INTRODUCTION:
In this lab you will study, experimentally, how the uncertainty in more than one measured quantity leads to an uncertainty in all other quantities calculated from them. You will measure the dimensions of a number of metal cylinders, calculate their volume, and then use Archimedes' Principle to measure their volume.

Notice that you will be called upon to write your own Introduction to this lab in your lab notebook. Like the Introduction above, it should describe what you are about to do and explain why you are doing it. You should not simply restate what I've just written -- even if you paraphrase it. And you should certainly never, ever use the words of the lab instructions without quoting them, nor the ideas of the lab instructions without properly citing them.

BEFORE LAB:
1. Write your introduction. You should include information about Archimedes principle.

THEORY:
Consider a simple metal block or cylinder with tiny holes for being suspended by a fine wire. Measure its dimensions in centimeters, using Vernier calipers. Your instructor can help show you how to use them.

Notice that there are at least two potential sources of uncertainty or error here for each dimension:

1. First, you can never measure any dimension of this object exactly. If your measuring instrument measures to the nearest 0.1mm, it is unlikely that the object is exactly some multiple of 0.1mm, and so your measurement is at best an estimate to the nearest 0.1mm. You would expect that if you kept measuring the same dimension of the object that you would always get the
Measurement Uncertainty

same measurement, but you would never obtain a more precise idea of its length however long you continued to measure. In this example, you can use 0.1mm for your uncertainty.

2. Second, the actual physical object may not be a perfect block or cylinder: its diameter or width, for example, may vary along the length, just as the Earth’s circumference about its poles is different than its circumference around the Equator. So each time you measure your object’s diameter or width, you might get a different value. It would make sense to measure its value several times along the different lengths of the object, and then calculate the mean and standard deviation of your measurements. In this case, the uncertainty is the standard deviation of your measurements, as long as it is greater than the resolution of your measuring device. (0.1mm in the example of the last paragraph) For a fine enough measuring stick, increasing the precision of the measuring stick should not decrease this kind of uncertainty/error. Right?

THE EXPERIMENT:
Measure the dimensions of your object, taking enough measurements to allow you to calculate the uncertainty. Have your lab partner repeat the measurements. Copy your raw data into each other’s notebooks. Once you know the dimensions, calculate the volume. Repeat this for all the metal pieces the instructor asks you to measure. This should include at least one “normal” cylinder and one irregular one.

What do we do with these individual uncertainties? Well, we can calculate the uncertainty of the volume. We will do this three ways:

1. The theoretical approach: Use the formulas in the text to calculate what the uncertainty of the volume is, given the uncertainties in each of the variables.

2. The "empirical" approach: What if the length of your object is closer to the high end of the range defined by your uncertainty? Calculate the
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volume of your object using every possible combination of extreme values for each dimension of the object \((d \pm \delta d, h \pm \delta h)\). From your results, record the maximum and minimum values for the volume.

3. The experimental approach: When you are done, use Archimedes’ method to measure the volume, directly measuring the buoyant “force” on the object to the nearest 0.1g. DO NOT USE GLASS BEAKERS! (Consider how this might be done with the equipment available in the laboratory.) Notice that a buoyant “force” of 3.0g means that 3.0g of water, equal to 3.0cc, was displaced, for a volume of 3.0cm³. Compare to your calculations and uncertainty. Does the measured value fit within the “acceptance interval”?

SHARING YOUR RESULTS:
Show all your measurements and calculations in your lab notebook. Report your volume and its uncertainty, using the appropriate number of significant figures for each. Add some explanation as you go along -- in full sentences -- of what you did and what you conclude. This is not a formal report, but I will ask you to turn in your notebooks, so I can see what you did. Be sure to describe each type of measurement that you make with enough detail to enable a physics student in a class in California to repeat it.

The “Conclusion” part of your report should answer the following three things in paragraph form: (1) What did you do? (2) What were your results? (3) What does this tell you? It should be no longer than half a page, and can be as short as three sentences, if you manage to adequately do all three things.