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Physics Laboratory Report Writing Guide
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Acknowledgment

Chapter 1 Introduction

Experimental work is a fundamental part of science as it provides a way of verifying and disproving theories. Obviously enough the work is bound to be undergone at B.Sc. is unlikely to be anything close to frontier experimentation. However, it is not as elementary as it might seem. For example, even with modern day technology, the best way to determine the acceleration due to gravity involves the use of a pendulum. In addition this work should provide the bases of how to go about when involved in the practical field and as thus it should not be underestimated.

An experiment usually involves, setting out an objective, establish a valid procedure of how to go about achieving it, performing the experiment and getting the results, interpreting the outcome and finally presenting the work undergone. The first criteria needs to be set and there is nothing much to be said about it. It is with the second that the real work starts.

Factually the main procedure that needs to be followed to reach the objective will be given (at least in the first two years). However this is usually only the skeleton on which to build the work. Each and every setup is bound to have errors that need to be identified and counteracted for by adequate precautions. The validity of the results of an experiment depends on how well such errors have been addressed.

There is no standard method that can be used to determine all the sources of errors that can be encountered. A general guide line together with a list of the most frequent problems that might be encountered will be given in Chapter 3. However it will be up to the student to develop the observational and analytical skills that are required to accomplish such a job.

The next stage, performing the experiment and getting the results, is a rather mechanical step. Nothing the less, it needs to be conducted with care since the outcome is indicative of the validity of the procedure that has been adopted to remove the errors present in the system. Apart from this it is expected that additional precautions are taken so as not to damage the apparatus or harm any person.

The results obtained in the last step will then have to be interpreted. Some of the conclusions, such as whether the results were close enough to those expected, would follow immediately. However others, like the reasons for obtaining the wrong values, are not of simple solution. This is where student's analytical capabilities will be put to the test. Once again there is no general procedure that can be followed. It is left to the experimenter to decide on the most likely source of error and what should have been done to overcome it.

The final step deals with the presentation of the work. This stage should not be underestimated since one's discoveries would not be of any factual relevance if he is not capable to communicate them to others. Such a thing needs to be accomplished using the appropriate format, which is bound to vary in accordance with the situation. Thus the layout requested in the first and second year practicals will be slightly different from the one been using in A-Levels. However, already by the third year it will become obvious that such a report design would not be suited for the type of experimentation

to be performed and it will be left up to the individual to make the necessary modifications. Hopefully, further on, there will be the need of writing scientific papers that would require still another format. Each and every one of these types of report designs has its reasons to be, and none of them is to be considered superior, only better fitted for the particular situation.

Even though the format may change the essence of what needs to be included will not. Thus although the layout provided in this work is mainly concerned with the reports that are being expected in the first two years it is also intended to give useful indications of what might be expected when requested a statement of what has been accomplished.

The final word goes to the structure of the practical sessions through the years. The first year experiments will not be much more complex than those covered at A-level. However, a substantial emphasis will be made on the actual procedural methods that are adopted, which will be indicative of one's capability of understanding the theory involved, and identifying the error and using adequate precautions to account for them; the individual observational and analytical skills; and the ability to communicate the work done and the conjectures might have been evolved. The last point is especially important as the report will be the main mode of assessment: Even though there is a laboratory demonstrator in the laboratories, it is unlikely that he will manage to keep up with everything that is going on. Thus it is up to you to say what has been accomplished, emphasising in particular what has been done over and above that expected. Learning to have pride in your work and promote it in the eyes of those around you is an important part of your academic development, which you are bound to find extremely useful in theses and paper writing and post university employment. In this respect, you have to keep in mind that those who are reading your reports, might not be in tune with your line of thought. Thus it is important to explain in the most clear and simple way the concepts that you want to express and this needs to be achieved using a good standard of English, which will be expected.

In the second year the complexity of the experiments will increase and even more stress will be given to the issues mentioned above. As for the third year, this is intended to give a real life experience of what is involved in the practical work. Here only the objective and the apparatus will be provided but no guidelines on how to proceed. Experiments will be open-ended and in the main substantial freedom will be given to the individual to decide what particular feature he is to investigate. In addition this year is designed to expose the student to alternative method in which experiments can be conduced such as programming computers so that they can perform the mechanical work. In this respect it is recommended that students should take the optional credits in programming indicated so that they will have the necessary background.

Chapter 2 General overview of the report layout

2.1 The general laboratory report layout

The laboratory report to be produced in the first two years should include the following sections:

1) Date and experiment name and number.
2) Name and Surname.
3) Instrumentation
4) Sources of errors and precautions.
5) Diagrams (if applicable)
6) Data Collection and Tabulation.
7) Graphical representation of the data.
8) Calculations.
9) Calculation of errors.
10) Brief discussion.

There will be no need to state the experimental procedure adopted as this will have already been given in the sheets provided. Likewise, repetition of the precautions indicated is not expected. In fact, the report should be concise and to the point including only the relevant details. Thus, there will be no need to indulge in extensive essay writing and a point form format should be adopted every where except in the discussion.

The following sections include the relevant definitions, modes of quantifying errors, and the formats and conventions that are usually employed when writing a scientific report. The detailed procedures of how these should be utilized will be given in Chapter 2.

2.2 Classification and handling of errors

Experimental errors are bound to occur while doing each and every physical measurement. This would limit the validity of an experiment and for this reason they need to be identified and removed or at least limited whenever possible. Since it is unlikely that all the errors are done away with, it will be necessary to find a way of quantifying them so as to determine a range where the correct value can reside. In order to decide the best approach it is convenient to divide experimental error into two main categories, systematic and random errors.

2.2.1 Systematic measurement errors

Systematic measurement errors consist of a shift from the true value of the readings. It is caused by a bias in the system that will not allow the correct value to be determined no matter how many times the experiment is repeated (*see* Figure 2.1).

Example 1: A metre ruler has been fabricated with a length of 98 cm. Each reading will be 2% less than the correct value.

Example 2: When measuring the speed of a trolley, the distance between the light gates used to determine the time of travel is set to 47 cm instead of 50 cm.

Systematic errors can be prevented by checking the apparatus and the setup. However, it is not simple to determine their presence as long as the apparatus and setup are not confronted with analogous ones. For this reason it would be advisable to make measurements in different ways.

Types of origin of the systematic measurement errors.

Apparatus: This is caused when the apparatus does not conform to the ideal conditions. Example: if a retort stand wobbles it could move during the experiment causing a bias.

Method: This is caused when the method used is not what it is meant to be. Example: if the oscillations of a simple pendulum are not small and planar then the conditions set by the derivation of the equation would not be satisfied.

Measuring instruments: These might not give the correct reading because:
- They were not perfectly calibrated. For this reason ideally they should checked with a known standard.
- They interfere with the measurement being made. For example the heat capacity of the thermometer that is being employed can alter the temperature being read.
- They do not start from zero causing what is called the *scale zero error*.

(a)   (b)
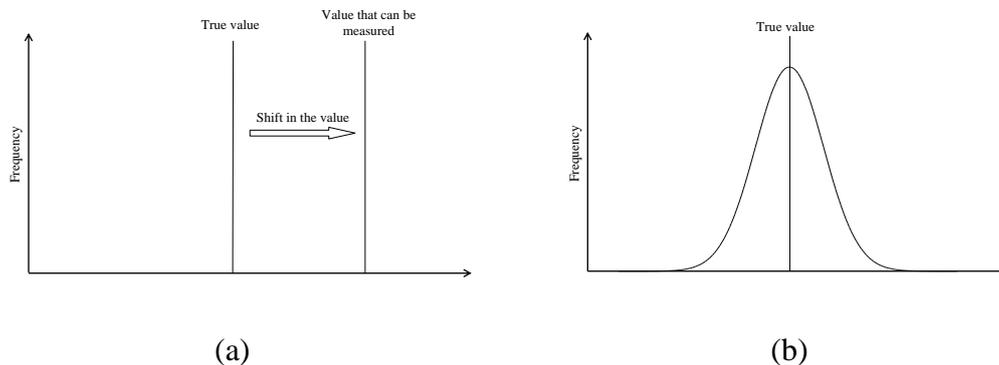
Figure 2.1 (a) show how a systematic error would act: it would shift its value to a new location; (b) shows what is meant by random error: there is a probability associated with the measurement of each value.

Personal: These are caused by the experimenter when he does not do the things properly. Example: reading a meniscus incorrectly. Obviously enough if the experimenter notices that he has committed such an error he is expected to repeat the procedure.

2.2.2 Random measurement errors

When taking a measurement it is unlikely that the true or exact value will result. This is caused by unpredictable fluctuations in the system that will introduce what are known as random measurement errors. In this way the value read can be either too high or too low. Thus it is possible to reduce them by taking the average of a large number of observations.

Random errors usually (but not always) have a normal (Gaussian) distribution, which for a variable x would take the form,

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2} \right],$$ (1)

with μ being the mean and σ^2 the variance. Taking a measurement is equivalent to sampling from such a distribution, with the true value being its mean (Figure 2.1). For this reason it is possible to analyze these kind of errors statistically, a topic that will be dealt with in Section 2.2.5.

Types of origin of the random measurement errors.

Accidental: This is due to the inability of the set up to stabilize environmental condition. Examples include variation in draughts intensity and temperature fluctuations.

Personal: This is caused by a limit in observational capabilities of the experimenter. An example would be parallax error when reading a scale.

Variation in quantities being measured: Such an error results due to the difficulty in obtaining and retaining uniformity in the objects being employed. An example would be the variation of the diameter of a wire along its length.

Scale rounding-of error: Any scale is accurate only up to a certain number of significant figures or decimal places. Thus any reading involves the rounding (i.e. rounding up or down) of the values. However such an error is often negligible when compared to others and as thus it should only be acknowledged if other sources of error are much less. An example would be provided by the case where all the readings were being taken using a micrometer screw gauge (that has a least count of 10^{-5} m) except for one that is taken using a metre ruler (that has a least count of 10^{-3} m). In such a case the error in the metre ruler will be much more significant than those of the others, a fact that should be pointed out.

2.2.3 Comparison between systematic and random measurement errors

In order to facilitate the discrimination between systematic and random errors the main differences between them are listed below:

Systematic Errors

- Consist of a constant bias in the system.

- They are repeatable, i.e. averaging over repeated readings will not reduce them.

- They can only be contained by setting up the apparatus carefully, accurate calibration of the instrumentation and cross-comparison with known values.

- It is difficult to study them statistically.

Random Errors

- Consist of varying fluctuations in the system.

- They are not repeatable, i.e. they can be both higher and lower than the true value.

- They can be contained by averaging repeating readings.

- Can be studied statistically.
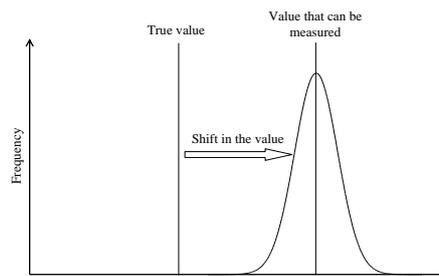
Figure 2.2 The error in every measurement is a combination systematic and random errors.

It is also important to mention that in an actual measurement it is not possible to isolate the systematic and random error. They would combine together to give a final error as illustrated in Figure 2.2.

2.2.4 The uncertainty in a single measurement

Some important definitions

The *absolute error* is the difference between the true and the measured value.

The *uncertainty*, *deviation* or *error* represent the variation in measured data. Numerically they give an interval about the value measured inside which the true value should reside.

The *least count* is the smallest scale division that is marked on the instrument. Example for a meter ruler the least count is 1 mm.

The *readability* refers to the precision with which a scale can be read.

The *readability interval* is the rounding off value used when taking a measurement. It is always equal to or smaller than the least count.

The *readability error* is the uncertainty associated with the readability of the instrument. This should be less or equal to the readability interval.

Each value that is to be adopted is correct up to some uncertainty, without which the quantity is meaningless. In general, for direct readings, students are instructed to quote the *least count* of an instrument (i.e. the smallest size of a division on the scale) as the error in the measurement. Factually such a quantity is only part of the uncertainty in a single measurement and it should be corrected for various factors including:

-   Intrinsic tolerances in the instrument that might vary along the scale. For example a digital meter might have a tolerance of 3% between 0 and 100 and 2% between 100 and 1000. Thus the least count should be multiplied by 1.03 if the reading is between 0 and 100 and 1.02 if it is between 100 and 1000.

-   Temperature fluctuations. For example, a metre ruler will extent itself if it is not under its standard conditions. Thus the least count should be adjusted accordingly. Factually the measurement taken with the metre ruler should also be corrected for such an event. However, temperature changes might not affect only dimensions but also the measurement of electronic devices.

-   Calibration tolerances. Calibration of an instrument will leave the device calibrated only up to some tolerance.

-   Variation in gravity.

However for your B.Sc. practicals the student will not be requested to take into account such corrections but only to quote the uncertainty associated with the reading from the instrument. In this respect the student should be aware of some issues. The first is that that the least count is not the only way of defining the rounding off value used when taking a measurement, which can be referred to as the *readability*. For example, when using a metre ruler frequently it is possibility to decide whether the border of the object resides closer to a scale division or to the centre. In this way it is possible to define the readability interval of the metre ruler as 0.5 mm. Such considerations apply to many other situations and for this reason it will be left up to the experimenter to decide on the readability of the instrument. The only requirement set is that the chosen values should be reasonable and that they are clearly stated before the commencement of the tabulation of the data.

A point that is linked with the readability is the error associated with it. In such a case one might easily be tempted to quote the value of the readability error as being equal to that of the readability. However, others might argue that the uncertainty given by the readability is symmetrically distributed about the value being taken and for this reason the readability error would become half the readability interval. Since there is no universally accepted convention it is once again left to the experimenter to decide on

the best value of the readability error, again with the proviso that the chosen value is reasonable and that it is clearly stated with the readability interval.

Another thing that should be borne in mind is that each measurement is being taken with respect to some datum or zero reference, from which the difference is being calculated. In this way the total error associated with one single measurement will end up being twice the readability error (*see* Section 2.2.6). This applies for any instrument and should be clearly shown in the report. The only time when it will be accepted that the error associated with a reading is equal to the readability error occurs when the zero reference will be subtracted at a later instant. For example this would be the case in an elastic modulus experiment when the unloaded reference point is not initially set to zero or when an instrument is offset. Here it is understood that subsequent to the readings the measurement will be calculated by subtracting the original height or offset. Note that in such cases the values read need to be provided and the full working shown.

2.2.5 The uncertainty in repeated readings of the same measurement

As mentioned in Section 2.2.2 taking measurements is equivalent to sampling from some distribution. This is usually the normal distribution or can be approximated by it. Thus it is possible to apply hypothesis testing in order to obtain confidence intervals for the uncertainty. A full analysis of such a subject would be too extensive to be covered here and it is way out of the intent of this work. For this reason only an outline of the methods used will be provided. The reader can refer to standard text books like Freund *et al*. (1999) for a more comprehensive review.

A theorem in sampling statistics gives that if $\overline{X}$ and s^2 are the mean and the variance of a random sample, X_i, of size n,

$$\overline{X} = \frac{1}{n}\left(X_1 + X_2 + \ldots X_n\right) = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{2}$$

$$\text{and } s^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2 = \frac{n}{n-1}\left[\frac{1}{n}\sum_{i=1}^{n} X_i^2 - \left(\frac{1}{n}\sum_{i=1}^{n} X_i\right)^2\right], \tag{3}$$

(where Σ, Greek *S*, is the symbol used for summation) from a normal population with mean μ and variance σ^2, then the statistic,

$$T = \frac{\overline{X} - \mu}{s/\sqrt{n}}, \tag{4}$$

has the *t* distributions with $n-1$ degrees of freedom. Using this sample distribution it is possible to define an interval about the measured value where we can be $1-\alpha$ confident that the true value will reside. Since the difference between of the sample

mean, $\overline{X}$, and the population mean can both be greater or smaller than zero, a two tailed test is required (*see* Figure 2.3). In statistic notation this can be written as,

$$P\left(\left|\frac{\overline{X}-\mu}{s/\sqrt{n}}\right|<t_{0.5\alpha,n-1}\right)=1-\alpha, \tag{5}$$

where the subscript 0.5α implies a two tail test and $n-1$ refers to the number of degrees of freedom. Now rearranging gives,

$$P\left(\overline{X}-t_{0.5\alpha,n-1}\frac{s}{\sqrt{n}}<\mu<\overline{X}+t_{0.5\alpha,n-1}\frac{s}{\sqrt{n}}\right)=1-\alpha. \tag{6}$$

Thus μ is to be found in the range $\overline{X}\pm t_{0.5\alpha,n-1}\,s/\sqrt{n}$, which provides an uncertainty of $\pm t_{0.5\alpha,n-1}\,s/\sqrt{n}$. The problem is that s might be zero in the case that all the values are the same. However an uncertainty $\delta(X_i)$ would still be associated with each reading. For this reason it will be convenient to use the equation,

$$\overline{X}\pm t_{0.5\alpha,n-1}\frac{\delta(X_i)}{\sqrt{n}}, \tag{7}$$

to calculate the uncertainty.
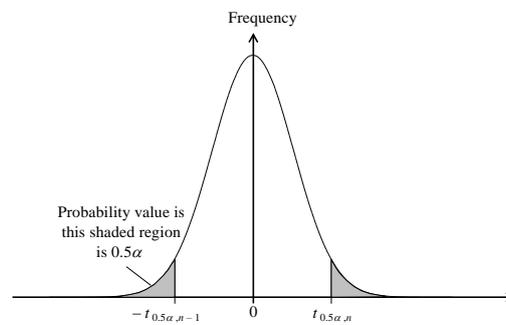
Figure 2.3 Schematic plot of the t distribution. It is desired to find $t_{0.5\alpha,n-1}$ such that it is ensured that the mean of the population resides in the interval, $\left[\overline{X}-t_{0.5\alpha,n-1},\overline{X}-t_{0.5\alpha,n-1}\right]$. This is done by determining the value of t above and below which the area under the graph is 0.5α.

Usually the confidence interval is quoted as a percentage, $(1-\alpha)100\%$, and it is customary to take the 95% confidence interval, giving α as 0.05. The corresponding values of $t_{0.5\alpha,n-1}$ can be obtained from many textbooks that provide the relevant tables.

However they are provided in Table 2.2.1 for easy reference. For an actual application using real values refer to Section 3.7, Point 3.7.7.

n	2	3	4	5	6	7	8	9	10
$t_{0.5\alpha,n-1}$	12.7	4.30	3.18	2.78	2.57	2.45	2.36	2.31	2.26

Table 2.2.1 The values of $t_{0.5\alpha,n-1}$ for $\alpha = 0.05$.

2.2.6 The uncertainty in a variable that is a function of other variables

Many a time the value that is ultimately being looked for is a combination of other quantities. The errors in these variables will propagate into the result giving an uncertainty in its value. There are various ways that can be used to estimate the error in the final answer. Some of these make a compensation of negative errors with positive ones. Others look for the most likely deviation. However in your work you will be requested to consider the worst possible case where all the errors add up.

To find the error in a quantity that is a function of some variable/s is will be convenient to use the results from calculus that if $z = f(x_1, x_2, \ldots, x_n)$ i.e. z is a function of x_i for $i = 1, \ldots, n$, then,

$$dz = \frac{\partial z}{\partial x_1} dx_1 + \ldots + \frac{\partial z}{\partial x_n} dx_n = \sum_{i=1}^{n} \frac{\partial z}{\partial x_i} dx_i \, . \tag{8}$$

where $\dfrac{\partial z}{\partial x_i}$ is the partial derivative of z with respect to x_i, found by keeping x_j, $j \neq i$ constant and differentiating as usual with respect to x_i.

Some of the most important results that can be obtained from Equation 8 and that will need are,

$$z = ax \qquad \Rightarrow \qquad \delta(z) = |a|\delta(x) \tag{9}$$

$$z = ax \pm by \qquad \Rightarrow \qquad \delta(z) = |a|\delta(x) + |b|\delta(y) \tag{10}$$

$$z = xy \text{ or } z = \frac{x}{y} \qquad \Rightarrow \qquad \frac{\delta(z)}{z} = \frac{\delta(x)}{x} + \frac{\delta(y)}{y} \tag{11}$$

$$z = x^p \qquad \Rightarrow \qquad \frac{\delta(z)}{z} = |p|\frac{\delta(x)}{x} \tag{12}$$

$$z = x^p + y^q \qquad \Rightarrow \qquad \frac{\delta(z)}{z} = |p|\frac{\delta(x)}{x} + |q|\frac{\delta(y)}{y} \tag{13}$$

$$z = \ln(x) \qquad \Rightarrow \qquad \delta(z) = \frac{\delta(x)}{x} \tag{14}$$

$$z = e^x \qquad \Rightarrow \qquad \frac{\delta(z)}{z} = \delta(x) \tag{15}$$

where x, y and z are variables while a, b, p and q are constants.

To obtain proves of the above equations is relatively simple. Consider for example $z = e^x$, using the fact that for $z = f(x)$ Equation 8 reduces to,

$$dz = \frac{dz}{dx}dx, \tag{16}$$

it is easy to show that,

$$dz = \frac{d(e^x)}{dx}dx = e^x dx = z dx, \tag{17}$$

which on rearranging gives Equation 15. The proofs of the other equations are left to the reader. In this respect it is worth noting that Equations 9 and 10 represent special cases of the following result,

$$z = \sum_{i=1}^{n} a_i x_i \qquad \Rightarrow \qquad \delta(z) = \sum_{i=1}^{n} |a_i|\delta(x_i), \tag{18}$$

Equations 11 and 12 can be viewed as special cases of,

$$z = x_1^{a_1} x_2^{a_2} \ldots x_n^{a_n} = \prod_{i=1}^{n} x_i^{a_i} \qquad \Rightarrow \qquad \frac{\delta(z)}{z} = \sum_{i=1}^{n} |a_i|\frac{\delta(x_i)}{x_i}, \tag{19}$$

(Π, Greek P, is the symbol used for multiplication.) As regards Equation **Error! Reference source not found.** this can be conveniently proved by first taking the $\ln$, and then using Equations 18 and 14 in succession.

Worked examples employing the above equation are found in Section 3.10, Point 3.10.1.

2.2.7 Linear Regression

Most of the experiments that should be performed are supplied with a theoretical relation linking the variable being varied with that being read. In A-level work, students were asked to linearize these equations so as to be able to find the gradient and the intercept using a graphical procedure. This method was highly subjective and in the B.Sc. practicals it will be substituted with statistical techniques.

This method to be adopted is called the *normal regression analysis*, where it is assumed that for each fixed x_i the conditional density of the corresponding random variable Y_i is the normal density,

$$w(y_i \mid x_i) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{ -\frac{[y_i - (mx + c)]^2}{2\sigma^2} \right\}, \quad -\infty \le y_i \le \infty \tag{20}$$

where *m*, *c* and σ are the same for each *i*. Using the maximum likelihood method it is possible to show that the from given a sample of size *n*, the best estimators of *m* and *c* are (Freund *et al*., 1999):

$$m = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{21}$$

$$\text{and } c = \frac{\sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}. \tag{22}$$

An indication of how well the sample points vary linearly is given by the correlation coefficient, *r*, defined as,

$$r = \frac{\sum_{i=1}^{n} x_i y_i - \overline{xy}}{n\sigma_x \sigma_y} \tag{23}$$

where $\bar{x}$ and $\bar{y}$ are respectively the means of x_i and y_i,

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{24}$$

$$\text{and } \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \; . \tag{25}$$

while σ_x and σ_y are respectively the standard deviations of x_i and y_i,

$$\sigma_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2 - \left(\frac{1}{n}\sum_{i=1}^{n} x_i\right)^2} \tag{26}$$

$$\text{and } \sigma_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2 - \left(\frac{1}{n}\sum_{i=1}^{n} y_i\right)^2} \; . \tag{27}$$

The absolute value of the correlation coefficient ranges from zero, where the two variables are independent, to one where the two variables are completely linearly dependent. Regarding the sign, the correlation coefficient will be positive if both variables increase together and negative if one variables increases while the other decreases.

It is also possible to compute the error in the estimators of the gradient and the intercept. These are obtained by calculating the range of uncertainty of their values using the normalized regression analysis, and are given by,

$$\delta(m) = \frac{m}{\sqrt{n-2}}\left(\frac{1}{r^2} - 1\right)^{1/2} \tag{28}$$

$$\text{and } \delta(c) = \delta(m)\left(\frac{1}{n}\sum_{i=1}^{n} x_i^2\right)^{1/2} . \tag{29}$$

Worked examples employing the above equation are found in Section 3.9, Point 3.9.8.

2.2.8 Relative errors and decimal consistency

Some important definitions

The *accuracy* describes how close the measured value is to the true value. The closer the measured value is to the true value the better is the accuracy.

The *precision* relates the uncertainty to the measurement being taken. The smaller the uncertainty the better is the precision. Note that an experiment can be precise but due to the systematic errors involved it might not be accurate at all.

It should be obvious that the importance of the magnitude of an error is related to that of the associated value. In order to quantify the significance of the uncertainty with respect to the experimental determined value, the relative percentage error, defined as,

$$\text{Percentage Error} = \frac{\text{Combined Error}}{\text{Experimental Error}} 100\% \qquad (30)$$

can adopted. The percentage error is thus a measure of the precision and its value should be less then 10% for the experiment to be considered as precise.

Another relative error that is of outmost importance is that relating the experimental value to the standard quotable one that is available from textbooks. A measure of this can be obtained from,

$$\text{Accuracy} = \left| 1 - \frac{\text{Experimental Value}}{\text{Quoted Value}} \right| 100\% . \qquad (31)$$

As its name implies, this quantity is a measure of the accuracy. Its minimum value is attained at zero, when the experimental and quoted value would be the same indicating maximum accuracy.

It is to note that the accuracy can also be equivalently defined as,

$$\text{Accuracy} = \left| \frac{\text{Experimental Value}}{\text{Quoted Value}} \right| 100\% . \qquad (32)$$

in which case the best performance is attained when this quantity is equal to 100%. Both definitions can be used as long as the meaning of their value is not confused. In this respect special care should be taken when determining whether the experiment is to be considered accurate or not, which would require the accuracy to be within $\pm 10\%$ of its best value.

At this point it should be acknowledged that as a consequence of the fact that each experimental value has an associated error, it is useless to specify the quantity to an infinite number of significant figures. Instead the value should be rounded up to the same number of significant figures its uncertainty is being quoted.

Likewise, the error should not be indicated with infinite precision, as this itself is bound to have some uncertainty in its value. Thus it would be good practise to specify the error up to one significant figure. In any case the uncertainty should not be quoted with more than three significant figures. These last two issues provide for what is referred to as the *decimal consistency* of the values.

2.2.9 The value (pure number), the error and the unit

A measurement will consist of three parts, the value, a pure number, the error and the unit. An Example is 0.50 ± 0.01 cm, where 0.5 is the value (a pure number), 0.01 is the error, while cm is the unit. There are many ways in which it is possible to define the unit of a quantity. For example length can be measured in metres or feet while mass can be given in kilograms or in pounds. Thus it makes no sense to write down the value or the value and the error if the unit is not specified.

2.3 Report format

A practical report needs to be both clear and intelligible to the reader. Thus in the B.Sc. practicals it is expected that reports are written using a word processor while graphs are drawn with the help of some computer software. The tools of choice are typically Microsoft Words® and Excel® and in the following proceedings there are some instructions of how to go about using some of the features that will be frequently required. However, any other software would be accepted as long as the requested format is supplied.

There are various conventions that can be used in report writing but for clarity it is recommended that the student sticks to the following basic rules:

- Adopt *New Times Roman* as font. This font clearly distinguished between each and every symbol it employs. This cannot be said of other fonts like *Arial* that uses the same symbol for "1" and "l".

- Employ a font size of 12 or larger. Smaller font sizes would be too small to read.

- Introduce 1.5 line spacing.

- Insert page number on the upper right side.

- Use adequate headers and footers:

    Headers:

    > (a) Left hand side: the experiment number and name.

    > (b) Right hand side: page number.

    Footers:

    > (a) Left hand side: Name and surname.

- Apply an adequate paragraphing system. The choice is left to one of the following:

    > (a) Indent the first line with no line spacing between successive paragraphs, or

    (b) Start flash with the left margin and introduce line spacing between successive paragraphs.

Do not in any case use a combination of the above two, like indenting the first line and then using line spacing between successive paragraphs.

- Apply particular formats to different types of variables and to their units for easy discrimination:

  (a) Simple variable: This is written italic, e.g. a voltage reading should be addressed as V .

  (b) Vector variable: This should be written bold, e.g. a velocity reading is to be referred to as **v** .

  (c) Unit: This is written in a normal fashion. No bold or italic should be applied and a space should be introduced between it and the magnitude. E.g. five volts should be written as 5 V. If more than one unit is to be quoted introduce a space between each unit. This is required to avoid confusion like for example between milliseconds (ms) and metre seconds (m s).

- Use an A4 paper and leave a margin of at least 2.5 cm on each side.

- When quoting units, negative powers should be preferred to the slash system.

Chapter 3 B.Sc. physics practicals layout

3.1 Date

Point 3.1.1:

Write the date of the day when the experiment was performed.

3.2 Name and Surname

3.3 Experiment number

3.4 Title

3.5 Instrumentation
Point 3.5.1:

Before starting to tabulate the date it is necessary to specify the readability interval and readability error. The reason for this is in these experiments it will be left up to the individual to decide on which values he should take. However such a freedom of choice is subject to the following restraints. The first is that these values are quoted before the tabulation of the data, something that is requested for each and every experiment since each individual may decide to change from time to time the values he is taking. The second is that they should be reasonable and the work should be consistent with the values quoted.

Example: Consider a metre ruler. The least count of the instrument is 1 mm. However the experimenter decides that he can determine if the edge of the edge of the object is within the upper or the lower half of the interval. Hence his readability is 0.5 mm. In addition he decides that this value is subject to an error equivalent to half the readability interval, i.e. the readability error is 0.25 mm. For such a situation the experimenter is expected to write:

Metre rule:
Readability interval 0.5 mm.
Readability error 1.0 mm.

3.6 Sources of error and precautions

Point 3.6.1:

You should have three subsections: Systematic errors, Random Errors and Precautions. Re-subdivide the error section by type like method, apparatus and personal type of errors.

Point 3.6.2:

Use point form, the past tense and an impersonal construction.

Point 3.6.3:

Be brief and concise. There will be no need to explain the error or precaution if it is self evident. Examples: For the Errors: "Contact potentials" is enough to indicate the presence of extra resistances that are not accounted for. There will be no need to specify this. For the Precautions: "Repeated readings were taken" will suffice. There will be no need to add "to reduce the errors." In cases where you think that the effect of what you are mentioning is not so obvious, you should include a brief explanation. Example: "Air currents might have induced the system to oscillate." In such a case simply saying "Air currents" might not have been clear enough to convey what you meant. Use your judgement to decide the best way of describing the error or precaution.

Point 3.6.4:

For the errors do not use absolute statements but only relative statements. Example: Do not write "The lens was not clean" since this would imply that you have not cleaned it. You should say "The lens might still have had some dirt even after cleaning."

Point 3.6.5:

For the precautions do not write what should be done but what has been done. Example: Do not write "The oscillations should be planar" but "It was made sure that the oscillations were planar."

Point 3.6.6:

Write all the errors that you might think about and precautions that you have used in this section. You should not mention other errors encountered and precautions used in other sections like the discussion without mentioning them here.

Tip: As an aid to determine errors and precaution use the fact that in general for every precaution there is an error but usually there will be more errors than precautions that can be taken. In addition everything that you have been asked for can be carried out in an incorrect way even if a precaution has been taken. Thus if you made sure for example to level a turn table, this might still not be perfectly levelled. Hence in the Systematic errors under apparatus you could write "The turn table might not have been perfectly levelled" while in the Precautions you could still say "The turn table was levelled."

3.7 Data collection and tabulation

Point 3.7.1:

Tabulate all the quantities you are requested to measure. This includes not only the data used for the graph but also additional measurements you need to make the calculation. Examples include, the tabulation of the original height or position in experiments that involve finding the extension or depression; the dimension of an object in order to find the volume; and the positions of a moving telescope needed to find the dimensions of an object. Note that in the case where a quantity suffers a constant variation while another is read more than once than both quantities should be tabulated twice. For example, when finding the IV-characteristics of a component, if a first set of reading is obtained by varying the voltage from 0 V to 10 V in steps of 0.5 V and measuring the corresponding current (I_1) and then a second set of reading is obtained by varying the voltage from 10 V to 0 V using the same interval and reading the current (I_2), then the Voltage will have to be tabulated twice, once for I_1 and once for I_2.

Point 3.7.2:

As a general rule you will always be asked to **make repeated readings**. There will be no need for the demonstrator or the instructions to specify it. It should be taken as the general practice.

Point 3.7.3:

In the first row (or column) of the table you will be requested to place the symbol of the quantity being measured. Since in the table we write only pure numbers in the case where a quantity has a unit (e.g. length that has metres as its unit) the quantity has to be divided by its unit. Hence we use the forward slash (/) between the quantity and its unit (e.g. l/ m).

Point 3.7.4:

Define symbols being used if they have not been given.

Point 3.7.5:

Remember that the values tabulated should be readable. Thus if the quantities are very large or very small it is good practise to divide the readings by a multiplicative factor. You can indicate this by inserting the multiplicative factor after the slash (e.g. l/ m $\times 10^{-3}$) or else write the multiplicative factor on the next line. It is to note that even though it is customary to divide by the multiplicative factor (which explains why its value is written after the slash), a multiplication sign is usually quoted.

Point 3.7.6:

The next line should be reserved for:

-   The **readability error** in the case of direct measurements. Direct readings have to be consistent with the readability interval. If the actual reading lies between two intervals you must decide whether to take the larger or the smaller value. In any such case do not take the average of the large and the

small value. Such a limit in the measuring instrument is accounted for by taking repeated readings.

- The **calculated error** for calculated values. You are requested to indicate the error of calculated values, to a reasonable number of decimal places or significant figures, if this does not vary along the length of a column. Examples include the errors for repeated readings and for quantities that are subtracted or added. You will be requested to show the calculations of the errors. Thus it would be good practice to include the working of such errors before you produce the table.

Tip: Do not change the unit of the readability or calculated errors. On the one hand since the quantity has been divided by the unit it makes no sense to quote a unit again; on the other writing the readability or calculated errors in the same form as the readings will help you to check the tabulation for decimal consistency, which is the next point to be considered.

Point 3.7.7:

Tabulated data must have decimal consistency. The Criteria for decimal consistency depends on whether the value has a readability or a calculated error or not:

- in the case the data has a readability or a calculated error the decimal places or/and significant figures must be consistent with the specified readability or calculated error.

- in the case the calculated data for which the calculated error will not be specified then a reasonable number of decimal places or/and significant figures has to be chosen and then all the values will have to be shown with that level of precision.

This might involve rounding some values and padding up others with zeros.

Note that it is good practice to have decimal consistency not just along one column but across columns to. That is, if you have two quantities that have been obtained using the same manipulative procedure from quantities with the same absolute error, then they should have the same number of decimal places.

For those using *Microsoft Excel®* the decimal consistency can be achieved by highlighting the cells then using the *Decrease / Increase decimal* button on the tool bar. If this does not give the requested result then you can go to *Format* and then *cells* (or right clicking and choosing *Format cells*). In the dialogue box that will appear choose *Number* and then under *Category* choose *Number*. You can then specify the required number of decimal places and press *OK*.[1]

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[1] Note that the procedures given in this manual refer to those for Excel 2003. If you are using Excel 2007 and later or Open Office you will probably have to adapt these instructions.

Illustrations:

Case 1: Single value.

       Sometimes a single reading would be enough i.e. no repeated readings are necessary. (Note that this is a very rare event.) To illustrate the situation, the case of measuring a length using a metre ruler (with a least count of 1 mm) will be taken:

Metre ruler:
       Readability interval 0.5 mm.
       Readability error 0.5 mm.

$$l = (12.15 \pm 0.10) \times 10^{-2} \text{ m.}$$

Note that the resulting error in the reading is twice the readability error, since this corresponds to the sum of the uncertainties induced at two edges. However, it is quoted to two significant figures to account for the fact that measurements have a smaller readability error.

Case 2: Repeated readings of the same quantity.

       In the case of a repeated reading for a single quantity, such as a diameter determined using a micrometer screw gauge (that has a least count of 0.001×10^{-2} m), it is possible to tabulate the data as follows:

Micrometer screw gauge:
       Readability interval 0.001×10^{-2} m.
       Readability error 0.0005×10^{-2} m.

d /10^{-2} m	$\pm$ 0.0010	0.0350	0.0360	0.0340

$$\delta \bar{d} = t \frac{\delta d}{\sqrt{n}} = 4.3 \times \frac{0.001 \times 10^{-2} \text{ m}}{\sqrt{3}} = 0.002 \text{ m.}$$

$$\bar{d} = (0.035 \pm 0.002) \times 10^{-2} \text{ m.}$$

Note that each quantity, including $\bar{d}$, has decimal consistency with the calculated error. Thus the values in the table give an illustration of padding.

Case 3: Values tabulated for a graph.

       In the case of data required for a graph, an example can be provided by three sets of reading taken by varying a voltmeter (with a least count of 0.1 V) and noting the corresponding current using an ammeter (with a least count of 0.01×10^{-3} A):

Voltmeter:
       Readability interval 0.1 V.
       Readability error 0.05 V.

Ammeter:

Readability interval 0.01×10^{-3} A.

Readability error 0.005×10^{-3} A.

$$\delta V = 4.3 \times \frac{0.1 \text{ V}}{\sqrt{3}} = 0.2 \text{ V} \quad \text{and} \quad \delta I = 4.3 \times \frac{0.01 \times 10^{-3} \text{ A}}{\sqrt{3}} = 0.02 \times 10^{-3} \text{ A}.$$

V_1 / V	I_1 / 10^{-3} A	V_2 / V	I_2 / 10^{-3} A	V_3 / V	I_3 / 10^{-3} A	V / V	I / 10^{-3} A
$\pm$ 0.10	$\pm$ 0.010	$\pm$ 0.10	$\pm$ 0.010	$\pm$ 0.100	$\pm$0.010	$\pm$ 0.2	$\pm$ 0.02
0.00	0.000	0.00	0.000	0.00	0.000	0.0	0.00
0.10	0.800	0.10	0.800	0.10	0.800	0.1	0.80
0.20	1.780	0.20	1.770	0.20	1.780	0.2	1.78
0.30	2.450	0.30	2.430	0.30	2.440	0.3	2.44
0.40	3.250	0.40	3.200	0.40	3.220	0.4	3.22
0.50	4.010	0.50	4.000	0.50	3.990	0.5	4.00

In this case the values of *I* in the third and forth row of the data give an illustration of the rounding of values. To note that even if *V* was kept constant this was tabulated for each value of *I*. This is considered necessary since writing *V* once means that you have set it once and have read *I* three times while writing *V* three time immediately indicates that you have set it for each value of *I* being taken. Hence the number of times you write *V* would be indicative of the procedure used. In addition *V* was set three times and each time its value might, to a slight degree, have been different. This has to be accounted for by calculating the error for its repeated reading.

Point 3.7.8:

When taking repeated readings if the values are significantly different it is good practice to repeat the measurements.

Point 3.7.9:

A minimum of five points is requested in order to draw a reasonable graph.

Point 3.7.10:

During some experiments, the dependent quantity (the one on the *y*-axis) will vary slowly over a particular region and fast in another. In such case it is good practice to take more points in the region where the dependent quantity varies quickly.

3.8 Graph

Point 3.8.1:

It is expected that you plot graphs using some computer program. Usually Microsoft Excel® is used. At the end of this section you will find a detailed description of how you can do this using this software.

Point 3.8.2:

As a general practice we always plot the independent[1] variable (that which we change) on the x-axis and the dependent variable (that which we read) on the y-axis.

Point 3.8.3:

Place a heading for the graph and for the axis. An example of a heading for a graph would be:

$$\text{“Graph of } l \text{ / m vs. } m \text{ / kg”}$$

where l lies on the y-axis, which will have the corresponding title "l / m" and m lies on the x-axis which will have the title "m / kg." Note that we always write y vs. x and never vice versa.

Point 3.8.4:

Remember that scales should be readable. Thus if the quantities are very large or very small it is good practise to plot the readings after dividing them by a multiplicative factor. You can indicate this on the *axis* title (but not in the chart title) by inserting the multiplicative factor after the slash. For example "l / 10^{-2} m."

Point 3.8.5:

Draw the best straight line or curve that can describe **all** the points. If the program used does not provide you with a suitable one, then you should plot it by hand using an HB pencil and a flexi curve.

Point 3.8.6:

If a point lies far away from this line or curve it would be good practice to repeat the reading to make sure it is correct. For this reason you should plot the points after the experiment to make sure they are correct. If, however, it is not possible to repeat the reading and you think that the point is necessary wrong and want to ignore it, then you can mark it clearly on the graph paper and justify your decision in the calculations and/or discussion.

---

[1] If there exist a relation between two variables, x and y, such that y is a function of x, then if x is given a particular value, y will be fixed. Thus we refer x as the independent variable, since it value is assigned and does not depend on anything else, while we call y as the dependent variable since it depends on the value of x.

Point 3.8.7:

      Gridlines: It is good practice to insert gridlines on the graph. This is especially important when reading values from the graph, which is the argument of the next point.

Point 3.8.8:

      Indicate on the graph any points that are being read. When reading a coordinate, a dotted line should be extended to cut the *x*- and/or *y*- axis as appropriate. The value read should be written on the graph at the point of intersection. The last point also applies when reading the point where a curve cuts an axis. The value read should be consistent with the minimum reading that a graph can provide. Since the minimum reading or error from a graph is equal to the minimum grid spacing the gridlines should be as closely spaced as possible.

Point 3.8.9:

      It is good practise to avoid using colour on the graph wherever possible.

Procedure[1]

- Input the data in a Microsoft Excel worksheet.

- Press the chart wizard icon on the tool bar.

- In the dialogue box under *Standard types* under *Chart type* select *XY* (*Scatter*) and under *Chart sub-type* leave the dot one (located at the top). Then click *Next*.

- Chose *Series* at the top of the next dialogue box.

- Clear or add series as appropriate using the *Add* and *Remove* buttons. In the case of multiple series chose a name for the series. This can be located in a cell. Then choose the *x*-range and the *y*-range. This can be done by clicking the *X* or *Y values* box as appropriate and then selecting the cell range. After finishing click *Next*.
- In the next dialogue box insert a heading for the graph in the *Chart title box* and one for the *x*- and *y*-axis using the *Value* (*X*) and (*Y*) *axis* box respectively. Do not bother about formatting at this stage. You could also move to *Gridlines* (at the top) and insert the minor gridlines of both axis and to the *Legend* to remove it. Then click *Next*.

- The next dialogue box asks you where you want to locate the graph as part of the worksheet or as a chart. For easy manipulation it would be recommended to place it as a *New chart*.

---

[1] Note that the procedures given in this manual refer to those for Excel 2003. If you are using Excel 2007 and later or Open Office you will probably have to adapt these instructions.

- Clear the background by right clicking the mouse in the space between gridlines and then selecting *Clear*.

- If the legend is not required and you have not removed it, click on it and press the delete button on the keyboard.

- If you have not inserted the gridlines, right click on the chart area, select *Chart options* and then *Gridlines*. Then chose the minor grid lines of both axis and press *OK*.

Illustration:

Graph of I / A vs. V / V
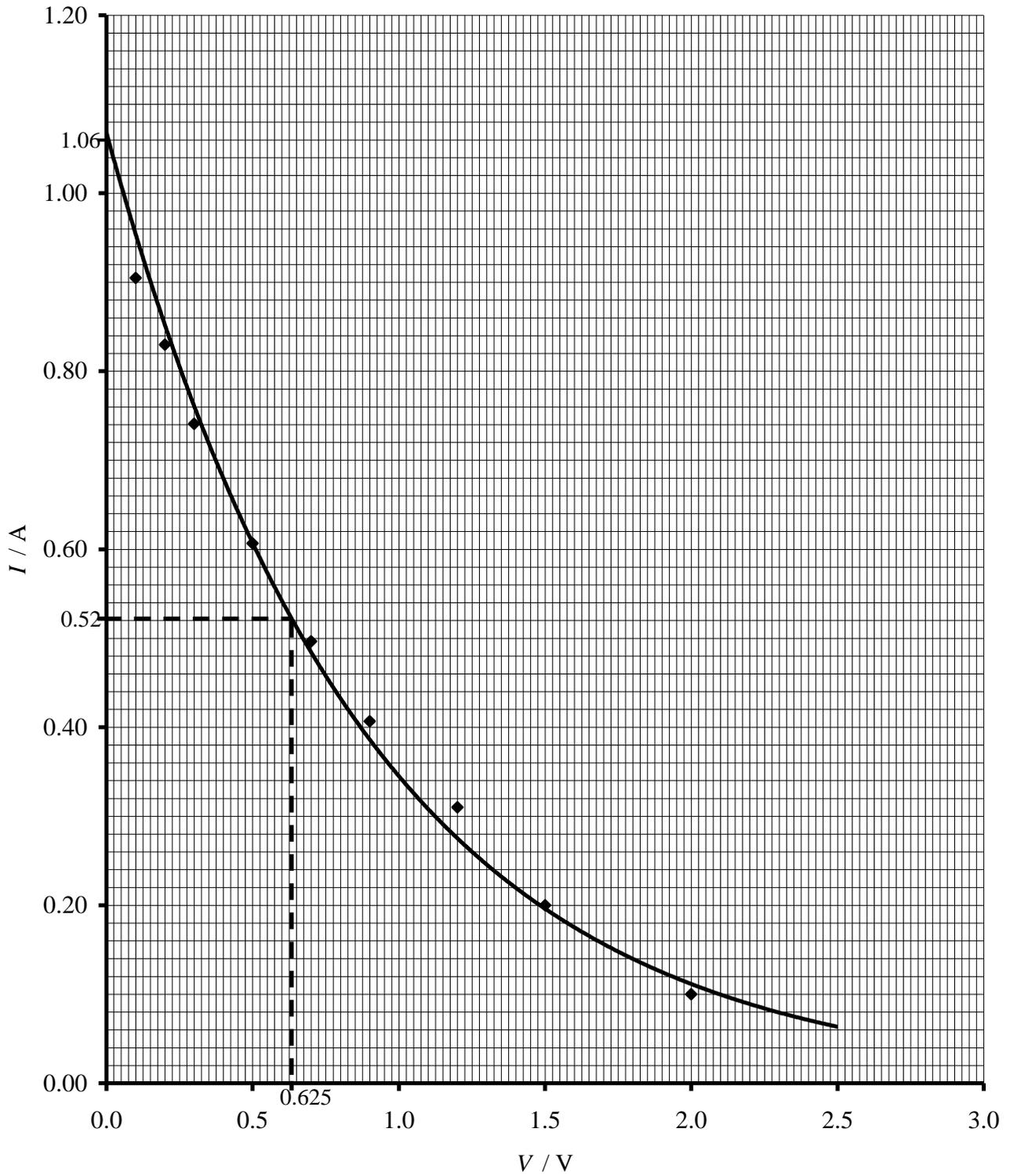
- Since the grid lines might not be fine enough right click on the appropriate axis and then select *Format axis* (or double click on the required axis), chose *Scale* and then adjust the *Minor unit* as appropriate. Press *OK* when you have finished.

- It might occur that you would like to extend the axis in order to adjust the plotting area. This can be done by going to the appropriate axis right click it and then chose *Format axis* (or double click on the required axis). Then chose *Scale* and adjust the *Maximum* and/or *Minimum* as appropriate.

- In order to have decimal consistency of the axis right click the axis and then chose *Format axis* (or double click on the required axis), chose *Number*, under *Category* chose *Number* and specify an appropriate number of decimal places.

- If you want you can emphasized the axis by increasing the thickness of the line. This can be done by click the axis and then chose *Format axis* (or double click on the required axis), chose *Pattern*, and then increase the *weight* of the line. Click *OK* when you have finished.

- Formatting Titles:

    a) **Superscripts and Subscripts**: To insert a superscript or a subscript you can highlight the letter, number or symbol, go to *Format* (or right click), chose *Format cells* and select *Superscript* or *Subscript* as appropriate.

    b) **Greek symbol**: To insert a Greek symbol you can use the corresponding Latin letter and *Symbol* as a font.

    c) **Font Size**: To increase font size in order to make the chart titles readable, highlight the title and then chose an adequate font size (the number on the tool bar).

- Insert trendline or curve: To insert a trendline, right click on the points, and then chose *Add trend line* (or *Edit trendline* in the case there is already a trendline). Select the most appropriate type of trendline. At this point you can also go to the *Options* (on the top) and indicate whether you want the equation and the R^2 value to be displayed.

    With respect to the R^2 value, it should be pointed out that the equation used to calculate it is not the one that you have been given and therefore you are not allowed to use it as a substitute for the correlation coefficient. In addition it should be noted that its value simply indicates how well the trendline fits your points. Thus in general it will give no indication of how good your readings are. The exception is given by straight line graphs where it can indicate how well your points conform to the expected behaviour. However in this case you are requested to use the correlation coefficient i.e. the equations given.

    You must also remember that you have to draw the best curve that describes the points. For this reason:

a) **Do not set the intercept to zero**. If the intercept should have been zero but in practice it is not, then you can try to explain this in the discussion.

b) Do not use a curve plotted by the program if you cannot find one that describes the points adequately. In such case you can either try to change the type of graph to a dot line (right click and then chose *Chart type*), or else use a flexi curve and draw the curve by hand.

From the *Add trendline* dialogue box, under *Options* you can also extend the chosen trendline or curve beyond the plotted points by adjusting the *Forward* and *Backward* options found under *Forecast*. When you have satisfied yourself you can click *OK*.

- If you need to change the way the points appear or their colour, right click on the data series and then choose *Format data series*. A dialogue box should appear with the top menu set on *Patterns* (choose *Patterns* if this is not so). This will allow you to introduce and format a line (generally not required for your laboratory experiments) or the marker. Thus under *Marker* you can define the *Style*, *Foreground*, *Background* as well as the *Size* of the indicator of the data point. Click *OK*, when you are satisfied with your choice.

- Excel by default prints the graph as landscape. However it may occur that some features are clearer if the graph is drawn portrait. In order to determine this, go to the *Print preview* from the tool bar or from *File* (in the main menu) and then chose *Page setup*. In the dialogue box under *Page* select *Portrait* or *Landscape* as appropriate. Click ok to see the result. To exit from the *Print preview* click close.

- Print as a full page from the *Print* icon on the tool bar or from *File* (in the main menu) or else copy and paste it as a full page in the text editor.

3.9 Calculations

Point 3.9.1:

Calculations should be written down in such a way that a reader can follow through all the steps. For this reason you should always indicate clearly from where the values are being taken. Example: In the case of values taken from linear regression, say specifically: using linear regression $r^2 = 0.9235$ and $m = 2.5$ m kg^{-1}.

Point 3.9.2:

Indicate units wherever appropriate. With this respect use of negative powers should be preferred. In addition those that use a word processor for their report should follow the following conventions:

- Variables should be written in italic while units should not.

- Bold non italic should only be used for vectors.

Point 3.9.3:

In the case that you have an equation identify the intercept, the independent variable (the one that you have varied, which in general will go on the *x*-axis), and the dependent variable (the one for which you have taken the readings, which in general will go on the *y*-axis). Then identify the gradient.

Tip: In order to identify the intercept, the independent and dependent variable, and the gradient you could use the following procedure. Write the equation given for the experiment and then underneath it write the straight line equation: $y = mx + c$. If there are only two terms[1], one on each side of the equals sign, then the intercept c is zero. If there are three or more terms, then the intercept is non-zero and needs to be determined. This can be done by identifying the term (or terms) that does (or do) not contain quantities that have varied. Note that this (or these) could have a negative sign in front of it (or them). Then identify the *y* term, which in general will consist of product and/or division of variables that have been read and/or have been calculated, and draw an arrow across it and across the *y* in the straight line equation to signify that you are equating them. Then look at the remaining term and identify the product and/or division of variables that have been varied. These constitute the *x* term. Draw an arrow across it and the *x* in the straight line equation. (Note that in the general case the *x* term will consist of a sum of terms that will need to be grouped as necessary.) The group of variables that have not changed during the experiment and that are multiplying and/or dividing the *x* term in the equation given for the experiment can be equated to the gradient.

Point 3.9.4:

If you need other quantities apart from the gradient to do the calculations, you should tabulate them, take repeated readings and indicate the readability and/or calculated error as specified in Section 3.7. Preferably these should already have been included in the data section.

Point 3.9.5:

Check if you need to multiply quantities read from the graph by any multiplicative factors you have used.

Tip: For the gradient, multiply the quantities by any multiplicative factors you have used before performing linear regression.

Point 3.9.6:

It is good practice to make the quantity being determined subject of the formula before you substitute values.

Point 3.9.7:

Check consistency of units.

---

[1] We are using the word "term" in an equation to refer to a product and/or division of variables and constant. Terms are hence distinguished from one another through the use of addition or subtraction.

Tip: For the gradient, multiply the quantities by any multiplicative factor need to bring them in the units desired before performing linear regression.

Point 3.9.8:

Unlike in A-level, you will be asked to find the gradient using linear regression. The equations are given in Section 2.2.7 and can be computed manually in which case you should show the work done. If you do this just remember that x_i and y_i refer to each and every value that you have **read** or **calculated** and that are found in the relevant table.

Illustration:

Referring to the values given in the table found in at the end of Section 3.7:

$$x_i = V_i \ , \ y_i = I_i \text{ and the number of data points } n = 6.$$

$$\sum_{i=1}^{6} x_i = \sum_{i=1}^{6} V_i = 0 + 0.1 + 0.2 + 0.3 + 0.4 + 0.5 = 1.5 \text{ V},$$

$$\sum_{i=1}^{6} x_i^2 = \sum_{i=1}^{6} V_i^2 = 0^2 + 0.1^2 + 0.2^2 + 0.3^2 + 0.4^2 + 0.5^2 = 0.55 \text{ V}^2,$$

$$\sum_{i=1}^{6} y_i = \sum_{i=1}^{6} I_i = 0 + 0.8 + 1.78 + 2.44 + 3.22 + 4 = 12.24 \text{ A},$$

$$\sum_{i=1}^{6} y_i^2 = \sum_{i=1}^{6} I_i^2 = 0^2 + 0.8^2 + 1.78^2 + 2.44^2 + 3.22^2 + 4^2 = 36.1304 \text{ A}^2,$$

$$\sum_{i=1}^{6} x_i y_i = \sum_{i=1}^{6} V_i I_i = (0 \times 0) + (0.8 \times 0.1) + (1.78 \times 0.2) + (2.44 \times 0.3) + (3.22 \times 0.4) + (4 \times 0.5)$$
$$= 4.456 \text{ VA},$$

$$\bar{x} = \bar{V} = \frac{1}{n} \sum_{i=1}^{6} V_i = \frac{1.5}{6} = 0.25 \text{ V},$$

$$\bar{y} = \bar{I} = \frac{1}{n} \sum_{i=1}^{6} I_i = \frac{12.24}{6} = 2.04 \text{ A},$$

$$\sigma_x^2 = \sigma_V^2 = \frac{1}{n} \sum_{i=1}^{6} V_i^2 - \bar{V}^2 = \frac{0.55}{6} - 0.25^2 = 0.02917 \ \text{V}^2,$$

$$\sigma_y^2 = \sigma_V^2 = \frac{1}{n} \sum_{i=1}^{6} I_i^2 - \bar{I}^2 = \frac{36.1304}{6} - 2.04^2 = 1.860 \text{ A}^2.$$

Hence,

$$ m = \frac{n\sum_{i=1}^{6} x_i y_i - \sum_{i=1}^{6} x_i \sum_{i=1}^{6} y_i}{n\sum_{i=1}^{6} x_i^2 - \left(\sum_{i=1}^{6} x_i\right)^2} = \frac{n\sum_{i=1}^{6} V_i I_i - \sum_{i=1}^{6} V_i \sum_{i=1}^{6} I_i}{n\sum_{i=1}^{6} I_i^2 - \left(\sum_{i=1}^{6} V_i\right)^2} = \frac{(6 \times 4.456) - (1.5 \times 12.24)}{(6 \times 0.55) - 1.5^2} $$

$$ = 7.9771 \, \text{AV}^{-1}, $$

$$ c = \frac{\sum_{i=1}^{6} x_i^2 \sum_{i=1}^{6} y_i - \sum_{i=1}^{6} x_i \sum_{i=1}^{6} x_i y_i}{n\sum_{i=1}^{6} x_i^2 - \left(\sum_{i=1}^{6} x_i\right)^2} = \frac{\sum_{i=1}^{6} V_i^2 \sum_{i=1}^{6} I_i - \sum_{i=1}^{6} V_i \sum_{i=1}^{6} V_i I_i}{n\sum_{i=1}^{6} V_i^2 - \left(\sum_{i=1}^{6} V_i\right)^2} $$

$$ = \frac{(0.55 \times 12.44) - (1.5 \times 4.456)}{(6 \times 0.55) - 1.5^2} $$

$$ = 0.0457 \, \text{A}, $$

$$ \text{and } r = \frac{\sum_{i=1}^{6} x_i y_i - n\overline{xy}}{n\sigma_x \sigma_y} = \frac{\sum_{i=1}^{6} V_i I_i - n\overline{VI}}{n\sigma_V \sigma_I} = \frac{4.456 - (6 \times 0.25 \times 2.04)}{6 \times \sqrt{0.02917} \times \sqrt{1.860}} = 0.9989. $$

Attention: Do not repeat symbols especially *m*. If in the analysis *m*, *c* or *r* have already been adopted do not use them again. In this case you could use *gradient*, *intercept* and *correlation coefficient* respectively as a substitute.

It is also possible to use Excel to obtain these values by following this procedure:[1]

- In the case that you have never used this tool before, go to *Tools* and choose *Add-Ins*. In the dialogue box make sure that the *Analysis ToolPak – VBA* is installed i.e. ticked. Click *OK*. In order to perform this operation you might be asked the original *MSOffice* CD, which should be at hand. If you cannot complete this operation, you can use the *Excel* facility given by the CSC.

- Enter the values in an Excel worksheet.

- Go to *Tools* and choose *Data Analysis*.

- In the first dialogue box, scroll down the tools given under *Analysis tools* until you find highlight *Regression*. Then double click it or press *OK*.

- In the next dialogue box insert the *y*- and *x*- values. This can be done by clicking the *Input Y* or *X Range* and then highlighting the cells.

- Do not set the intercept to zero.

- Press *OK*.

- A new work sheet will be outputted with a substantial number of quantities. The only ones relevant to you are the *Multiple R* (*r*), *R Squared* (*r^2*), the

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[1] Note that the procedures given in this manual refer to those for Excel 2003. If you are using Excel 2007 and later or Open Office you will probably have to adapt these instructions.

intercept (as its name implies the intercept) and the *X Variable* 1 (the gradient). Ignore the standard error of the intercept as its equation is not given.

- Print the first two columns together with the standard error of the gradient and provide it as evidence of your working.

Here it is worth remembering that the correlation coefficient (r^2) gives a measure of how much the two variables tend to vary together i.e. to determine if they are linearly dependent. Its absolute value varies from zero, where the two variables are considered to be completely independent, to one where the two variables are considered to have a linear dependence. In the case of negative values the same criteria applies except for the fact that the closer to minus one the value is the more the relation between the two variables approaches inverse proportionality. Thus it makes no sense to apply it in cases where it is known that the relation is not linear such as in the case of exponential decays.

Point 3.9.9:

Make sure that the values obtained are reasonable when compared to the quoted ones before considering that you have finished this section. If they are not then you should check your working since the problem is usually there. If it is not there try to check your values.

Tip: If the value is not of the same order of magnitude (i.e. the ratio of the experimental to the quoted value is not around one) but there is a difference of the order of magnitude of *N* (i.e. the ratio of the experimental to the quoted value is around 10^N) then probably you have forgotten to convert some units or to take adequate account of another multiplicative factor that has been used. In any case if the order of magnitude is greater than one than you should check your work.

Attention: You are requested to **adhere to the values obtained** even when they vary substantially from the expected result. Remember that in physics a negative result is not a useless one and generally it provides the stimulus for further investigation. Hence if the results are not as expected and you cannot find anything wrong with the calculations you will have a platform from where you can show your analytical skills. Use it!

Point 3.9.10:

Be reasonable in the number of decimal places and significant figures in which you quote calculated values. Remember that these have an error and it makes no sense to use more decimal places or significant figures than the maximum error.

Point 3.9.11:

In the case of an equation of the form $y = mx$ it makes no sense to state that $m = y/x$ since you are working with the gradient. Hence you should always use,

$$m = \frac{\Delta y}{\Delta x} \; .$$

Point 3.9.12:

If you include any comment you should use an impersonal construction and the passive voice.

Point 3.9.13:

For those using Microsoft Word to present their report, in order to facilitate the writing of equations, the *Equation Editor*, can be used. The following procedure will indicate how to bring the *Equation Editor button* on the tool bar:[1]

- Go to *Tool* and then chose *Customize* to get the required dialogue box.

- Under *Commands* in the *Categories* box chose *Insert*.

- Scroll the entries of the in the *Commands* box until you find *Equation Editor* which has the following symbol: $\sqrt{\alpha}$.

- Click and drag the icon on the tool bar and then close the dialogue box.

- To use the *Equation Editor* just click the icon. Note that you may be asked for the original *Office* CD, which should be kept at hand.

3.10 Calculations of errors

Point 3.10.1:

Unlike A-level, you will be asked to calculate the maximum error in your readings. The relevant algorithms are given with the practical sheets. Some examples on how to calculate errors for repeated readings have been given in Section 3.7. The following are some other examples that are intended to help you get used to the other algorithms.

Example 1: Find the error in the pressure (*P*) where $P = h\rho g$.

Since on left hand side the ρ and *g* will be considered to be constants, it immediately follows that:

$$\delta(P) = \rho g \, \delta(h).$$

Example 2: Find the error in e/m_e where $\dfrac{e}{m_e} = \dfrac{2Vr_H^2}{0.72^2 \, \mu_o^2 N^2 m}$.

We will only consider the case where only *m* is variable. (Note that this is not the case in your practicals.) Hence like in Example 1,

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[1] Note that the procedures given in this manual refer to those for Words 2003. If you are using Words 2007 and later or Open Office you will probably have to adapt these instructions.

$$\delta\left(\frac{e}{m_e}\right) = \frac{2Vr_H^2}{0.72^2\,\mu_o^2 N^2}\,\delta\left(\frac{1}{m}\right)$$

We can now ignore the constant part and work only with the variable term for which we have to calculate the error. This can be found using,

$$\frac{\delta(1/m)}{1/m} = \frac{\delta(m^{-1})}{m^{-1}} = \frac{\delta(m)}{m}.$$

(If the above step is not clear, substitute $z = 1/m$, and work it out.) Hence,

$$\delta\left(\frac{1}{m}\right) = \frac{\delta(m)}{m^2}.$$

Substituting back,

$$\delta\left(\frac{e}{m_e}\right) = \frac{2Vr_H^2}{0.72^2\,\mu_o^2 N^2}\,\frac{\delta(m)}{m^2}.$$

Example 3: Find the error in the error in η where $\eta = \dfrac{\pi P a^4}{8Ql}$.

In this case only l, 8 and π are constants (Note that this might not be so in your practicals). Hence again as in Example 1,

$$\delta(\eta) = \frac{\pi}{8l}\,\delta\left(\frac{Pa^4}{Q}\right),$$

and we can now concentrate on the variable term. The error in this is given by,

$$\frac{\delta\left(\dfrac{Pa^4}{Q}\right)}{\left(\dfrac{Pa^4}{Q}\right)} = \frac{\delta(P)}{P} + \frac{\delta(a^4)}{a^4} + \frac{\delta(Q)}{Q}.$$

(If the above step is not clear, substitute $z = Pa^4/Q$, and work it out.) It can be noted that the second term involving a is not in a linear form. To simplify it we can use the fact that,

$$\frac{\delta(a^4)}{a^4} = 4\,\frac{\delta(a)}{a}.$$

(If the above step is not clear, substitute $z = a^4$, and work it out.) Hence substituting back,

$$\delta(\eta) = \frac{\pi}{8l} \left(\frac{\delta(P)}{P} + 4\frac{\delta(a)}{a} + \frac{\delta(Q)}{Q} \right) \left(\frac{Pa^4}{Q} \right).$$

Example 4: Find the error in the dimension (*d*) of an object if it was found by subtracting two positions (x_1 and x_2) of a moving telescope.

Since $d = x_2 - x_1$ and knowing that errors are additive, it immediately follows that,

$$\delta(d) = \delta(x_1) + \delta(x_2) = 2\delta(x).$$

Example 5: Use the table found at the end of Section 3.7 and the values of linear regression calculated in Section 3.9: Point 3.9.8 to find the error in the gradient and in the intercept.

$$\delta(m) = \frac{m}{\sqrt{n-2}} \left(\frac{1}{r^2} - 1 \right)^{\frac{1}{2}} = \frac{7.9771}{\sqrt{6-2}} \left(\frac{1}{0.9989^2} - 1 \right)^{\frac{1}{2}} = 0.1872 \text{ A V}^{-1}$$

$$\text{and } \delta(c) = \delta(m) \left(\frac{1}{n} \sum_{i=1}^{n} V_i^2 \right)^{\frac{1}{2}} = 0.1872 \sqrt{\frac{0.55}{6}} = 0.05669 \text{A}.$$

Point 3.10.2:

Be reasonable when indicating errors for calculated values. Usually one significant figure will suffice. In any case three significant figures should not be exceeded.

Point 3.10.3:

You are specifically requested to find the combined error for every result being asked. Example if you are asked for the ratio of e/m_e, you do not simply find the error in the gradient. With this respect one should note that it is not necessary that the result's error is involved in the error of the main term requested for the investigation. It is sufficient that you have been asked to calculate the term itself. Example, if you are asked to find the apex angle of a prism in order to calculate the refractive index, you are expected to produce the error in the apex angle.

Point 3.10.4:

You are also requested to find the **percentage error** for each of the main quantities being asked for. The equation is given by,

$$\text{Percentage Error} = \frac{\text{Combined Error}}{\text{Experimental Value}} 100\% .$$

This should also be included in this section. Note that its value should be reasonable i.e. does not exceed 20%. If it does this would be indicative that your calculations have something wrong and should be checked.

Note that **the percentage error is a measure of the precision**. This is a measure of the readability error of the instruments used and/or how precise have been your readings. In general a value smaller than 10% indicates good precision. You are expected to restate and comment on the precision in your discussion, justifying any high value.

Point 3.10.5:

Whenever there is a quoted value you are expected to calculate the **Accuracy**, a quantity that should also be included in this section. This is defined by,

$$\text{Accuracy} = \left| 1 - \frac{\text{Experimental Value}}{\text{Quoted Value}} \right| 100\% \ ,$$

Note that in general this should be reasonable i.e. does not exceed 20%. If it does this would be indicative that your calculations have something wrong and should be checked.

Note that **accuracy is a measure of the accuracy of the experiment**. It is a measure of how close your value was to the expected one. As it is defined, the accuracy is in terms of the difference from the quoted value, hence the closer to zero it is the better. In general a value smaller than 10% indicates good accuracy.

You can also define the *Accuracy* in terms of the ratio of the experimental and quoted values. In this case the closer to 100% your answer is the better it is. The important thing is that you do not confuse the two definitions, i.e. be consistent it you start with one definition keep on using it.

Since the *Accuracy* is very important to determining how correct you final result was you are expected to restate and comment on in your discussion, justifying any high value.

Point 3.10.6:

Once you have calculated the combined error, you will be requested to write the result together with its error in a consistent way. Example $m = (2.34 \pm 0.03) \times 10^{-3}$ kg. Usually such a representation should be included in the discussion.

3.11 Conclusion or discussion

Point 3.11.1:

Use an impersonal construction and the passive voice.

Point 3.11.2:

State the values of the quantities you were supposed to calculate including the error, percentage error and accuracy that you have calculated.

Point 3.11.3:

In the discussion you are expected to:

- Interpret the results obtained.
- Understand the physical principles and procedures involved.
- Do research work.

The following list of points can help you to show all this.

Point 3.11.4:

Mention the order of magnitude difference between the experimental and the quoted value. By order of magnitude we refer to the ratio between the experimental and the quoted value. If this is approximately equal to 10^N then the order of magnitude difference is N.

Point 3.11.5:

Comment on the percentage error and the accuracy: Are they low or high? If they are high what is the most likely reason? Does the percentage error justify the accuracy? i.e. does the uncertainty interval defined by the combined error encapsulate the quoted value?

Point 3.11.6:

Comment on the sources of errors giving their relative contribution to the discrepancy between your value and the expected one. Discuss the precautions and see if some things could have been performed better.

Point 3.11.7:

Comment on the graph(s) indicting how well the points describe the line or curve they should have given.

Point 3.11.8:

Propose improvements on the procedure adopted. Be reasonable in your comments making only sensible comments. Remember that your setup has been previously used to obtain remarkably good experimental values.

Point 3.11.9:

Comment on the results obtained, this time in terms of their physical significance or indications that they give. For example a plot of the IV-characteristic of a component will allow you to decide if it is ohmic or non-ohmic. In any case a description of the behaviour should be given.

Point 3.11.10:

Comment on the physical principles involved.

Point 3.11.11:

Specify the use of the experimental value you have been asked to calculate.

Point 3.11.12:

Mention other methods used to determine the experimental value you were requested to obtain and compare them.

3.12 References

Since you are expected to do some research on the topic you should also include from where you have derived the information you are writing down. This is usually done in two parts. At the end of the report there should be a full list of the references under the heading "References." Then in the text, whenever it is necessary to indicate from which reference you have obtained the information you are using. A detailed explanation of how to carry this out can be found in Section 5.16.

Please keep in mind that adequate referencing in your work is a must. Failure to do so leads to plagiarism that is a very serious academic offence. In Section 5.17 you will be directed to where you can obtain further information about this topic.

3.13 Check the sheet to see that you have done everything

Point 3.13.1:

Read the entire sheet provided again to see that you have left nothing out.

Point 3.13.2:

Sometimes you will not be asked to do something specifically but it will only be hinted. Make sure to identify such requests.

3.14 Check list for B.Sc. practicals:

1) Date

- Write the date of the day when the experiment was performed.

2) Name and Surname

3) Experiment number

4) Title

5) Instrumentation

6) Sources of errors and precautions

- Three subsections: Systematic errors, Random Errors and Precautions. Error section divided by type.
- Use point form, the past tense and an impersonal construction.
- Be brief and concise as consistent with what you want to say.
- For the errors use relative statements.
- For the precautions write what has been done.
- Write all the errors that you might think about and precautions that you have used in this section.

7) Data collection and tabulation

- Tabulate all the quantities you are requested to measure.
- **Take repeated readings**.
- Quote the readability interval and error.
- Work the errors for quantities that will be tabulated.
- In the first row (or column) of the table write the quantity divided by its unit.
- Define symbols being used as appropriate
- In the second row divide by the multiplicative factor if/as required.
- Use the next line for the absolute or calculated **error**.
- Check values for decimal consistency.
- Take a minimum of five readings.

8) Graph

- Plot the graph(s) using a computer program.
- Place a heading for the graph and for the axis.
- Divide quantities in the headings by the units as appropriate.
- Use multiplicative factors as required and indicate this on the axis only.
- **Draw the best straight line or curve** that can describe **all** the points.

- Check readings or calculations for points that lies far away from the best straight line or curve.

- **Insert Gridlines**

- Indicate on the graph any points that are being read.

- Remove colour from the graph.

9) Calculations

- Use clear intelligible steps.

- Indicate units wherever appropriate.

- Write the equation indicating the intercept, the independent and dependent variable and identify the gradient.

- Make sure that all quantities you are using have been tabulated.

- Check if you need to multiply quantities by any multiplicative factors.

- Make quantities to be determined subject of the formula.

- Check consistency of units.

- Use linear regression to find the quantities needed.

- Print the results obtained from linear regression (first two columns).

- Do not repeat symbols especially m.

- Make sure that the values obtained are reasonably good.

- Be reasonable in the number of decimal place and significant figures in which you quote calculated values.

- Use an impersonal construction and the passive voice for any comment you want to include.

10) Calculations of errors

- Calculate the errors for any value you have been asked for.

- Be reasonable in the number of significant figures you use when indicating errors.

- Give the calculated error to a reasonable number of significant figures.

- Find the **percentage error** for each of the main quantities.

- Calculate the **Accuracy** wherever possible.

- Write the result together with its error in a consistent way.

11) Conclusion or discussion

- Use an impersonal construction and the passive voice.

- State the values of the quantities you were supposed to calculate including the error, percentage error and accuracy.

- Interpret the results obtained.

- Do research work.

- Mention the order of magnitude difference between the experimental and the quoted value.

- Comment on the percentage error and the accuracy.

- Comment on the sources of errors giving their relative importance.

- Discuss the precaution and see if some things could have been performed better.

- Comment on the graph(s).

- Propose improvements on the procedure adopted.

- Comment on the physical significance or indications of the values derived.

- Comment on the physical principles involved.

- Specify the use of the experimental value you have been asked to determine.

- Mention other methods used to determine the experimental value you were requested to obtain and compare.

12) References

- Include all reference used.

- Indicate citations in text.

- Do not copy and paste from internet.

13) Check the sheet to see that you have done everything.

- Read the entire sheet provided again to see that you have left nothing out.

- Identify hinted requests.

Chapter 4 Errors and Precautions

Each and every experimental procedure is bound to have an associated error. It is quite unlikely that it will be possible to remove completely the error. However, it will definitely be possible to minimize its effect on the reading to be taken. The following provides a list of the most common sources of error, together with the precautions that should be taken and the way to refer to the error and precaution.

4.1 Alignment

Sometimes the apparatus needs to be aligned in order to obtain reasonable readings. This is especially true in the case of optics experiments. Such an error can be quoted as,

"The apparatus might not have been perfectly aligned."

Obviously the associated precaution would be that the set up is aligned at its best. This can be written as,

"The apparatus was aligned."

Note that the error could still be present even though it has been accounted for with a precaution. For this reason it should be mentioned in the error section.

4.2 Cleanliness

Dirt can interfere with the readings being taken, by for example, refracting, diffracting or reflecting incoming light rays or prevent two surface or mediums to make good contact. This error can be referred to as,

"The apparatus might not have been perfectly clean even after cleaning."

As can be noted from the way in which the error was quoted, it is expected that the apparatus is thoroughly cleaning:

"The apparatus was cleaned."

4.3 Contact potentials

When two materials are place in contact, electrons will flow from the more electronegative one (which is more prone to give off the electrons) to the other. This creates a potential across the junction, which will either need to be overcome before any current can flow or will add up to the applied potential increasing current flow. Thus, the potential will change across the junction, inducing an error that is simply referred to as:

"Contact potentials."

There is little that can be done for such an inconvenience. One such thing is to reverse the order of the materials in a second junction so that the potential lost at one end would be gained at the other:

"The order of the materials was reversed in successive junctions so as to reduce contact potentials."

4.4 Human time reflex action

The human being is not a perfect machine. For this reason a delay is introduced between the perception of an external stimulus and the reaction to it. This can provide an error when instantaneous reactions are required like for example starting a stop watch at a particular instant or taking a reading at a pre-established time. This is referred to as,

"The human time reflex action."

Considering the fact that this is a radon error, the only way to limit it (apart from automating the process something that is not considered here) would be to take repeated readings:

"Repeated readings were taken."

In the case were the time for one cycle is required but it is possible to take the time for multiple cycles, then more then one cycle should be timed and then the time for one cycle determined by dividing the total time with the number of cycles:

"The time for a number of cycles was determined and then the time for one cycle was calculated."

It is to note that if the time of one complete oscillation is required from a pendulum system, then in general, as a minimum, twenty complete cycles should be timed. Also the fact that this precaution has been taken does not mean that the experimenter can be undergone without taking repeated reading, i.e. a second reading of twenty oscillations would be requested.

4.5 Parallax error

The parallax error is encountered when the measuring device cannot be placed directly in contact with the scale. Examples include analogue meters and measuring a length at a distance due to a limit in the design of the equipment or apparatus. Such errors can be referred to as:

"Parallax error when reading the analogue meter" and
"Parallax error when measuring the height of the cantilever from the ground."

Remember to specify the device if this is not immediately clear.

The precaution for this error involves taken readings from a perspective perpendicular to the measuring device. This act is can be referred to as:

"Readings were taken at eye-level."

It is to note that in this case no reference needs to be made to the devise as this would have already been specified in the error section.

4.6 Scale rounding-off error

The scale rounding-off error is rarely quoted. It arises when the combined error in a quantity is heavily dependent on that of some term due to the limited precision with which this has been obtained. Using the example indicated in Section 2.2.2, is should be expressed as,

"Scale rounding-off error in the metre ruler: readability error $\pm 0.001\,\mathrm{m}$."

In order to decrease this error, it would be necessary to increase the precision of the term causing it. For this reason it is good practice to choose an adequate measuring instrument for each reading. Thus, for example, the device of choice to measure the diameter of a thin wire would be a micrometer screw gauge and not a meter ruler or a venire calliper.

4.7 Scale zero error

Every measuring instrument has a datum or zero level from where to take the readings. This zero level could be off set due to some mechanical or electrical reason. Examples include the shifting of the pointer of a stopwatch from the zero value and the change in the zero reading of a voltmeter due to noise in the circuit. In the first case the error should be referred to as,

"The stopwatch had a scale zero error."

The correction for this error involves noticing the bias of the instrument and adjusting the measurements accordingly:

"The readings were corrected for the scale zero error of the stopwatch."

The procedure adopted should also be evident in the tabulation of data section, where the shift from zero should be specified, together with the values read and those corrected. Failure of including this work in the report will lead to a penalization in the markings.

4.8 Variation of dimensions

Frequently the dimensions of an object will vary in space, not simply due to a ware and tear of the object but also to a limit in the production phase. Such an error is frequently encountered when measuring the diameter of a wire (or rod) and can be referred to as,

"Variation of the diameter across the length of the wire (or rod)."

Since this is a random error the way to limit it is by taking repeated readings:

"Repeated readings were taken."

Note that a good way to account for the variation in diameter of a wire consist of choosing at least five points and at each point take two readings at right angles to each other.

4.9 List of errors and precautions

The list of all possible errors and precautions is probably too extensive to be summarized in any real effective way. Thus the text below only attempt to summarise the most commonly encountered errors and precautions one expects to come across when doing a simple laboratory experiments. Note that the actual writing down of the error or precaution might need to be adjusted to suite the particular setup you are using. In addition, the comments in square brackets i.e. [] are there only to explain the error and should be omitted during the write up.

4.9.1 Common errors

- {System} not perfectly aligned.
- {System} might not be uniform [this would be due to imperfection at construction stage].
- {Resistive forces} have been ignored [for example friction at the point of pivoting and air resistance on the motion of a pendulum].
- {System} not perfectly vertical [example a ruler to measure] or horizontal [example when finding the centre of gravity of a rod].
- Parallax error [occurs when you are measuring a scale at a distance, such as length when the metre rule is not in contact with the object or an analogue metre].
- Human time reflex action [occurs due to a human time delay between observation and doing something else such as starting a stopwatch].
- {System} not perfectly clean [this is particularly important when you are using optical instruments such as lenses, prisms or diffraction gratings].
- Scale zero error in the {instrument} [occurs when the instrument does not start from zero but from some other value; this is most frequently encountered when using the micrometer screw gauge].
- Variation of {dimension} along {some length} [this occurs because rods, bars, wires, disks and the like do not have exactly the same size everywhere due to a limit at the production phase or due to ware and tier].
- Contact potentials [error due to a potential barrier created when wires of two different materials are placed in contact; it applies to most of the experiments involving electric circuits].
- Miscounting a {quantity} [examples include counting 21 oscillations when you should count only 20]
- {Substance} not pure [occurs when you want the property of some substance but you are not using a pure sample; an example would be using tap water, which is not pure water].

- Ammeter does not have zero resistance [ammeters should ideally have zero resistance; this cannot be the case in practice as some energy is used to drive them; when using a multimeter as an ammeter its resistance is very small].
- Voltmeter does not have infinite resistance [ammeters should ideally have infinite resistance; this cannot be the case in practice as some energy is used to drive them; when using a multimeter as an voltmeter its resistance is very high].
- {Instrument} might not have been perfectly calibrated.
- Resistance wires were ignored [applies to almost all experiments involving current].
- Changes in {physical properties} due to changes in temperature [examples include wires that heat up causing their resistance to increase; object that heat up and expand; and density of a substance].
- Draught [light flow of air] changing or disturbing the setup [example by cooling some component or pushing a pendulum].
- Mass of hanger was ignored.
- Misjudging the position of best alignment [applies when you are using a Vernier scale].
- Apparatus might have moved while taking the readings [applies when not every piece of apparatus is held tightly and the change in position affects the results]
- Beam of light was not narrow [in optics experiments this can limit the precision].
- Variation in the supply voltage and/or current [applies to most experiments involving electricity].
- Oscillations might not have been perfectly planar [in the case of pendulum like systems] or linear [in the case of mass spring systems; this is a frequent assumption made in the derivation of the equations].
- Oscillations might not have sufficiently small [in most derivation oscillation are assumed to have small amplitudes].
- Not enough time might have been given to the {system} to reach thermal equilibrium.

Note that the errors have be written in a general form. Whenever they are used in a write-up the terms in curly brackets {} should be replaced by the system, instrument, quantity, etc. that it is being referred to. Likewise the terms in square brackets [] should be omitted.

4.9.2 Common precautions

- Repeated readings were taken [since taking repeated readings is considered part of the procedure this type of precaution should be used when no other major precaution has been carried out].
- {System} was aligned [see associated error].
- {System} was as vertical or as horizontal as possible [see associated error].
- Reading on the {instrument [to be specified]} were taken at eye level [see parallax error].
- The time for twenty oscillations was found and then divided by twenty to determine the periodic time [one of the possible precautions corresponding to the human reflex action error].
- {System} was cleaned [see corresponding error].

- {Instrument} was checked for scale zero error and if found it was accounted for [this is done by using the smallest value that the instrument can read as the new zero; see corresponding error].
- Doors and windows were closed in order to avoid draught [see corresponding error].
- Care was taken not to move the apparatus while taking readings [see associated error].
- The {instrument [such as micrometer screw gauge and Vernier calliper]} was locked in position while taking the readings.
- When using the micrometer screw gauge the ratchets was used to limit the force exerted on the object being measured [avoids squashing the object].
- The {system} was allowed to stop vibrating before taking the readings.
- It was ensured that the connections were tight [applies to almost all experiments involving electricity].
- The circuit was switched on for the least amount of time possible to take the readings so as not to heat up the components where possible [applies to most experiments involving electricity].
- Care was taken not to disturb the lamp when lit so as not to damage it.
- Care was taken not to exceed the scale on the ammeter and/or voltmeter [this could break the instrument whether it is analogue or digital].
- Oscillations were as planar (or linear) as possible [see corresponding error]
- Oscillations were as small as possible [see corresponding error].
- The oscillations were timed from a position that was at right angles to the plane of oscillations at the point where the amplitude is at its maximum [such positioning helps to assess when the system is exactly at its maximum.]
- The {system} was given a significant amount of time to settle before taking readings in order to ensure that it has reached thermal equilibrium.

Note that the precautions have be written in a general form. Whenever they are used in a write-up the terms in curly brackets {} should be replaced by the system, instrument, quantity, etc. that it is being referred to. Likewise the terms in square brackets [] should be omitted.

Chapter 5 Write-up formatting

5.1 Importance of proper formatting

It often happens that students are more interested in the scientific content of the write-up then in the actual presentation or formatting. A typical statement that a student may use to justify his attitude is: "If the scientific content of my write-up is good, why should I bother with the formatting?"

However, things are not that easy. Remember that science revolves around having a systematic approach in your dealings. This applies not just to the scientific investigations begin carried out but also to the grammar, punctuation, spelling, formatting and the like involved in the write ups. For this reason, proper formatting of the write-up is part of the skill you are expected to learn while reading your degree.

If such an explanation does not convince you, there is always another way of looking at things. We live in a world that is dictated by aesthetics: When we decide to buy a product, tendentiously we don't just look at its performance but we also take into consideration it looks. A simple way of checking this out is asking yourself whether you would prefer a car that runs on almost nothing but looks as if it came from prehistoric times or a sports car irrespective of how much it consumes. Put in simple terms: If you want to sell something you'd better make it look nice otherwise you will not make a good profit.

5.2 Language, spelling and grammar

Preferably the write-up should be in UK English, even though US English will also be accepted. However, you should ensure that you don't mix the two. As a tip remember that the default spell check language of most word processors is English US. Thus if you want to make sure that you don't have a mixture of spelling of UK and US English, you should change the default setting.[1]

The write-up should also be free from spelling and grammatical mistakes. You can use the spell check utility provided by the word processor you are using to help you discover this type of errors. Even so, some typos like writing "meat" instead of "meet" can still persist as it often happens that when we proof read our own work we repeat the same mistakes. One way of trying to reduce the number of spelling mistakes is to proof read the work a month or so after first writing it. This will allow you to look at it with fresh eyes.

In some cases sentence structure might be an issue. The generally recommended procedure would be to use short sentences and to limit the number of ideas expressed in one sentence to the minimum. This will avoid getting you into long argumentations that can end up being hard both for you and any reader to follow. As a general rule

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[1] Please note that due to the variety of word processors currently in use, it is not possible to give instructions that apply for each one of them. You should refer to the help manual of the word processor you are using for assistance.

remember that if a sentence is more than a couple of lines long, it can probably be split up into two. Also a paragraph consisting of one single sentence is definitely not on.

Please remember that it will always be your duty to ensure that the write-up is free from grammatical and spelling mistakes and you should not expect your tutor to deal also with this problem. If you think that your English is not good enough it is permissible to ask a third person to proof read your work. This does not mean that you are allowed to ask a third person to write the report himself but just to read your work and suggest improvement. Obviously the person's work should be duly acknowledged in your write-up.

5.3 Font and font size

The font should be preferably Times New Roman. This will avoid confusion between similar letters and numbers such as the letter "l" (ell) and the number "1" (one).

Regarding the font size this should be at least set to 12 points so as to make the text readable.

5.4 Paragraph and line formatting

There are two accepted ways of formatting a paragraph:

- Either you start flesh form the left and you skip a line between paragraphs, or

- You indent the first line but then you don't skip a line between paragraphs.

You may choose any of the two. However, a mixture of the two, like indenting the first line and then skipping a line each time, is not acceptable.

The paragraph should have a margin to the left and to the right of about 3 cm. In addition a space of about 2.5 cm should be left at the top and bottom of the page. The typed text should also be justified.

Regarding the line spacing in general this should be kept to 1.5. Note that the default value in the most common word processors is single spacing (i.e. 1).

5.5 Capitalisation

Well this might sound easy – just ensure that the first letter at the beginning of each sentence and of names is a capital letter. In most cases you are right. However, you should remember that capital letters are generally harder to read than small captions. Thus you should try to limit the amount of capital letter you use. For example a title consisting of more than one word should only have the first one capitalised unless a name is used. Likewise if you want to emphasise some word or words, you should try to use italic, bold or underline rather than capitalise. This will make your work more readable.

5.6 Footnotes

Footnotes are a way of inserting annotations to the main text. They should be used with care so as not to break the flow of the work. In the case a footnote is required this should be placed at the bottom of the page. The preferred symbols to use in order to cross-refer to the footnote are Arabic numerals superscript, with the footnotes being numbered consecutively according to the order in which they are referred to in the main text. Preferably numbering should restart on every page.

The footnotes should be written in the same font as the main text but with a smaller font size, namely 10 points. They should also be justified and the order in which they are listed should reflect the order in which they are cross-referred to in the main text.

5.7 Short hand notations and acronyms

You should not assume that the reader is familiar with short hand notations or acronyms even if they are standard in the field of work. Thus you should define all short hand notations and acronyms the first time you use them. In the case the number of short hand notations and acronyms is extensive, you should write a list explaining them at the beginning of your work.

5.8 Numerical values

In the case numerical values appear in the text, it is customary to write numbers from zero to ten as words while higher order values using Arabic numerals, namely a combination of 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9. In the case of a list containing values higher and lower than 10 they should all be written using Arabic numerals. On the other hand, if the number occurs at the beginning of a sentence this should be written as text.

It is important to keep in mind that the Arabic numerals should never be italic not even when they are used as subscripts.

5.9 Mathematical operators

The following is a table of mathematical operators that you might need to use in your work:

Mathematical operator	*Symbol*
Addition	$+$
Subtraction	$-$
Multiplication	$\times$
Division	$\div$ or $/$

Mathematical operator	Symbol
Equals	$=$
Not equal	$\neq$
Approximately equals	$\approx$
Greater (or smaller) than	$<$ (or $>$)
Much greater (or smaller) than	$<<$ (or $>>$)
Implies	$\Rightarrow$
Derivative with respect to x	$\dfrac{d}{dx}$
Partial derivative with respect to x	$\dfrac{\partial}{\partial x}$

List of common mistakes:

- Minus sign: This is a hyphen "-" while this is a minus sign "–". In general word processors give a hyphen as the default option. You can insert the minus sign either using the *insert symbol* or else most word processors convert a hyphen to a negative sign when you write something of the form "xxx - xxx" and then press space or enter.

- Multiplication sign: This is the letter "x" (ex) while this is the multiplication sign "$\times$". You can insert the multiplication sign using the *insert symbol* utility.

- Degrees symbol: This is the letter "o" superscript "º", while this is the symbol for the degrees "°". You can insert the partial derivative using the *insert symbol* utility and then looking for the *degrees sign*.

- Partial derivative: This is the Greek letter delta "δ" while this is the partial derivative sign "∂". You can insert the partial derivative sign using the *insert symbol* utility.

5.10 Brackets

It can often happen that you will have to use a set of brackets within another set of brackets. In order to facilitate the understanding of the order of the brackets the following system is suggested:

- First use a round bracket, i.e. ( )
- Then use a square bracket, i.e. [ ]
- Finally use a curly bracket, i.e. { }

-    If this is not enough, repeat.

Thus you should have something of the form $\{\ [\ (\ )\ ]\ \}$.

5.11 Units

In general the units should be in SI unless one is dealing with some particular subject where there is some other conventionally employed system. They can be written either in full for example newton seconds or else using the standard abbreviations for example N s. However, a mixture of the two would not be considered acceptable.

There should be a space between the numerical value and the unit and another between each unit. The latter requirement is needed to distinguish between for example metres seconds (m s) and milliseconds (ms). The negative power notation like $\mathrm{m\,s}^{-1}$ is preferred to the slash notation like m/s.

It is important to keep in mind that the standard abbreviations of units should never be italic.

Common mistake: The fact that a space should be included between the unit and the value includes the use of percentages (%) and degrees Celsius (°C). The only common expectation to this rule is given by the degrees (°) when they refer to angles, in which case no space should be included.

5.12 Variables

The way in which we write variables depends on what they represent. In the case they represent quantities that have only a magnitude, we can write them in italic like for example the speed which can be written as v. It is also generally accepted to write symbols representing matrices and tensors in the same way.

If the quantity being represented is a vector the symbol should either be bold, e.g. **v** or over lined with an arrow, e.g. $\vec{v}$.

Note that letters indicating a point are not considered as variables and hence should not be written in any special way. Thus for example if we have two points we can call them Points P and Q and the displacement between them can be written as $\overrightarrow{PQ}$.

In the case the number of symbols used in the work is very large, it would be recommended to have a list of symbols at the beginning of the work. The list should start with Roman type followed by the list of Greek symbols each of which should be given in alphabetical order.

5.13 Subscripts and superscripts

The way in which subscripts and superscripts are written follows the same rules as those given for numerical values and variables. Thus, Arabic numeric used as subscripts and superscripts should not be italic while variables should generally be italic unless they represent vectors, in which case we can write them as bold. Examples include, x^2, y_i and $d_\mathbf{v}$.

In the case the subscript or the superscript is a word, this should not be italic. For example the effective velocity can be written as, $v_{\text{Effective}}$. If one wants to abbreviate effective to "Eff" it is possible to write v_{Eff}. In short if the subscript or superscript represents a word or a short hand for a word it should not be italic.

As a particular point, please note that generally the original or initial value is denoted by a zero as a subscript not the letter "o" (ow). Thus the original length should be written as l_0.

In the case that the number of subscripts and superscripts used is extensive, it is recommended that a list is provided at the beginning of the work. This should be placed immediately following the list of variables (Section 5.12) with the roman type coming first, and the Greek symbols second.

5.14 Equations

Equations should be labelled using consecutive Arabic numerals, starting from one, in the same order in which they appear. Conventionally the number is placed in curly brackets flash on the right hand side of the paper as shown below:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \tag{10}$$

If the work is extensive and there are many chapters, it is possible to include the chapter number at the beginning. For example if the equation above is the 10th in chapter two it can be labelled (2.10). If this notation is used then the equations should start to be numbered again from one at the beginning of each chapter.

Regarding the location of the equation, this can either be placed at the centre of the remaining space or else it can be written after an indentation to the left. Both of them will be allowed provided the work is consistent.

In the case you are wondering how you can write the above easily using a word processor, the suggestion would be to use tables. As a tip also remember that most word processors offer the possibility of automatically numbering your equations.

The numbering of the equations allows easy reference to them. For example to refer to the equation above, it is possible to write Equation 10, Equation (10), Eq. 10 , Eq. (10)

or simply (10). All of them would be acceptable provided the work is consistent. The only limitation occurs if you refer to the equation at the beginning of the sentence, in which case you should write the word "Equation" in full.

5.15 Figures and tables

Figures and tables should be used to represent results or to help in explaining things. They should be used with caution as too many figures or tables might hinder the reader from following the arguments in the text. If the number of figures or tables becomes extensive, and no way is found in order to limit their number, it is possible to place them in an appendix and only include in the main text a summery of what they represent.

The figures and tables should have a caption explaining what is contained within them. In general the caption should start with the words Figure for a figure and Table for a table followed by a number. Both the letter and the number should be written bold. The number is assigned in increasing order starting from one depending on their appearance in the work. Thus the first figure to appear is assigned the number one, the second one to appear the number two and so on. In the case the work is very long and there are a number of chapters, it is customary to also label the figures and table using the chapter number in which they are included. In this case the numbering restarts at every chapter.

All figures and tables that are included in the work should be referred to in the main text. One should take care that if a figure or a table is referred to in the main text, it should also be found somewhere in the work. The order in which the tables or figures are referred to should also reflect their position within the text. Thus, for example, the first figure to appear in the text should be labelled **Figure 1** and should also be the first one to be discussed in the main text.

In order to refer to the figures and tables in the main text one can use the label and the number. Thus if you want to refer to the second figure you can just write Figure 2 or Fig. 2. In the latter case the full label (Figure or Table) should be used when the cross reference appears at the beginning of a sentence. While there are other ways of referring to the figure and the tables, such as the use of the words, "above" or "below" their use is discouraged. The reason for this is that the position of the figure or table might change in time due to formatting needs so that something that was initially above might end up below leading to an error in the cross-reference. Hence, in order to avoid such problems, it is advisable to use only the caption and the number.

Please note that to improve the flow of the work the figures and tables should be blended within the text so as to maximise the use of the available space. Preferably their location should be close to the location in the text where they are referred to.

A list of figures and another one of tables should be provided at the beginning of the work irrespective of how many figures or tables have been used.

5.16 References and bibliography

Applying proper references is a factor of major importance in any scientific write up. References are used either to validate the arguments or concepts being expressed or else to acknowledge the fact that what is being written is not a product of one's own work but of someone else's. One should be very careful on how to deal with references as mismanagement can lead to plagiarism which is a type of academic misconduct that is considered to be very series and can lead to disciplinary actions against the perpetrator.

The use of references has two parts. One of them is to have a section at the end of the work, before the appendices, where you include a full description from where you have obtained the reference. The other is to cross-refer to the reference in the main text whenever you want to validate your argumentations or indicate that you are using someone else's work. The details of how to do this depend on which referencing system you decide to adopt. The main referencing systems are the Harvard and the Vancouver (or author-number) system. These are described in the sections that follow.

On going through these sections, please keep in mind that different institutions can adopt slight variations to what is suggested in this work. All of these will be considered acceptable in your write-ups provided you are consistent throughout your work.

Note that all the references included in the reference section should be cross-referred to in the main text. In the case that you have read a book, an article or the like but you are not using anything directly in the main text, then you should include that reference in another section called bibliography. Thus the bibliography will contain all the sources you came across in you work and that you actually have read but that you are not making direct use of them in your work. For consistency the style used in your bibliography should be the same one employed in the reference section. Note that a bibliographic section might not be needed if all references are used in the main text.

5.16.1 The Harvard system

Reference section:

The way in which the references are described in this section depends on the nature of the source. Thus for example the way to write a reference of a book will be different from that of a paper from a journal. A comprehensive list of the format that should be adopted when writing references is given below. Once the reference has been written in the appropriate manner, the list should be arranged in alphabetical order.

Books:

Surname, Initials (Date of publication). *Name of book in italic*; Publication House: Country of publication.

Illustration:

Batschelet E. (1981). *Circular Statistics in Biology*; Academic Press: New York.

Papers:

Surname, Initials (Date of publication). Title of paper; *Title of Journal in italic*, **volume(issue)**, pages.

Illustration:

Ackermann, G.R. (1983). Means and Standard Deviation of horizontal wind components, *Journal of Applied Meteorology*, **22(2)**, 959–961.

Castans, M. and Barquero, C.G. (1998). Some Comment on the Study of Low Persistence Wind: Discussion, *Atmospheric Environment*, **32**, 253–256.

Technical report:

Sometimes, a commercial company, a state agency or some academic institution produce a report that is not properly published. By this it is meant that the work carried out as well as conclusions are not published in a book or a peer reviewed journal. Hence such technical reports, as they are called, are considered to be non-standard references (*cf*. Section 5.16.4). At the same time, given that they are endorsed by the commissioning entity and are written by fully qualified people, the contents can in general be taken to be correct. However, alternative sources, namely books or/and published journal articles, detailing the same material should be preferred over technical reports. In case this is not possible, you can use the following format in order to list them in the reference section,

Surname, Initials (in case of a single or multiple authors) or corporation name (in case of a corporation), (Date of publication). *Title of technical report*, report reference number or code if available; institution endorsing the report, url address if available online, date of last accessed if available online.

Illustration:

Cho, S., Im, P. and Haberl, J.S. (2005). *Literature Review of Displacement Ventilation*, Technical Reports from the Energy Systems Laboratory.

PG&E (1997). *Thermal Energy Storage Strategies for Commercial HVAC Systems*, an application note of the Pacific Gas and Electric Company, available online at http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/inforesource/thr mstor.pdf, last accessed on 3rd March 2012.

Websites:

Websites are a type of non-standard reference. Thus caution should be used if one decides to resort to them (*cf*. Section 5.16.4). Given that it is only recently that references to websites have become popular, the way in which they are referred to is in constant evolution. The following describes one of the currently suggested versions:

Surname, Initials (in case of a single or multiple authors) or corporation name (in case of a corporation), (Date of publication), *title of page*, url, date on which it was accessed.

Illustration:

Weisstein, E.W. (2010). *Exponential Function From MathWorld--A Wolfram Web Resource*, http://mathworld.wolfram.com/ExponentialFunction.html. Date accessed, 14th of August 2010.

Busuttil C., (2009). *timesofmalta.com – What's that mysterious light in the night sky?*, http://www.timesofmalta.com/articles/view/20090323/local/whats-that-mysterious-light-in-the-night-sky, Date accessed, 14th August 2010.

The data of access is required due to the volatile nature of the websites that can change daily without prior notice.

Citations in text:

In order to support your argumentations or in order to indicate that the work you are referring to has not been conducted by yourself, a cross-reference is included immediately after or before the text under consideration. For all the case mentioned above, if the number of authors is less than three the format (Surname, Date) or Surname (Date) is used. Example (Johns, 1986) or Johns (1986), (Johns and Smith, 1986) or Johns and Smith (1986), Johns and Smith (1986) and Walters (1995) or (Johns and Smith, 1986, Walters, 1995). If the work has been carried out by more than two authors than you can use the format Smith et al. (1990) or (Smith et al. 1990).

Sometimes accessing the original text where work was originally carried out can be difficult and we only get to know the information we need through a second source, called the secondary source. In such a case we need to make clear that we did not read the primary source. This can be carried out by using one of these formats: Jones (1986) as cited by Smith (1990); Jones (1986 cited in Smith, 1990); or (Jones, 1986 cited in Smith, 1990).

5.16.2 The Vancouver system

Reference section:

The reference section is very similar to the one for the Harvard system except that each reference is given a number. The order of the reference should reflect the order in which the references appear in the text. Thus the first reference to appear in the text should be given the number one, the second reference to appear the number two and so on.

Illustration for a book:

[1] Batschelet E. (1981). *Circular Statistics in Biology*; Academic Press: New York.

Illustration for a paper:

[2] Ackermann, G.R. (1983). Means and Standard Deviation of horizontal wind components, *Journal of Applied Meteorology*, **22**, 959–961.

[3] Castans, M and Barquero, C. G. (1998). Some Comment on the Study of Low Persistence Wind: Discussion, *Atmospheric Environment*, **32**, 253–256.

Illustration for a technical report:

[4] Cho, S., Im, P. and Haberl, J.S. (2005). *Literature Review of Displacement Ventilation*, Technical Reports from the Energy Systems Laboratory.

[5] PG&E (1997). *Thermal Energy Storage Strategies for Commercial HVAC Systems*, an application note of the Pacific Gas and Electric Company, available online at http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/inforesource/thr mstor.pdf, last accessed on 3rd March 2012.

Illustration for a website:

[6] Weisstein, E.W. (2010), "Exponential Function From MathWorld--A Wolfram Web Resource," http://mathworld.wolfram.com/ExponentialFunction.html. Date accessed, 14th of August 2010.

[7] Busuttil C., (2009), "timesofmalta.com – What's that mysterious light in the night sky?," http://www.timesofmalta.com/articles/view/20090323/local/whats-that-mysterious-light-in-the-night-sky, Date accessed, 14th August 2010.

Citations in text:

In the text, it is possible to refer to the references using their corresponding number. For example if you want to refer to the fifth reference you just need to write [5]. In the case you want to refer to a number of references in succession, for example from one to four, you can use [1-4]. You can also combine single and continuous referencing such as [1-3,5] meaning that you are referring to reference one to three and five. Regarding information obtained from secondary sources one of the following formats can be used, [1] as cited by [2] or [1] (as cited by [2]).

An alternative that is commonly used is to include the name of the author. In the case where there is only one author it is possible to write Johns [1]. If two authors are involved one can write Johns and Smith [2] and while Johns et al. [3] can be adopted in the case of three or more authors are involved. Note that the references are sometimes written as superscripts.

Please remember that the order of the references in the reference section should be the same as that in the main text. Thus the first reference to use is [1] and not for example [3].

5.16.3 Comparison of the Harvard and Vancouver systems

The Harvard and Vancouver systems are widely used with one beginning preferred in journals on some topic and the other being preferred in journals with a different topic. Thus you are free to use whichever you prefer.

However, there are some points to consider when carrying out the choice. In the Harvard system, you can include a new reference in the middle of the others without major modifications of the text. On the other hand if you include a new reference in the Vancouver system, you will have to renumber all the following references both in the

reference section as well as in the text. The Harvard system has the added advantage that if you refer to a well known source in your field, for example Batschelet (1981), from the name and year one can easily identify the work without having to check the reference section.

The advantage of the Vancouver system over the Harvard system is that you can condense a lot of references. The fact that you can identify multiple consecutive references by simply writing for example [10-25] dramatically reduces the amount of text needed.

5.16.4 Non-standard references

Non-standard references refer to work that has not been formally published and hence has not been peer reviewed. The fact that it has not been validated makes its use questionable. For this reason efforts should be taken to try to avoid their use and instead adopt standard references such as books and journal articles.

The most common of the non-standard references are websites. In this internet era it has been come common practice to first brows the internet for information before looking somewhere else. However, in doing so, one must always remember that there is nothing that regulates the information found on websites. Thus you need to use the information with caution.

Case in point is Wikipedia – possibly the currently number one source of information on the internet and usually the first one to pop up when queering a search engine. While Wikipedia gives very useful information, there is nothing to guarantee that what is written is exact. Wikipedia can be edited by anyone, anytime, without any quality control. Thus, one cannot trust blindly what is found on it.

So should one just forget about Wikipedia? Not necessarily. Wikipedia generally provides an extensive list of peer reviewed sources. In this way Wikipedia can become a very useful starting point for obtaining peer reviewed information. This means that you are allowed to use Wikipedia as one of your references, however it should never, ever be your main or sole reference on the topic.

5.16.5 When do I need a reference?

If you are not sure if you need a reference or not ask the following two simple questions:

- Did I know the subject before reading about it?

- Did "I borrow" any idea or words?

If the answer to the first one is no or the answer to the second one is yes, you need a reference. This is especially true of the second one, where it is likely that you are plagiarising some work. In this case you might need to do more than just adding a reference. One example would be to write the "borrowed" words between inverted commas to indicate that those are not your own words but those of the author or authors indicated in the reference.

5.17 Plagiarism

Plagiarism follows if you use the work of others without fully acknowledging the original authors. Another way to say it is to induce someone to think that you have done the work when in reality you just copied it in some way. This is considered to be a very serious academic offense and severe disciplinary actions can result.

The treatment of what exactly constitutes plagiarism is very extensive and goes beyond the scope of this work. The student is referred to the *Plagiarism and collusion guidelines* provided by the University of Malta downloadable from http://www.um.edu.mt/__data/assets/pdf_file/0009/95571/University_Guidelines_on_ Plagiarism.pdf and the manual *How to avoid plagiarism* found at http://www.um.edu.mt/__data/assets/pdf_file/0006/95568/how_to_avoid_plagiarism.p df.

If you are in doubt whether or not the way you are writing falls under the definition of plagiarism it is suggestible that you ask for advice immediately. Your tutor, supervisor, or any member of academic staff should be able to guide you in this respect. However, remember that it is your duty and of no one else to ensure that your work is not plagiarised.

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Bibliography

Freund, J. E.; Miller, I.; Miller M. (1999). John E. Freund's Mathematical Statistics, sixth Edition; Prentice Hall: New Jersey.