Density

Purpose

Problem 1: Determine the density of a metal cylinder to three significant digits.
Problem 2: Determine the density of a metal sphere to four significant digits.

Introduction and Theory

The density ρ of a solid object is defined as:

$$\rho = \frac{\text{mass}}{\text{volume}} = \frac{m}{V}$$

and is expressed in units of kg/m^3 in SI. We usually use 10^3 kg/m^3 as the units for density, which is the same as g/cm^3. For example, the density of water is 1.00×10^3 kg/m^3 or 1.00 g/cm^3.

In this lab, we will find the density of a metal cylinder (length l, diameter d_{cyl}) and the density of a metal sphere (diameter d_{sph}).

The volume formulas for cylinders and spheres are:

$$V_{\text{cylinder}} = Al = \pi r^2 l = \frac{\pi d_{\text{cyl}}^2\, l}{4}, \qquad V_{\text{sphere}} = \frac{4}{3}\pi r_{\text{sph}}^3 = \frac{\pi d_{\text{sph}}^3}{6}.$$

So the final expressions for the densities:

$$\rho_{\text{cylinder}} = \frac{4m}{\pi d_{\text{cyl}}^2\, l}, \qquad \rho_{\text{sphere}} = \frac{6m}{\pi d_{\text{sph}}^3}$$

A major emphasis in this lab is on significant digits.

For both problems, one mass measurement and three length measurements are made. For the cylinder, the mass is determined using a 2-pan (or equal arm) balance, which is relatively imprecise whereas for the sphere we will use the more precise 4-beam balance. The length measurements for the cylinder are made using a Vernier caliper but we will use the more precise micrometer caliper to determine the diameter of the sphere. Therefore, the measurement result of Problem 2 will have more significant digits than Problem 1.

For the devices we use in this lab, the balances and the Vernier caliper should read zero at the beginning of the measurements (their zero readings are zero.) However, the zero reading on the micrometer caliper is likely to be non-zero and most likely negative, and we have to make appropriate corrections.

As this is a complete lab report, you must pay close attention to the format. Write in non-erasable ink and draw in pencil. Write down your name, partner's name, desk number and today's date at the top-left corner of the first page, then write the title of the report in the centre. The report will contain 5 sections: Purpose, Apparatus, Data, Calculations and Conclusions.[1] You will write a SEPARATE lab report for each problem.

[1] A number of items have been spelled out in detail in this report lab, since they will subsequently recur in later labs. They will not be reiterated, so you may want to refer to this lab later on.

Problem 1 Density of a Cylinder

Purpose

State the purpose of this experiment in a short sentence.

Apparatus

List *all* apparatus that you use, along with any identifying numbers, like:

Cylinder # ____, 2-pan balance # ____, Vernier caliper # ____.

Data

1. Measuring the mass of the cylinder with the 2-pan balance

Slide all the weights on all the bars on the 2-pan balance to their zero marks, remove all masses from the pans and wait until it balances. This is the zero reading. If the needle pointer does not point exactly to the centre line, adjust it using the adjusting screw on the right[2].

Place the cylinder on the left-hand pan and slide the sliders along the bars until the pointer again points to the balance mark. One-half the smallest division of the 2-pan balance is 0.05 g, which should be the uncertainty of the cylinder's mass. Record the mass of the cylinder in the "Data" section of your lab report like this:

Mass of the cylinder m = (##. ## ± 0.05) g (Note: zero reading = 0.)

Note that the reading and the uncertainty have the same number of decimal places. You must do so for all the raw data readings.

If the mass is over 200 g, you may have to place some counter masses on the *right-hand* pan to help achieve balance. This will increase the uncertainty, since the counter masses, although clearly marked, have uncertainties themselves. For each counter mass, add another 0.05 g to the uncertainty. So if you used 2 counter masses, your uncertainty for the mass of the cylinder will be 0.15 g. Then you should record the mass like this:

Mass of the cylinder m = (###. ## ± 0.15) g (Note: zero reading = 0. Used 2 counter masses)

2. Measuring the diameter and length of the cylinder with the Vernier calipers

The Vernier calipers consist of a main scale and a slider, which is called a Vernier scale. The reading is the position of the zero mark of the Vernier scale on the main scale. Close the jaws of the caliper to take the zero reading. Most likely, the zero mark of the Vernier scale will point at zero on the main scale, which means the zero reading is zero. If not, ask the instructor for a different caliper.

[2] If the pointer still does not point to the centre, you can make a note of the pointer's position and use that to judge the balance when measuring masses. This forces your zero reading to be zero.

The Vernier calipers can read to 0.01 cm precision. This is likely to be the uncertainty of the length and the diameter of the cylinder as it is quite a perfect cylinder. The centimetre and first decimal readings are read from the main scale. The last digit is determined by which mark on the Vernier scale matches a mark on the main scale. There are 10 marks after the zero mark on the Vernier scale. If the 6^{th} mark lines up with a mark on the main scale, the last digit of the reading is 6.

Take three readings of the length and diameter, find average values, and record in a table like the one below. All entries have the same unit "cm" as indicated in the header of the table: Don't repeat the unit for each entry!

Our raw readings all have 2 decimal places – same as the uncertainty. However, the calculator may give you more or fewer decimal places for the average reading. If it is more, keep some extra digits so your average has 4 or 5 decimal places. If it is less, add 0's at the end until it has 2 decimal places.

Table 1: Dimensions of the Cylinder (cm)

	Length *l*	Diameter *d*
Reading 1 Reading 2 Reading 3		
Average reading		
Uncertainty		

Note: zero reading of the Vernier caliper is 0.

Calculations

First convert all measurements to standard units: diameter and length from centimetres to metres, and mass from grams to kilograms. Then calculate the density of the cylinder using the equation for ρ_{cylinder} on Page 1. Your calculations should have 3 steps: (1) Symbolic equation as given on Page 1; (2) Substitution of the mass, diameter and length with their numbers and units (metres or kilogram); (3) Numerical result with units. Do not round off the result to sig. figs. if your calculator gives many digits, as you may need them for further calculations. Keeping 5 non-zero digits should be enough.

Next, compare your result with the reference value. Ask the instructor for the reference value of your cylinder, state it in your report, then calculate the *percentage discrepancy* between your value and the reference value:

$$\text{percentage discrepancy} = \frac{|\text{your } \rho \text{ - reference } \rho|}{\text{reference } \rho} \times 100\%$$

Round the result of the percentage discrepancy to 1 or 2 non-zero digits.

Conclusions

Round off your result to the correct number of sig. figs. then state it like below:

"The density of the cylinder #117 was found to be #.## $\times$ 10^3 kg/m^3, which is #% lower/higher than the reference value."

Check if your conclusion meets the following requirements (do these checks for future experiments too):

- answers the purpose of the experiment;
- has the right units;
- has the correct number of significant digits (use scientific notation if needed);
- is close to the reference value and/or agrees with your common sense! (How much will one cubic metre of metal roughly weigh?)

Problem 2 Density of a Sphere

Purpose

State the purpose of this experiment in a short sentence.

Apparatus

Sphere # ____, 4-beam balance # ____, micrometre caliper # ____.

Data

1. Measuring the mass of the sphere with the 4-beam balance

The smallest division of the 4-beam balance is 0.01 g. It suggests that the uncertainty is likely to be 0.005 g and you can read the mass to milligrams. Either turn the adjusting knob or mark the balance position so that your zero reading is zero. Measure and record the mass of the sphere similarly to Problem 1.

2. Measuring the diameter of the sphere with the micrometer caliper

Important! When tightening the jaws of the micrometer, only use the frictional knob at the very end. Otherwise you may damage the threads inside the micrometer.

The micrometer caliper, or the micrometer, consists of a straight main scale and a circular micrometer scale. For our micrometer, one full turn of the barrel, which is 100 divisions of the micrometer scale, is equivalent to 1 mm. (Check this for yourself.) Therefore, each division of the micrometer scale is 0.01 mm.

Depending on your eyesight, you can quote the uncertainty to be either 0.01 mm or 0.005 mm. Remember to read the length to the same decimal place as the uncertainty. The millimetre reading is taken by where the moving part crosses the main scale. The remainder of the reading is based on where the horizontal line crosses the micrometer scale.

Measure the diameter 3 times and record the results in a table like below. The zero reading of our micrometer is likely to be negative, so a corrected reading is needed. Calculate the average reading first, then correct it by:

$$\text{corrected reading} = \text{average reading} - \text{zero reading}$$

It is fine for both the average reading and the corrected reading to have more (but never less) decimal places than the uncertainty.

Table 2: Diameter of the Sphere *d* (mm)

Zero reading	
Reading 1 Reading 2 Reading 3	
Average reading	
Corrected reading	
Uncertainty	

Calculations

Calculate the density of the sphere using the equation for ρ_{sphere} on Page 1. Again, first convert all measurements to kilogram or meters, then calculate the density following the steps "symbols, numbers and result". Calculate the percentage discrepancy as you did in Problem 1.

Conclusions

State your result with the correct number of sig. figs. in a sentence. Check your conclusion as you did in Problem 1.

Questions (Answer them at the end of the report.)

1. Why did we have 4 significant digits for the density of the sphere but have only 3 significant digits for the density of the cylinder?

2. Is it possible, with all the equipment in this lab, to measure the density of the cylinder also to 4 significant digits? Why or why not? (Hint: our micrometer can only measure up to 25 mm.)