APPENDICES

1 ERROR ANALYSIS

An essential part of any scientific measurement is an estimate of the uncertainty (or the confidence level) of this result. Each of your original experimental observation has an uncertainty which is determined by the precision with which the measuring instrument can be read. In the case of complicated electrical or electronic devices, it is wise to consult the manufacturer's specifications as the uncertainty is often greater than what you would expect from the accuracy to which the scale can be read.

1.1 Propagations of errors.

Having identified the uncertainties of the individual measurements, it is necessary to determine what uncertainty will arise in a calculated result based on these measurements. You are probably familiar with certain simple rules regarding the combination of uncertainties; *e.g.*, when quantities are multiplied or divided, add the percent errors; when they are added or subtracted, add the absolute errors.

These rules, and more complicated ones arising when there is a complicated functional relationship between result and measurements, can be derived as follows. It is assumed that the ratios of uncertainties behave like derivatives, and the rules of calculus are used to determine the relationship. Thus, for example, if

$$y = x^2 \tag{1}$$

and the uncertainty in x is Δx, then make the approximation that

$$\frac{\Delta y}{\Delta x} \approx \frac{dy}{dx} \tag{2}$$

and, hence, that $\Delta y = 2x\Delta x$ or, since $y = x^2$, that $\Delta y/y = 2(\Delta x/x)$; i.e., that squaring a number causes the percent (or relative) uncertainty to double.

The subject of error propagation is treated in more detail in S&G, chapter II. Note that, with a function of several variables $F = f(x, y, z, \ldots)$ and the corresponding uncertainty Δx, Δy, Δz, … attached to each the variables, an approximation involving partial derivatives is used. This leads to the practical expression giving in general a good approximation of the uncertainty ΔF attached to F:

$$\Delta^2 F = \left(\frac{\partial F}{\partial x}\right)^2 \Delta^2 x + \left(\frac{\partial F}{\partial y}\right)^2 \Delta^2 y + \left(\frac{\partial F}{\partial z}\right)^2 \Delta^2 z + \ldots \tag{3}$$

Note that if you are simplifying complicated expressions in the manner of S&G, the auxiliary variables *A, B* etc. must be *independent*; ie, they must *not* be functions of the same experimental variables.

Most of the times, the standard deviation σ may be used as the uncertainty.

1.2 Reporting Numerical Results.

Once the error associated with a certain measurement or with a derived quantity has been determined, it is essential to report the result with the proper number of significant digits justified by the precision of the measurements. There are two commonly accepted manners to report such results,

1) using the symbol "+/−" (or ±) followed by the actual values of the absolute standard deviation, or
2) indicating in parenthesis the magnitude of the standard deviation on the last digits quoted.

EXAMPLE 1:

The result of a calculation as displayed by the calculator is Slope = 0.586298276 and the standard deviation on this slope has been calculated as σ_{slope} = 0.000145297. The result should be reported as:

Slope = (0.5863 ± 0.0001) *units* (**Do not forget the *units*!**)

or Slope = 0.5863(1) *units.*

Note that the error itself is reported (in general) with only *one* significant figure.

EXAMPLE 2:

Calculations give μ = 6.367923734E−31 with the corresponding standard deviation σ_μ = 4.002893682E−32. The final result should be reported as:

$\mu = (6.4 \pm 0.4)\times 10^{-31}$ *units* or μ = (6.4 ± 0.4)E−31 *units* or $\mu = 6.4(4)\times 10^{-31}$ *units* or μ = 6.4(4)E−31 *units.*

EXAMPLE 3:

Sometimes, when there is a large (positive or negative) power of 10 in the result, the symbol for the result may be shown multiplied by the inverse power of ten such that the result is expressed as a number between 0 and 10. Taking the above example, one could write:

$\mu \times 10^{31} = 6.4 \pm 0.4$ *units* or $\mu \times 10^{31} = 6.4(4)$ *units* or μ (*units*$\times 10^{31}$) = 6.4 ± 0.4 or μ *units* $/10^{-31} = 6.4 \pm 0.4$

These notations are encountered mostly in table headings.

2 AVERAGE

2.1 Normal average.

In the case of *n* measurements y_i, of the same physical quantity Υ, each carrying the same uncertainty σ (or standard deviation), the best estimate Y of Υ is given generally by the average value (or the mean):

$$Y = \frac{\sum_{i=1}^{n} y_i}{n} \quad (4)$$

with the corresponding standard deviation of the mean (the standard error):

$$\sigma_Y = \frac{\sigma}{\sqrt{n}} \quad (5)$$

Note: in this situation where several measurements of the same quantity have been obtained, one should verify that the observed standard deviation calculated with Eqn. (6) for the particular set of measurements

$$\sigma_{obs} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (6)$$

is in reasonable agreement with the standard deviation predicted by Eqn.(5).

2.2 Weighted average

In many cases, the standard error on individual measurement may not be the same. In other words, some measurements are "better" than others, or the level of confidence is different for each measurement. Let σ_i be the standard error associated with y_i. The best estimate Y of Υ is obtained by calculating a weighted average, in which each y_i is assigned the weight, ω_i, $= 1/\sigma_i^2$:

$$Y = \frac{\sum_{i=1}^{n} \omega_i y_i}{\sum_{i=1}^{n} \omega_i} \quad (7)$$

where the standard error on the weighted mean is given by:

$$\sigma_Y = \sqrt{\frac{1}{\sum_{i=1}^{n} \omega_i}} \quad (8)$$

Example: given the following data set, calculate the weighted average and the standard error.

Y	σ_Y	"Normal" average	Observed standard deviation (Eqn. 5)	Weighted average	Standard error
1.5	0.1	1.59	0.27	1.423	0.001
1.45	0.02				
1.423	0.001				
2	1				

3 LEAST SQUARES

In most situations, the experimental data (or related quantities derived from the measurements) are expected to behave according to some function, $y = f(x,a,b,...)$, which contains constant parameters *a, b* ..., as well as the variable *x*. In other words, we have experimental values of *x* and *y* and we wish to determine values of the parameters *a, b* .., which will cause the function to fit best the experimental results.

3.1 Simple Linear least-squares.

The simplest, non-trivial case of this is a straight line, $y = a + bx$. We have several sets of *x* and *y* values which constitute our experimental data. We want to find the best straight line through these data; that is, we want to find those values of the parameters *a* and *b* which will cause the straight line equation to fit the data as well as possible. For the straight line case, this can be done by plotting the data and drawing the best line by eyeball. There is, however, an analytical procedure which is independent of human judgment and which can be used for more complicated cases than a straight line. This is the method of "least squares".

If we have only two experimental points, it is a matter of simple algebra to find the straight line which passes through them. However, if there are more than two points, they will not all lie on exactly the same line because of experimental errors. In this case, we have to decide what we mean by the "best" straight line through the points. If we pick definite values for *a* and *b*, the parameters of the line, then at the *i*th experimental point, where the *x* value is x_i, the straight line equation predicts a *y* value of $a + bx_i$. This will, in general, not be equal (because of experimental errors) to the experimental *y* value, y_i. Thus, there will be a deviation, d_i, at the *i*th point between the experimental and predicted values of *y*. This is given by

$$d_i = y_i - (a + bx_i) \tag{9}$$

It can be shown statistically that, with certain assumptions mentioned below, the best line is that for which the sum of $(d_i)^2$ over all experimental points is a minimum. This sum is given by

$$S \equiv \sum_{i=1}^{N} d_i^2 = \sum_{i=1}^{N} \left[y_i - \left(a + bx_i \right) \right]^2 \text{ where } N \text{ is the number of points,} \tag{10}$$

$$= \sum y_i^2 - 2\sum y_i \left(a + bx_i \right) + \sum \left(a + bx_i \right)^2 \tag{11}$$

$$= \sum y_i^2 - 2a\sum y_i - 2b\sum x_i y_i + Na^2 + 2ab\sum x_i + b^2 \sum x_i^2 \tag{12}$$

after using the fact that the sum of a constant over *N* points is *N* times the constant. We can now find the values of *a* and *b* which minimize *S* by setting $\partial S/\partial a$ and $\partial S/\partial b$ equal to zero.

$$0 = \frac{\partial S}{\partial a} = -2\sum y_i + 2Na + 2b\sum x_i \tag{13}$$

$$0 = \frac{\partial S}{\partial b} = -2\sum x_i y_i + 2a\sum x_i + 2b\sum x_i^2 \tag{14}$$

which leads to solve the system

$$aN + b\sum x_i = \sum y_i \tag{15}$$

$$a\sum x_i + b\sum x_i^2 = \sum x_i y_i \tag{16}$$

Since the x_i and y_i are known experimental values, the indicated sums can be calculated from the experimental results and the above equations become two simultaneous linear equations which may be solved for a and b. These values of a and b define the "least squares line"; *i.e.*, the straight line which best fits the data in the above sense.

A similar derivation could be carried out for any functional dependence of y on x. If the function contains n parameters, a set of n simultaneous equations will result. If the parameters enter linearly into the function, the resulting equations will be linear; if not, there will be one or more non-linear ones. Small linear least squares problems can be solved by hand, although a computer is more convenient. A large or non-linear problem involves enough calculation that a computer would always be used. For this matter, EXCEL provides the built-in function LINEST which can output slope, intercept, error on slope, error on intercept and other statistical parameters; take some time to learn how to use correctly this function.

3.2 Weighted Linear least-squares.

The simple least squares procedure outlined above gives, statistically, the best line if the following conditions are met:

1) The experimental errors are normally distributed.
2) The error, at any point, is independent of the error at any other point.
3) The errors, at all points, *have the same absolute magnitude*.

The last condition is the one which is most often not satisfied. In this case, it can be shown that the best parameters are determined by minimizing the sum of $\omega_i d_i^2$, where ω_i, (called the weight attached to point i) must be set proportional to σ_i^{-2} where σ_i is the absolute uncertainty of the ith point. The result of such a procedure is called a "weighted least squares fit".

Note that a functional transformation of experimental data which have equal errors can result in transformed data which do not. For example, suppose we measure for a set of x values, the corresponding y values of the dependent variable having the same error σ_y at each point. We then decide to do a linear fit of $\ln y$ against x. The values of $\ln y$ do not have equal uncertainties, because $\sigma_{\mathrm{Ln}_y} \approx \Delta \ln y = \Delta y / y. \approx \sigma_y / y$. In this case, a weighted least squares fit would have to be performed.

For your information, the expressions giving the slope, the intercept and the corresponding standard deviation of the best line parameters using a weighted fit are:

$$a = \frac{\sum \omega_i \sum \omega_i x_i y_i - \sum \omega_i x_i \sum \omega_i y_i}{\Delta \sum \omega_i} \tag{17}$$

$$b = \frac{\left(\sum \omega_i x_i^2 \sum \omega_i y_i - \sum \omega_i x_i \sum \omega_i x_i y_i\right)}{\Delta \sum \omega_i} \tag{18}$$

$$\sigma_a = \frac{1}{\sqrt{\Delta}} \tag{19}$$

$$\sigma_b = \sqrt{\frac{\sum \omega_i x_i^2}{\Delta \sum \omega_i}} \tag{20}$$

where

$$\Delta \sum \omega_i = \sum \omega_i \sum \omega_i x_i^2 - \left(\sum \omega_i x_i\right)^2 \tag{21}$$

and the weighted standard deviation of the fit is:

$$\sigma_{\text{fit}} = \sqrt{\frac{N}{(N-2)} \frac{\sum \omega_i d_i^2}{\sum \omega_i}} \qquad \text{using } \omega_i = 1/\sigma_i^2 \tag{22}$$

In addition, if one uses the above slope and intercept to predict what would be the estimate Y for a value X of the independent variable (*ie*, calculate $Y = aX + b$), the standard deviation on Y, σ_Y, is given by

$$\sigma_Y = \sqrt{\frac{1}{\sum \omega_i} + \frac{1}{\Delta}\left(X - \frac{\sum \omega_i x_i}{\sum \omega_i}\right)^2} \tag{23}$$

Note that these expressions can be used to get the corresponding equations valid for an unweighted linear least squares by setting the weight $\omega_i = 1$.

3.3 General weighted least squares fit.

If the experimental data do not show a linear behaviour, the above treatment may be extended to the more general weighted least squares fit to a polynomial of appropriate degree (the linear fit a just the particular case of a fit to a polynomial of degree 1). For more complicated functional behavior of the data, one may have to use non-linear weighted least squares fit methods.

3.4 Why Do Least Squares?

It is an unfortunate fact that least squares fits are often done for the wrong reason. The correct application is that mentioned above; the determination of parameters in a formula when the formula is known. Least squares are sometimes also used to interpolate, differentiate or integrate experimental data whose functional form is not known. In this case, polynomials of varying degree are often used. This is a potentially dangerous procedure if the data is not really polynomial.

Polynomial fitting is justified by the theorem that an arbitrary continuous function can be approximated *over a finite interval* as accurately as desired, using a polynomial of sufficiently high degree. You should bear in mind that polynomials go to + ∞ or - ∞ infinity as *x* goes to infinity, so a polynomial is no good for data which goes to a finite limit at infinity (such as heat capacity as a function of temperature).

Quite apart from the above, there is the problem that experimental data contain errors. Thus, if you have 10 experimental points, you can make a 9th degree polynomial go through them exactly. However, this polynomial is of no use for interpolating intermediate values, since it will have a spurious oscillating character due to the experimental errors. It will be of even less use for differentiating the data. (You should avoid differentiating experimental data whenever possible and replace it by integration. Differentiation inevitably magnifies experimental errors.)

Thus, if we are forced, as is often the case, to fit a polynomial to data of unknown form, we want to fit the smoothest possible polynomial. That is, we should fit the lowest degree consistent with agreement within experimental error. In simple cases, this can be done with a straightforward polynomial fit. If you want to get serious about it, look up "spline fitting" in a text on numerical analysis.

3.5 How to perform weighted least-squares fit.

Many computer programs are available which can perform least squares fit; however, be aware that even the most popular statistical packages commercially available do not provide built-in <u>weighted</u> least–squares fit. If you use any of the more popular spreadsheet programs, you'll have to design your own template using the formulae provided above, although the templates WLSQFIT.XLS and WPOLYFIT.XLS are available in the PCHEM lab for EXCEL fans (can be also downloaded from the course web site).

4 SAVING DATA AS TEXT (ASCII format)

Data given in digital form (diskette, memory key or email) to the instructor will be accepted only if they are in text format; this is to avoid compatibility problems and the chance of spreading a potential computer virus. To save or transfer data, whether numerical or textual, within the program you are running, highlight the relevant block , <u>C</u>opy, then <u>P</u>aste *as text* this block into a text file editor (like Notepad) or into your email composer.

5 USE OF VACUUM APPARATUS

Several of the experiments in the 366 lab involve the use of high vacuum apparatus. The following section gives some hints for successful use.

- Be sure that you have read the chapter in S&G on vacuum technique. You will need to understand the operation of rotary and diffusion pumps and of McLeod gauges for all the vacuum experiments.
- When you need an accurate McLeod reading, you cannot simply interpolate on the pressure scale provided, since this scale in non-linear. In this case you have to measure mercury heights in cm and calculate pressure using the bulb volume and capillary diameter which are provided with each gauge.
- The main source of trouble in vacuum systems is leaks and the main source of leaks is greased stopcocks. Before an experiment, check all stopcocks to be sure that there are no streaks of air in the grease. If any are found, get help to re-grease.
- Turn stopcocks slowly, using *both* hands while applying gentle pressure to pus the plug into the barrel as you turn. If the vacuum line is equipped with greaseless O-ring valves, do not over-tighten when closing the valve; when opening the valve turn the teflon plug only the necessary amount otherwise the plug might come out.
- A common source of disaster is turning the wrong stopcock. Before you turn any stopcock, trace its connections, think what gas pressure is on each side and consider the consequences of your proposed action.
- When operating McLeod gauges and gas burettes, remember that 100 ml of Hg weighs 1.4 kg. Such a mass, if moving at high velocity, will destroy any glass objects in its path. *Go slowly.*

SAFETY GLASSES MUST BE WORN WHEN PERFORMING EXPERIMENTS INVOLVING VACUUM LINES DUE TO THE RISK OF FLYING GLASS IN THE EVENT OF AN IMPLOSION.

6 COMPUTERS

Several PC's of various degree of obsolescence are available for this laboratory. They are all IBM-compatible, the older models operating on MS-DOS or MS-Windows 3.1, the newer one on Windows 95/98/XP. Several custom programs or custom spreadsheets are offered; they can be accessed through a simple screen menu or by clicking on the corresponding icon.

Although, in principle, all the data manipulations for these labs could be done without computers, practically it is not a recommended option. You are strongly encouraged to invest some time at the beginning of the term in familiarizing yourself with some of these programs. You will find life much easier if you know how to use

- a file editor,
- a spreadsheet program,
- a data fitting package.

Again, as far as least squares fitting is concerned, you should be aware that most of the popular commercial packages do not provide built-in weighted least-squares fit, which is an essential tool to in order to get meaningful results from some experimental data.

During laboratory sessions, computers attached to an experiment have priority for data acquisition. At any other times, you are welcome to use them for calculations. For more complete description on how to operate these computers and the useful software, you'll have to consult the relevant manuals or ask knowledgeable persons.

7 LAB REPORT FORMAT

Next pages show the general format expected from a lab report. This format is available as a MS-Word template from the course web site. It is given here for convenience.

EXPERIMENT TITLE

My Name Student ID: 12345678

Partner Name (*if applicable*)

Performed: xx-Jun-3004 Submitted: Thursday, 29 November 2012

Abstract. The abstract should present very concisely the context of the experiment, the main results, how they compare with accepted values and the conclusions. Some short comments may be included. The abstract must be self-contained, ie, no reference to the body of the report, to figures or tables should be made. It is meant to provide at the same time 1) enough information for the general scientific reader to get quickly a good idea of the content of the paper but 2) not enough details to the more specialized reader, who will want to read the full paper to obtain the relevant information. It should not be much longer than approx. 200 words.

PURPOSE

This section contains a brief statement about the purpose of the experiment.

INTRODUCTION, THEORY

The theoretical basis and the principle of the experiment should be explained fully but *concisely* (no more than one page); long passages copied directly from a text book or manual, will be frowned upon. Equations or formula to be used to analyze and interpret the data need not be derived but literature reference to the derivation must be indicated.

EXPERIMENTAL PROCEDURES

Simple reference to the manual and/or text book in which the detailed procedure are given is usually sufficient. However,

- *do* indicate clearly changes from the procedures and the reasons for such changes such that the experiment could be repeated under identical conditions.
- Make note of specific information relevant to the experiment; *eg*, stock solution concentration, type, model number, or serial number of particular piece of equipment, ambient temperature, bath temperature, atmospheric pressure, etc...
- Indicate also unusual happening or failure of equipment which occurred during your session. A diagram of the apparatus may be included — again indicate deviations from manual description. In particular, if you feel that a diagram is warranted, make sure that the drawing you include in your report represents the actual apparatus encountered in the lab. The external aspect of the set-up used may be quite different from the picture in the text book, although both do the same thing.

RESULTS, CALCULATIONS

You should present the actual results of your experiment.

- These should be neatly organized into tables or graphs, as appropriate.
- All results should be presented to the precision justified by experimental uncertainties and an estimate of these uncertainties should be given.
- The raw data (the actual data collected during the lab session, whether in tabular form or plots from a chart recorder) *must be included or attached*; they may appear as an appendix at the end of the report, may be found on a diskette or submitted electronically in a format specified by the instructor. For data collected by a computer, DO NOT include a printed list of the numerical results; provide the data in some electronic form or indicate on which computer the data can be

found and the corresponding file name. Accessibility to the original data is the only way for the grader to trace back the reason for mistakes or strange results.

- If it is felt that some data should be discarded, indicate clearly this, the reason why and the justification; one must have very good reasons (other than aesthetics or convenience) to reject experimental data.
- Eventually the final results should be summarized in a table including the uncertainties (see below) and literature or accepted values.

1 Tables

Table format should be as shown in Table 1 (do not forget to indicate the appropriate units in the column – or row – headings); the caption appears *above* the table. The caption and the content of the table should as self-contained as possible.

Table 1. Example of a five column table. Note that the different rows or columns are NOT separated by lines. Horizontal lines are drawn only on top and bottom of the headers and under the last row of the Table. Empty cells are indicated by a "-" sign.

Temperature/K	±	**Pressure/**Atm (± 0.03)	$\mathbf{C_p}$ / J mol^{-1} K^{-1} (± 0.1)	**Filename**
8.02	0.01	1.00	1.2	Lowtemp.dat
175.2	0.1	20.04	4.2	Medpress.dat
300.2	0.1	-	5.2	Hitemp.dat

2 Graphs

Chart should be clear, well labelled and legible – no stamp-size pictures please. Do show experimental error bars, and include only trend lines (linear or curved) which are meant to represent a theoretical fit to the data. In particular, for the type of data collected in the Pchem lab, do NOT let your graphical software join the experimental points with some curve (smooth or jagged) which has no physical meaning. Adjust the scales to get sensible axis intercept, legends, numbers and tick marks. The figure caption and the figure content should be as self-contained as possible; the figure caption appears *below* the picture. See Fig.1 for typical example of a chart format.

3 Calculations.

You should document how quantities derived from your original experimental data are obtained.

If you submit typewritten reports, the "Calculation" section can be very tedious to type; it is totally acceptable to submit this section hand-written – in particular the equations.

- Give the literal formula to be used, followed by the value of each member of the formula, then the results (with units); DO NOT retype (or rewrite) the formula with numbers substituted in. For example, suppose one needs to calculate the mole fraction x which is given by

$x = \dfrac{n_s}{n_s + N_{Solvent}}$ where n_s and $N_{Solvent}$ are number of moles of solute and solvent respectively.

Then, using some numbers, after showing the literal formula, one could write, n_s = 0.011 ± 0.001 moles, $N_{Solvent}$ = 9.91 ± 0.01 moles,

thus, x = (1.04 ± 0.09)x10^{-3},

but *do not write*

$$x = \frac{0.011 \pm 0.001\,\text{moles}}{0.011 \pm 0.001\,\text{moles} + 9.61 \pm 0.01\,\text{moles}} = (1.04 \pm 0.09) \times 10^{-3}$$

- If a repetitive calculation is done many times on similar data, it is sufficient to give the calculation once, in detail, and just report the results of the subsequent calculations.
- If a computer program or a spreadsheet were used for calculations indicate the origin; a typical output may be included in your report, but make sure that the various entries are properly and unambiguously labeled.

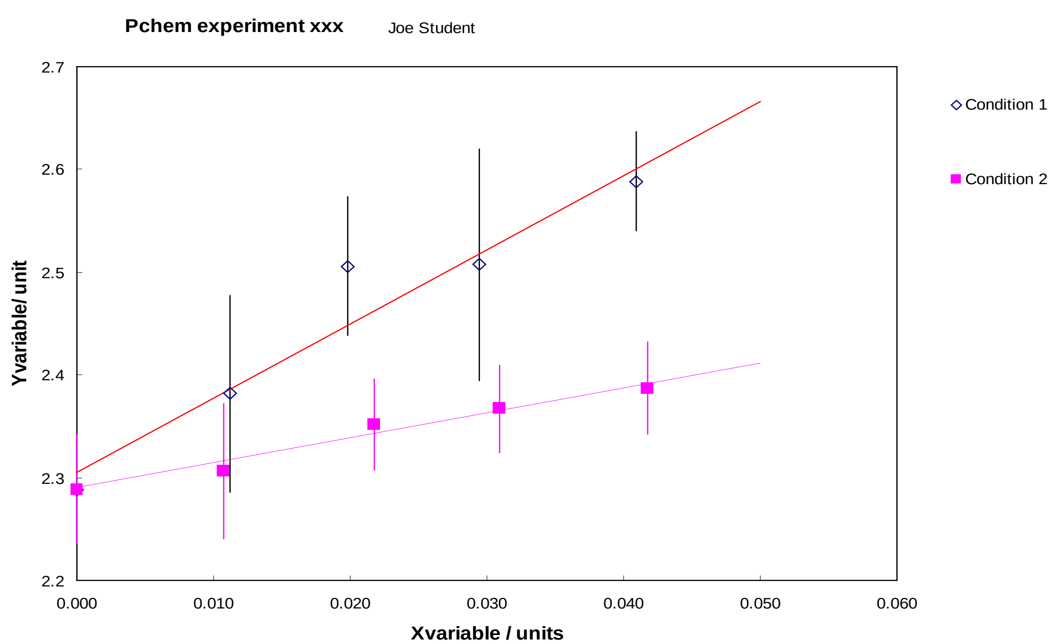

Fig. 1 Variation of Yvariable with Xvariable under Condition 1 (t = 123 K, P = 345 Torr) and Condition 2 (t = 234 K, P = 345 Torr).

4 Error analysis

An essential part of Calculations is a calculation of the errors (or confidence levels) expected in the final results. This must be done from your estimates of the errors in original experimental quantities and a calculation of how these errors combine to produce errors in the final calculated result. If you do not know how to do error propagation calculations, read the corresponding section in S&G, or the ERROR ANALYSIS section in the Appendix of the lab manual, or other specialized reference. The reader must be told how accurate the final result is expected to be, based on the actual experimental technique used.

DISCUSSION

This section should give any necessary concluding discussion, including comparison of results with literature or theoretical values, if available. Do follow points of discussion raised in the text book and in the lab manual.

CONCLUSION.

This should be a short statement summing up the experiment and the main results, usually in the context of the objective set out at the start of the experiment.

REFERENCES.

This section should give a numbered list of all sources quoted, in order of appearance in the report. The corresponding number should be inserted as the superscript (or in between square brackets) in the body of the report, at the point where the quotation is made. Common reference formats are:

1 Author1name, Initials.; Author2name, Initials. *Journal*, **Year**, *Volume*, firstpage.
2 Author3name, Initials.; Author4name, Initials., page no., *Monograph or Book Title*; Edition, Publisher: City, Year.

APPENDICES

Include in Appendices any material (not already in the report) which may not be essential to the understanding of the report but which should be available for the reader to be able to reproduce fully your experiment and/or your numerical conclusions.

The reports will be graded according to the following guidelines:

- *A*, very good, *ie*, clear writing and correct presentation, sensible data, correct calculations and results, discussion complete and correct.
- *B*, good but some points amongst those listed above are incorrect or missing.

- *C*, acceptable but with some serious flaws in presentation, mistakes in the calculations, or serious misconceptions.
- *D*, very serious flaws and not acceptable; if such a grade is assigned, the student will be given a chance to correct the mistakes and resubmit the report. In this situation, the new grade, after correction can not be higher than *C*; if the corrections are judged insufficient, the original *D* grade may stand.
- *F,* totally insufficient report, report submitted too late or not submitted at all, or breach of academic honesty (in this last situation, more serious penalty can ensue).

Note that late report may be downgraded, and report late by more than two weeks may be assigned a failing grade.

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