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Phy 462

Introductory Measurement Procedures and Error Analysis

Introduction:

A measurement of any physical quantity is not complete unless the experimenter specifies his/her uncertainties in performing the measurement. Such error analysis is crucial to give the experimental results meaning, so that they can be compared with theoretical predictions or related measurements. Fortunately there are standardized procedures for estimating measurement uncertainties and propagating these errors through various calculations. In this introductory project for **Phy 462**, you will work on several exercises involving simple measurements and learn these error analysis procedures that will be important for the rest of the experiments you will perform in the lab this semester, as well as throughout your future scientific career!

This project should be possible to complete after the first few class periods. While working on these exercises, you will be reviewing the general procedure for maintaining a lab notebook, which should include sketches, descriptions, tables of data, calculations, plots, and a discussion of your results. Please see the course syllabus for more details about the lab notebooks. You will also review the use of the Origin plotting and analysis software that will be useful for many of the experiments you will perform throughout the semester. For this project you will submit your lab notebook only and will not be expected to turn in a separate lab report.

Required Reading: Read chapters 1-5, 8, and 10 of the Taylor error analysis textbook.

Exercises:

A. Measuring the density of a sheet of paper

In this exercise, you will measure the necessary quantities to compute the density of a sheet of printer paper and estimate the associated uncertainty, following the procedures detailed in the textbook.

1. List the quantities you will need to measure in order to compute the density.
2. Choose instruments for measuring each of these quantities and estimate the associated uncertainties.

3. Make the necessary measurements for a single sheet of paper and compute the density, along with your uncertainty in the density.
4. Can you devise another technique for obtaining the density of a single sheet of paper that would reduce the fractional uncertainty from your initial measurement? If so, describe this alternative technique in your notebook, record your measurements, and compute the density along with its uncertainty. Make sure to list any assumptions you must make in order for this approach to be successful.
5. Describe possible sources of systematic error in this measurement and discuss possible methods for quantifying and reducing these.

B. Measuring the radius of a sphere

For this exercise, you will measure the radius of a sphere by observing the volume displacement of water in a beaker.

1. Obtain a metal sphere (check with instructor or TA) and a large beaker with water.
2. Submerge the sphere in the water and record the change in water level – make sure to describe this measurement process in your notebook. Compute the corresponding volume displacement, along with the uncertainty.
3. Compute the radius of the sphere and the uncertainty of this quantity. Describe any assumptions you must make for this computation to work.
4. Repeat the measurement of the radius of this same sphere using a different beaker or graduated cylinder with a smaller diameter and more finely-spaced tick marks.
5. Compute the radius and uncertainty for this second measurement and compare the fractional uncertainty with that from the first measurement.
6. Describe possible sources of systematic error in this measurement and discuss possible methods for quantifying and reducing these.

C. Measuring capacitance with RC filter response

A divider circuit consisting of a resistor R and a capacitor C can be arranged to form a low-pass RC filter. Discuss this circuit with the instructor or TAs, then sketch the circuit and work out the relevant calculations in your notebook. A good reference here is the introductory chapter of “The Art of Electronics” by Horowitz & Hill.

1. Choose a signal generator and oscilloscope. Take the capacitor designated by the instructor along with four of the designated resistors, with values covering a range of at least one order of magnitude.
2. Measure the resistance for each of the resistors with a multimeter and record these values and their uncertainties.
3. Discuss the arrangement with the instructor for attaching the components for the filter circuit and measure its response for one of the resistors from your set.
4. Using the oscilloscope, observe the response of the circuit to a low-frequency sinusoidal drive – describe in your notebook how one chooses a "low" frequency for your circuit.
5. Increase the frequency of the drive signal while measuring the response on the oscilloscope. Determine the frequency corresponding to the 3 dB point, that is, the frequency where the magnitude of the response is reduced by $1/\sqrt{2}$. Report your uncertainty in this determination and discuss how you arrived at this value.
6. Repeat this measurement by assembling and measuring the filter circuit for each of the resistors in your set with the same capacitor.
7. Make a plot of your measured 3 dB frequencies for each resistor, including error bars, in such a way that a simple fit will allow you to determine the value of the capacitor. From this fit, compute the uncertainty in this value for C.
8. Describe possible sources of systematic error in this measurement and discuss possible methods for quantifying and reducing these.

D. Measuring a limiting distribution of a set of poker chips
In this exercise, you will use a box containing an ensemble of poker chips to explore the binomial distribution and its relationship to the Gaussian distribution. Read Chapter 10 and review Chapter 5 in Taylor before you begin these measurements.

1. Study the poker chip box and get a sense of how you will quantify the state of the poker chips, for example, number of chips with a particular color facing up.
2. Make a table to record the value you have chosen to quantify the configuration for many trials.

3. Shake the poker chip box 10 times, recording your configuration value for each trial.
4. Compute the fraction of your 10 measurement trials for each possible configuration and plot a histogram of this fraction vs. configuration value using Origin.
5. Choose three particular configuration values and for each one, compute the corresponding expected probability for the binomial distribution (see section 10.3 in Taylor). Compare these values with the corresponding points in your measured distribution.
6. Repeat the shaking procedure to collect data to combine with your initial measurements for a total of 100 trials.
7. Again plot a histogram of the measurement fraction vs. configuration value. Compare your previously computed points for the binomial distribution with the corresponding values in your measured distribution.
8. Compute the expected mean and standard deviation for this system and compare this with your measured distribution (see Taylor 10.4).
9. Make a plot with the histogram of your 100 trials, with the corresponding Gaussian distribution curve (same mean and standard deviation) superimposed. What would you expect if you were to make even more trials?