SMS-204, 2016: Integrative marine sciences, physics. Lab 1

Knowledge: mass, volume, and density; no-slip condition; sinking in a highly viscous fluid.

Skills: basic statistics, propagation of uncertainty, graphing data.

The lab is performed in groups of 3-4 students. Choose a name for your group. By the end of the lab you will take a quiz (as individuals first and then as a group) to assess your understanding of the class and lab exercises. The quiz may result in your group all getting a pizza dinner.

Station 1: Density rods.

In this station you have 8 rods.

Measure the mass of each, and estimate the uncertainty of the mass (see Appendix). Measure the diameter and length of each rod and their uncertainties (See Appendix).

Rod #	1	2	3	4	5	6	7	8
mass								
length								
diameter								

Uncertainty in measuring length or diameter _______

Uncertainty in measuring mass_________

Discuss with your group and agree on how you would compute the uncertainty in the volume of the rods and the uncertainty in their density (you will need to do it for your homework). To do it you will need to **propagate** the uncertainties (see appendix).

Be sure to enter your data in the class data spreadsheet + uncertainties. You will need them to complete the homework.

Station 2: No slip condition

You are about to turn on a rotating table over which a tank full of water is set.

a. What do you expect will happen to the water in the tank as it starts rotating? Will the water rotate as well? Will there be a difference between fluid right next to the boundary vs. in the center of the tank?

b. Put some sawdust or dye next to the rim of the tank and some further towards the center. Start the rotation of the tank and observe the motion. How would you explain it? How is it related to the no-slip condition?

c. You will soon stop the tanks rotation. What do you expect will happen in the fluid when you do it?

d. Stop the tank's rotation and watch the sawdust to investigate the fluid's response.

Station 3: Sinking in a viscous fluid

Measure the mass and diameters of 5 different size beads. Then measure their sinking speeds in Glycerin using a stopwatch and a ruler. Measure the sinking speed three times to establish some confidence in the sinking speeds you are getting (You will need it for the homework). Start measuring after the beads have attained a constant settling speed (denoted by a tape). Make sure to put units into the table below. Note the uncertainties in mass, distance and time and add them to the table below. Discuss within your group the balance of the forces acting on the bead when it reaches constant settling velocity. Why does it keep sinking and why doesn't it sink faster with time?

Distance bead falls each time__________ (remember: sinking speed=distance/time)

Bead Size	Bead diameter	Bead Mass	Sinking time (1)	Sinking time (2)	Sinking time (3)	Sinking speed (1)	Sinking speed (2)	Sinking speed (3)
Size 1								
Size 2								
Size 3								
Size 4								
Size 5								

Uncertainty in measurements: diameter_______ mass_______ time_________

Copy the data from this table to the laptop in the lab. I will aggregate the data so that you can use them in your homework. Use the data collected at station 1 and 3 (including the data from other groups that will be posted shortly on the WWW) in the homework assignment.

Station 4: Densities of oceanic and continental crust.

a. Determine the densities of the two rock samples (basalt and granite) with the materials provided to you. How do they compare?

b. The average elevation of land *above* sea level is 875m (average density of rocks is about 2.8g cm^{-3}). The average depth of the ocean floor is 3795m *below* sea level and water density is about 1.02g cm^{-3}. Given that, which crust (oceanic or continental) would you expect to be denser? Is it consistent with what you found?

Appendix:

Uncertainties of a measurement:

Any time something is measured there is an uncertainty in the measurement. The degree of uncertainty depends on the precision of the measuring device and the measuring technique. A general rule for estimating the uncertainty in measuring devices is to report the uncertainty as one half the smallest unit the device can resolve. For example, if the smallest mark on a ruler is 1 millimeter, we estimate the uncertainty as 0.5 mm. However the uncertainty in measurement technique must also be considered. For example, if you use a foot long ruler (marked with mm) to measure the length of a car, do you really think you can claim the measurement is accurate to 0.5 mm? Another example is measuring time by clicking a stop watch – just because the watch reports 0.01 seconds, it is doubtful any human can operate the watch that precisely, so a larger uncertainty should be reported.

This uncertainty provides the precision of the measurement. We assume that the measurements are unbiased, that is, that our measuring devices are accurate. Our only assurance that this assumption is true is that the scale and meter that we use are regularly calibrated.

Uncertainties in multiple *independent* measurements of the same quantity:
Each measurement (*e.g.,* of settling velocity) has uncertainty (*e.g.,* due to the precision of the stopwatch and length-measuring device) that is most often smaller than the uncertainty of the group of measurements (due to variability in measurement techniques between different individuals and between groups). These sources of variability are separated in analysis of variance into errors within and among groups and can be nested to any arbitrary degree (*e.g.*, multiple observations by a single individual within a group are pooled to produce the group's measurements, which in turn are pooled to produce the class' measurements). In a normal distribution, spread is quantified by the standard deviation; 68 % of data lie within one standard deviation from the mean; 95.5 % of the lie within 2 standard deviations. Uncertainty of the estimate of the mean is reduced by a factor of $1/\sqrt{n}$ by making *n independent* measurements. This outcome reflects the way that *n* independent measurements increase confidence in the outcome. Notice that when *n* = 2 a few more replicates decrease uncertainty a lot, whereas once you reach about 20 or so replicates, it takes a good many more replicates to improve matters much further. While the standard deviation of a measurement does not necessarily change as we add more measurements, the standard error of the mean equals the standard deviation divided by $\sqrt{n}$.

Uncertainty in a derived quantity (propagation of uncertainty):

We often need to combine measurements to calculate a new quantity. For example to get the volume of a box we need to multiply the length, width and height of the box. Because each measurement has an associated uncertainty, we must find a way to combine the uncertainties to calculate the total uncertainty for the new quantity (for example the uncertainty in the box volume). The rules for combining or "propagating" uncertainties can be derived from the chain rule in differentiation or see it in Taylor J., 1997, *An Introduction to Error Analysis,* 2nd, Ed., University Science Books, Herndon, VA.

In the following equations x and y represent two independent measurements, each with an associated uncertainty denoted by dx and dy. The calculated quantity is represented by z, and **the calculated uncertainty associated with z is denoted by dz**.

If the x and y variables are added or subtracted to calculate z, the uncertainty in z (called dz) is found as follows:

If z = x + y or z = x-y then the uncertainty in z is $dz = \sqrt{(dx)^2 + (dy)^2}$

If the x and y variables are multiplied or divided to calculate z, then the uncertainty in z is found as follows:

If z = x*y or z=x/y then the uncertainty in z is $dz = z\sqrt{\left(\frac{dx}{x}\right)^2 + \left(\frac{dy}{y}\right)^2}$

Example 1: From measurements of Length, Width and Height of a box (say, L+/-dL, W+/-dW, H+/-dH) we would like to compute the volume of the box and the uncertainty of the volume (called dVolume). The following formulas may be used:

$$Volume = L \cdot W \cdot H \rightarrow$$

$$\rightarrow dVolume = Volume\sqrt{\left(\frac{dL}{L}\right)^2 + \left(\frac{dW}{W}\right)^2 + \left(\frac{dH}{H}\right)^2}$$

Example 2: If a round or circular object is measured, the uncertainty in radius is used multiple times. For example the volume of a sphere is 4/3(pi) R^3, so the uncertainty in volume would be

$$\rightarrow dVolume = Volume\sqrt{\left(\frac{dR}{R}\right)^2 + \left(\frac{dR}{R}\right)^2 + \left(\frac{dR}{R}\right)^2}$$

Example 3: Sometime multiple steps are required, with uncertainties calculated at each step. For example, suppose we want the density of a box. Density is mass divided by volume, so if we have the uncertainty in the mass measurement as well as the calculated uncertainty in volume we can calculate the uncertainty in density (denoted by d_density):

$$density = \frac{Mass}{Volume} \rightarrow d\_denstiy = density\sqrt{\left(\frac{dMass}{Mass}\right)^2 + \left(\frac{dVolume}{Volume}\right)^2}$$

