass	**1.59**	**1.59**	**1.58**	**1.57**	**1.583**	**0.01583**	**0.000096**	**0.00005**
Iron	**1.90**	**1.90**	**1.90**	**1.90**	**1.900**	**0.01900**	**0.000000**	**0.00000**

Density Data and Calculations Table

	ρ_{exp} (kg/m^3)	α_ρ (kg/m^3)	ρ_{known} (g/cm^3)	Err (kg/m^3)	% Error
Aluminum	**2.790 x 10^3**	**0.009 x 10^3**	**2.70 x 10^3**	**0.09 x 10^3**	**3 %**
Brass	**8.41 x 10^3**	**0.05 x 10^3**	**8.40 x 10^3**	**0.01 x 10^3**	**0.1 %**
Iron	**7.625 x 10^3**	**0.009 x 10^3**	**7.85 x 10^3**	**0.23 x 10^3**	**2.9 %**

Questions

1. In the standard deviations of aluminum and iron the significant figure is in the third place to the right of the decimal which means there are 4 significant figures for those measurements. For brass the significant digit in the standard deviation is in the second place to the right of the decimal which gives 3 significant figures for the density of brass.
2. The accuracy of each of the measurements is determined by the percentage error compared to the known values of the densities. For aluminum it is 3%, for brass 0.1%, and for iron 2.9%.
3. The percentage standard errors are: aluminum = (0.009)/(2.790)×100% = 0.3%, brass = (0.05)/(8.41)×100% = 0.6%, and for iron = (0.009)/(7.625)×100% = 0.1%. Only for brass is the percentage error compared to the known value within the percentage standard error. For aluminum the error is 10 times larger and for iron it is 29 times larger than the percentage standard error.
4. The errors far exceed the standard errors for aluminum and iron. This seems to be a systematic error and is very likely to be caused by samples that are alloys of mostly the assumed metal, but not pure samples of aluminum or iron.
5. (*Hint: Consider the form of Equation 4.*) Since the density depends upon the square of the diameter its percentage uncertainty is 4 times as important as the other uncertainties as shown by Equation 4.