# PHYSICS 151L

**ORIENTATION**

The purpose of the physics laboratory is two fold. The primary aim is to give you the student an opportunity to see the principles that are studied in the lecture illustrated by simple experiments. A secondary purpose is for you to learn some elementary laboratory techniques and especially the proper way to write a lab report.

As this is a laboratory course, attendance for all experiments is expected. One make up period at the end of the semester is provided for an excused absence. Three or more unexcused absences will result in a failing grade.

Your laboratory reports are the principal criteria for determining your grade in the course. The instructor will explain his/her grading procedure and the features he/she considers important. In general, however, the emphasis is on correct use of your original data to obtain results consistent with this data, together with a presentation that is clear, complete, and concise.

The reports may be written on any type of paper but must be neatly written, printed in ink, or typed (which is highly suggested). Graphs must be submitted on graph paper. The reports are due at the beginning of the lab period one week following the performance of the experiment. Late reports will be marked down severely, as the instructor deems proper.

## Significant Figures

Almost every experiment involves recording and calculating numerical data. In working with these numbers, it is important to retain only **significant figures**. The measuring device will ordinarily dictate how many significant figures should be used. For example, with an ordinary meter stick, one can measure to with in 1 mm. A result of measurement should be recorded, then, as 0.327m not 0.3270m or 0.33m. This result contains three significant figures. For smaller objects, a result might give 0.088m, two significant figures, or 0.003m, one significant figure. The zeros used to locate the decimal point are not significant, but the zeros on the end of a number are, i.e. 0.080m has two significant figures. In any kind of measurement, judge all the factors affecting the accuracy of that measurement and record the data using the appropriate number of significant figures.

When adding and subtracting numbers, significant figures can be gained or lost.
Thus:

$$\begin{array}{r} 0.74\text{s} \\ +\ \underline{0.68\text{s}} \\ 1.42\text{s} \end{array}$$

The result has more significant figures than the original numbers. On the other hand,

$$\begin{array}{r} 0.74\text{s} \\ -\ \underline{0.68\text{s}} \\ 0.06\text{s} \end{array}$$

and a significant figure had been lost. To add 1.54cm (three significant figures) to 1.2cm (two significant figures), round off 1.54cm to 1.5cm and then add.

To multiply and divide and get a result with the proper number of significant figures, the rule is that the result must contain the same number of significant figures as in the original quantity which has the least number. Some examples are:

$$34.2\text{cm} \times 0.57\text{cm} = 19\text{cm}^2$$

57.0cm / 0.4820s = 119cm/s

and 25.3m x 37.42m x 0.2m = 2 x $10^2$ $m^3$

In the last example, the power of 10 notation was used because 200$m^3$ implies three significant figures.

**Treatment of Errors:**

Associated with the measurement of every physical quantity, there is an inherent uncertainty. This uncertainty may arise from any of several causes: non-uniformity in the quantity being measured (e.g., the surface not smooth, ends not square), lack of precision of the measuring instrument, etc. It is important that your learn to recognize uncertainties and treat them properly. Below is a brief discussion of some important techniques in estimation and working with errors or uncertainties.

In order to determine the uncertainty in a measurement, find the mean value of several determinations of the quantity. The formula for the mean value of N numbers $x_1$, $x_2$, ,$x_N$ is:

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots.. + x_N}{N}$$

To find the **numerical uncertainty**, which will be denoted "**s**", first find all the squared differences of the measurements from the mean, i.e. find $(\bar{x} - x_1)^2, (\bar{x} - x_2)^2$ , etc. Finally use these in the formula:

$$s = \sqrt{\frac{(\bar{x} - x_1)^2 + (\bar{x} - x_2)^2 + \ldots. + (\bar{x} - x_N)^2}{(N-1)}}$$

As an example, suppose four measurements of a length are: 2.1cm, 2.2cm, 2.0cm, 2.5cm. The mean is :

$$\bar{x} = \frac{2.1cm + 2.2cm + 2.0cm + 2.5cm}{4} = 2.2cm$$

and

$$s = \sqrt{\frac{(2.2cm - 2.1cm)^2 + (2.2cm - 2.2cm)^2 + (2.2cm - 2.0cm)^2 + (2.2cm - 2.5cm)^2}{4}} = 0.2cm$$

(Thus "s" = 0.187, but only one significent figure is taken, also called standard deviation from the mean)

To find the numerical uncertainty in a sum or difference of quantities, the following procedure, which comes from the theory of errors, is used. It is best explained by an example so suppose we want the value and numerical uncertainty for:

(2.2 ± 0.3)cm + (4.5 ± 0.4)cm

The value is:

2.2cm + 4.5cm = 6.7cm

The numerical uncertainty is given by:

$$s = \sqrt{(0.3cm)^2 + (0.4cm)^2} = 0.5cm$$

i.e. the square root of the sum of the squares of the numerical uncertainties is used. Thus, the final result of adding the numbers is:

(2.2 ± 0.3)cm + (4.5 ± 0.4)cm = (6.7 ± 0.5)cm

The formula for the numerical uncertainty in a subtraction is just the same. If more than two numbers are being added or subtracted, the numerical uncertainty in the result is the square root of the sum for the squares of all the individual numberical uncertainties.

To find the numerical uncertainty in a product or quotient, the fractional uncertainty, S, is needed. It is found by:

$$S = \frac{s}{x}$$

The fractional uncertainty in a product or a quotient is found as follows. Let:

$$F = x/y, \text{ (or } F = xy)$$

then

$$S_F = \sqrt{S_x^{\,2} + S_y^{\,2}}$$

Now subscripts have been added to show which quantity the uncertainty refers to. But knowing $S_F$, $s_F$ can be found from:

$$s_F = F \times S_F$$

Here is an example:

$$F = \frac{(4.7 \pm 0.3)m}{(0.74 \pm 0.05)s} = \frac{x}{y}$$

$$S_x = \frac{0.3}{4.7} = 0.06, \quad S_y = \frac{0.05}{0.74} = 0.07$$

$$S_F = \sqrt{(0.06)^2 + (0.07)^2} = 0.09$$

$$s_F = (6.4\text{m/s}) \times (0.09) = 0.6\text{m/s}$$

Finally:

$$F = (6.4 \pm 0.6)\text{m/s}$$

The one other rule you may need is that of a quantity raised to a power. Thus if:

$$F = x^3y$$

$$S_F = \sqrt{(3S_x)^2 + S_y^{\,2}}$$

i.e. the fractional uncertainty in " x " is multiplied by the exponent before squaring.

**Graphs:**

To present data in the form of a graph, attention must be paid to the following.

1) Choose a scale so that the graph is as large as possible but, of course, still fitting on the paper.
2) Label the abscissa (horizontal axis) and the ordinate (vertical axis) with

both a numerical scale and the proper units.

3) If a line is to be drawn through the data points, use your judgement to locate it as close to the points as possible. For a straight line, you may think of the points as small, equal weights which should be balanced above and below the line.

4) To compute a slope from such a line, take two points that lie far apart, i.e. near the ends of the line. The equation of a straight line is

$$y = mx + b$$

where "m" is the slope and "b" is the y-intercept. A sample illustrating these instructions is given below.