

Guide to minimize errors

General:

1. Always write (and read!) the procedure for the experiment you are supposed to do before you come to the laboratory. Draw a diagram/circuit diagram of the apparatus as it will help you to set up the experiment. If there is any data to be noted down only once, e.g., the least counts of apparatus, room temperature, (note these down first). You are likely to forget to do so at the end. Always record all observation with a pen, not a pencil and do not overwrite. If you have taken down a wrong reading, cross it out so that the original can still be seen and write the correct reading next to it.
2. In every experiment if possible, first carry it out once without recording anything. This gives you an idea of what are the difficulties you may have when you actually record observations.
3. Always try to complete all the calculations before you leave the lab, that way you will immediately know if you have forgotten to note down some essential observations.

Tables:

1. On instruments like spectrometers which have two scales, always record readings from both scales separately. Similarly when you measure temperature difference with two thermometers or any other difference with two "identical" instruments interchange them and record a second set

in the same table.

2. When calculating differences from a table use the method given below. Take an even number of readings and divide the table into two halves. Take the difference of the first reading of the first half and the first reading of the second half of the table. Then take the difference of the second reading of the first half and the second reading of the second half of the table. Proceed in this fashion down the table taking the difference of the corresponding readings from the two halves of the table.

Table 1: *

Example:		To	find	the	deflection/150	g.
S.No.	Weight in g.	Deflection in cm.	Deflection/150g (cm/g)			
1	w	65.2	—			
2	$w + 50$	65.4	—			
3	$w + 100$	65.6	—			
4	$w + 150$	65.7	$65.7 - 65.2 = 0.5$			
5	$w + 200$	66.0	$66.0 - 65.4 = 0.6$			
6	$w + 250$	66.2	$66.2 - 65.6 = 0.6$			
7	$w + 300$	66.4	Ignored for even no. of readings			

Never use any of the readings more than once, even if one of the values remains unused as above. This way any errors you may have made in recording a particular reading only affects one of the differences in the table.

Graphs:

1. As far as possible, choose the scale on the axis of any graph such that the least count of the graph paper is equal to the least count of the variable being plotted on that axis. Always write the proper units on the labels for each axis, and the proper units for the slope if you find it.
2. To calculate slopes there are two possibilities.

- (a) If the data falls on a straight line, make a table of differences as shown above and calculate the slope from the table.
- (b) If the data does not fall on a straight line, proceed as follows.

To calculate the slope at (x, y) , take the data from three points on either side of (x, y) , and form a table as given below. The slope at x, y is then

$x - 2.5h$	y_1	—	$- y_2 - y_1 = dy_1$ ——— $- y_4 - y_3 = dy$ ——— $- dy_2 - dy = d(dy_2)$	$- dy - dy_1 = d(dy_1)$ $- y_6 - y_5 = dy_2$ ———
$x - 1.5h$	y_2	—		
$x - 0.5h$	y_3	—		
x	y			
$x + 0.5h$	y_4	—		
$x + 1.5h$	y_5	—		
$x + 2.5h$	y_6	—		

equal to,

$$Slope(x, y) = [dy + \{dy_1 + d(dy_1)/2h\} + \{dy_2 - d(dy_2)/2h\}]/3h$$

The above formula follows from the usual definition of the derivative and Taylor series expansions about (x, y) .

If the data are not equally spaced about (x, y) then the two second derivative terms will not cancel but if h is comparable to the least count then no appreciable error is made in using this simple formula even in such a case.

Though it might appear from the above that every calculation can be done from a table. plotting a graph always shows you the general behavior of the data and should be done. When doing so, the curve need not pass through all the data points but (must be smooth and as close as possible a fit) to all of them.

To draw such a curve, take a piece of transparent plastic tube, of the type used in room coolers, or a strip of transparent plastic 1" * 12" of the type used for covering books or making overhead transparencies. Bend this strip on your graph paper (it must be stiff) so that it passes close to the data points. Hold it in position and use it as a guide to draw the curve.

Results:

Calculate and report the error in your results, as will be described in detail below, the three most commonly used measures are,

1. Probable error
2. Maximum possible error or instrumental error.
3. Percentage error or deviation from the standard value.

The last need not be reported, as the conditions of your experiment are not the same as those under which standard values are measured. You can however mention the standard value if you know it.

If you have more than five independent observations always calculate the probable error otherwise use the maximum possible error.

An example of how to report your results. If you measured the coefficient of linear expansion of copper to be $0.00001856/\text{K}$ with a maximum possible error of $0.000002365/\text{K}$ then write the answer as,

Coefficient of Linear expansion of Copper = $(1.86 + 0.24) * 10^{-5}/\text{K}$

the standard value at room temperature is = $1.66 * 10^{-5}/\text{K}$.

While calculating results, retain all the significant figure in the result is comparable to the most significant figure in the error.

Errors:

As mentioned above, errors can be of many kinds and a brief description follows. First of all there are the so called systematic errors, e.g. personal ones like parallax in observing meter readings, or instrumental ones like backlash or wrong marking of the scale. Please avoid these errors while taking down your readings.

Apart from these however the fact that every instrument has finite accuracy (a finite least count) means that if you take several observations very carefully they will still not give you identical results,. If your observations are good then the results of each set will be distributed randomly about a mean value which is the true result.

To characterize this spread in the results due to the finite least count of the apparatus we use two kinds of error measurements:

1. Maximum Possible Error

2. Probable error.

Maximum Possible Error:

Consider the measurement of the density of a solid cube of Mass M and side L . Then the density is,

$$D = \left(\frac{M}{L^3}\right) \tag{1}$$

However any measurement of mass M or weight can only be performed to an accuracy dM , the least count of the balance used. Similarly, lengths L can be measured to within the accuracy dL of the measuring rod used. To calculate the inherent (instrumental error) due to the least counts of the measuring instruments we start by taking logs on both sides followed by differentiation:

$$\frac{\Delta D}{D} = \frac{\Delta M}{M} + 3\frac{\Delta L}{L}. \tag{2}$$

As the errors is general can be positive or negative, to find the maximum error, we must take the absolute magnitudes of all the derivatives involved and add them. The corresponding fractional error is referred to as the (maximum possible error or instrumental error). This formula is also sometimes referred to as the log error. This error must always be calculated and the result written down as,

$$Density = D \pm \Delta D \tag{3}$$

Note that in this method, if the difference or sum of two experimental quantities appears in a formula, then the error doubles. For example, the heat transferred per unit time Q across a sample by conduction is proportional to the temperature difference $(T_1 - T_2)$ across it. $Q = S(T_1 - T_2)$. The maximum possible error in this case is:

$$\frac{dQ}{Q} = \frac{dS}{S} + \frac{2dT}{(T_1 - T_2)} \tag{4}$$

Apart from such inherent instrumental errors, there are the random individual errors that you make in taking down each reading. To deal with these, we use the concept of probable error.

Probable error:

You are probably aware from courses on probability theory that under very general assumptions, any long sequence of independent observations of a variable x will be found to follow a Gaussian or normal distribution,

$$p(x)dx = (1/2S)\exp[-(x - \bar{x})^2/2S]dx. \quad (5)$$

Here $p(x)$ is the probability that the observation lies in an interval dx about the value x . Then as can be easily seen,

$$\text{The mean} = \bar{x} = \int xp(x)dx \quad (6)$$

$$\text{and standard deviation} = S = \left\{ \int (x - \bar{x})^2 xp(x)dx \right\}^{1/2} \quad (7)$$

The quantity S is a measure of how spread out your observations are about x and thus a measure of "goodness" or otherwise of the readings. It is referred to as the (probable error).

The formula as given above is impractical as it requires an infinite number of observations to evaluate the integrations. When only a finite number, n of observations is made, we replace the integrals by summations to obtain,

$$\bar{x} = (1/n) \sum_j x_j, \quad (8)$$

$$S = (1/n) \sum_j (x_j - \bar{x})^2. \quad (9)$$

This quantity must always be calculated and reported when the number of observations is large (> 4). The result then is reported as,

$$\text{Result} = x \quad \pm dx \quad \pm (S) \quad (10)$$

instrumental error probable error

Note that the two errors are not to be summed.

Problems:

1. Student in a class get the following marks out of 50, 36.5, 30, 20, 32, 29, 36.5, 26.5, 22, 32.5, 22, 29.5, 18.

Find the mean mark and the standard deviation after normalizing the total to 100. Plot a gaussian with the same mean and deviation along with the data given above on a graph.

Parallax Removing:

For optics experiments (in this lab for the Fresnel's Biprism experiment) another important error introducing factor is parallax- so for such experiments, we have to learn how to remove parallax.

In all cases of optical measurements where an accurate determination of the position of an image is sought for, we take recourse to the method of parallax.

Let P_1 represent a line drawn on transparent screen and P_2 , the image of a linear object. Both P_1 and P_2 stand perpendicular to the plane of paper. An eye placed in the position E behind the screen sees both the line coincident. As the observer moves his eyes to the position E_1 and E_2 , a relative motion occurs between P_1 and P_2 . The same relative motion takes place when the image is formed between P_1 and the eye. this relative motion ceases only when P_1 and P_2 coincide. This method of finding the position of an image by making it coincide with a reference line and point is known as the method of parallax.

In order to ascertain, during adjustment, whether the image is formed in front of or behind the screen, move your eyes across the line joining P_1 and P_2 . If the image moves in the same direction as the eye (with respect of P_1 the reference line), then the image is further away from the eye than the screen. If the image moves in the opposite direction, then it is nearer to the eye than the screen.

To avoid parallax, either the screen or the lens or the mirror forming the image or the object itself is slowly displaced until there is no parallax between the image and the reference line.

Using the balance:

1. Look at the plumb-line and make sure, that the balance is level. If necessary, level it by turning the leveling screw at the base or ask for help.
2. Determine the 'zero point', i.e. the equilibrium position of the pointer when passed are empty.
3. Place body to be weighed on left-hand pan and weights systematically, only when the beam is in the arrested position and then release the beam and check.

4. By trial put enough weight on right pan so that the new position of the pointer appears to lie within 5 pointer to the right of zero point. Allow the beam to oscillate and take readings of 3 to 5 successive turning points. Call it Q.
5. Add 10 mgm weight to right-hand pan and find corresponding rest-position call it R. Record the data as follows:

Load on left-pan	Load on right pan	Turning points		Mean		Zero point	Rest positions
		Left	Right	Left	Right		
Nil	Nil	a) 4.9 b) 5.3 c) 5.6	a) 15.1 b) 14.8	5.2	15.0	10.2 (P)	
Body	15.23 g	a) 10.1 b) 10.5 c) 10.8	a) 20.4 b) 20.1	10.5	20.3		15.4(Q)
Body		a) 3.8 b) 3.4 c) 3.1	a) 9.6 b) 9.5	3.4	9.7		6.6(R)

Mass of body:

$W = 15.23$ is smaller than that of body by an amount which causes displacement of pointer = $15.4 - 10.2 = 5.2$ div. Now, causes displacement of 5.2 div would be caused by $5.2/8.8 * 10mgm = 5.9mgm = 0.0059gm$. Therefore mass of body = $15.23 + 0.0059 = 15.2359$.