School of Physics
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Guidelines for the preparation of laboratory reports in the 3rd and 4th Year Laboratory

The following guidelines, extracted from a number of sources, are devised to help you in the preparation of your laboratory reports. These guidelines are quite general, and may not necessarily apply to all the experiments you carry out throughout the year.

The purpose of the laboratory report is to demonstrate that you have carried out an experiment, made the appropriate measurements and gained some understanding which you should be able to use to discuss and extract some conclusions from your results. It may also include evidence of any related research that you have carried out whilst doing the experiment. Remember that the goal of the laboratory report is to document your findings and to convey your interpretation of the results obtained, not to prove that you got the right answers. Of course, you should ensure that the results are of the best possible quality before beginning to write.

An essential pre-requisite for writing a good report is that you keep an accurate record of your work in the laboratory. You must do that in your laboratory notebook. If requested, this notebook must be made available for consultation.

The laboratory report is normally divided into a series of distinct sections: *Abstract, Introduction, Apparatus and Experimental Procedure, Results, Discussion, Conclusions, References* and *Appendices*. Each of these sections is described below.

In addition to the laboratory handouts, taken in their majority from the *American Journal of Physics*, you are encouraged to browse through the pages of this journal (available in the library or via internet at http://ojps.aip.org/ajp/) for other examples of reports written in this format. You are also encouraged to consult other texts on experimental procedures in physics available in the Departmental Library, such as the recent *Practical Physics*, by G.L. Squires.

Abstract

A report normally opens with a paragraph summarising the purpose of the experiment, the main findings and the conclusions reached. The main purpose of the abstract is to communicate to the reader the essence of the report. It should, therefore, be written after completion of the rest of the report to accurately and precisely reflect its contents.

Introduction

The introduction should describe the aims of the experiment and provide a framework for understanding the results presented in the following sections. A short outline of the theory necessary for understanding the results should be presented (with appropriate references), but all the material should have a direct relation to the experiment or its analysis (i.e., avoid long derivations or explanations with little relevance to the experiment). Cite your references either by number (i.e., [1], [2], etc...) or by author and year [e.g., Shanker *et al.* (1985), George(1989), ...]. A list of references used must be included at the end of the report.

Equations are part of the text. They are normally written on separate lines and should be numbered consecutively so that they can referred to later in the report, but otherwise should fit smoothly within the sentence, as in the example given below (Shanker *et al.*, 1985):

Example: "The equation of motion for this system may be written as

$$I \frac{d^2 \theta}{dt^2} + \gamma \frac{d\theta}{dt} + C\theta = T_o e^{i\omega t} \tag{1}$$

where I, γ and C are, respectively, the moment of inertia, the damping coefficient, and the torsion constant of the system.".

End the introduction by stating the objectives of the experiment as in the example given below (George, 1989), and try to explain how the information discussed in the introduction will relate to your experiment.

Example: " The main purpose of the present experiment is to study on one hand the band systems of the iodine molecule and to use the data to obtain the dissociation limit, the dissociation energy, and the force constant from the fundamental vibrational frequency of the molecule. These quantities can further be used to study the nature of potential energy curves of various electronic states.".

Apparatus and experimental procedure

This section should describe what was actually done. It should provide enough information on the experimental arrangement, measuring conditions (e.g., bias voltages, amplifier gains, aperture dimensions, lens focal lengths, etc.), procedures and precautions taken so that the reader could use the description to replicate the experiment. A clearly labelled diagram of the experimental apparatus used, such as the one in the example below (Weiner *et al.*, 2001), is generally necessary and can save a lot of written description. As with all figures, a descriptive caption should accompany the diagram (see example below).

Example: "Figure 1 shows a diagram of the experimental setup. An unpolarized 1-mW helium–neon (He–Ne) laser (Edmund Scientific, #F61337), with a wavelength of 632.8 nm, is directed through the center of a glass cuvette with square cross section (a square of side length 1 cm), containing the sphere suspension (one drop of spheres in 100 ml of water; ~10^{10} spheres/ml). The suspension is created using filtered water to eliminate any scatterers other than the latex spheres. The beam was directed using two mirrors, which aided in laser alignment and reduced the length of breadboard required for the experiment. The cuvette was mounted directly above a rotation stage using optical posts and other common equipment. A photodetector (ThorLabs, #PDA55) was attached to the rotation stage via a rail. The photodetector was placed 24.5 cm from the center of the cuvette. Our setup allowed the photodetector to measure scattered light at angles as small as 4°; at angles smaller than this, the attenuated laser beam was incident upon the photodetector. We were able to achieve an angular resolution of ±1°. This resolution proved adequate for our purposes; however, it would be a trivial matter to increase it further by closing the iris at the front of the photodetector. Data were collected for angles ranging from 4° to between 24° and 40°.

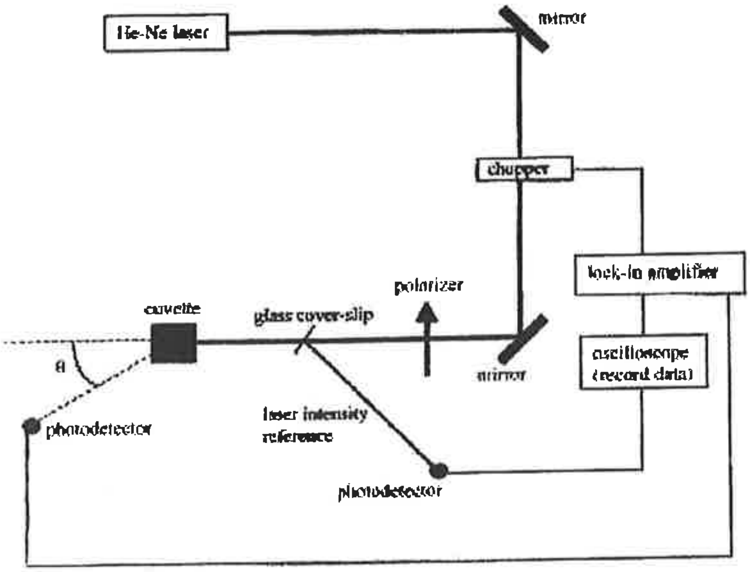

Figure 1. Configuration of the experiment. The lock-in amplifier is helpful in increasing the signal-to-noise ratio of the scattered light intensity, but is not essential. Both the scattered light (signal output from the lock-in amplifier) and the reference intensity (signal from the photodetector looking at the glass cover-slip) are recorded as a function of emission angle θ.".

Results

In this section, relevant data, observations and findings arising from your experiment should be presented in a clear, logical sequence. Remember that the report is an account of what you really did and what actually happened, and not of what was supposed to happen or what the manual or references used for the experiment said it should happen. Although some raw data can be included in the report, avoid presenting large blocks of unprocessed data, as they make the report difficult to read. Instead, when possible, try to summarise the data in the form of tables. It is important, however, to keep a record of raw data and calculations (e.g., MathCad worksheets) and these should *always* be included as an appendix to the report. A copy of all computer files employed should be kept until the end of the year.

Graphs are usually the best way of presenting your results, and are an invaluable tool for showing what is going on in the experiment. By using a graph, for example, it is easy to show where the proportionality relationship between two variables is broken, or whether the experimental results are in agreement with a theoretical curve. In the report, graphs should be numbered so that they can be cited in the text. They should always be accompanied by a caption so that the reader can understand its content. The caption should also indicate whether any plotted lines or curves are theoretical fits, best fits or simply experimental data points. In the case of more than one set of data being plot together (e.g., for comparison purposes), the different symbols used should be identified in the graph or the caption. Graphs should always have two labelled axes. The units employed for the quantities plotted should be specified (e.g., is the *distance* measured in metres, centimetres?).

Where appropriate, include the uncertainty in the experimental values as error bars. Little would be gained for example by adding the error bars to the points in Figure 2 below. On the other hand, the significance of deviations from a theoretical curve may depend on the estimated error, and in that case the errors should be indicated. Thus, in Figure 3a the deviations would not be considered to be significant with respect to the theoretical straight line, whereas in Figure 3b they would. Plotting the experimental results with the estimated error is a useful way to show the agreement or discrepancy between the experimental data and the theoretical curve. Another situation in which errors are commonly shown is when they are different for the various experimental points.

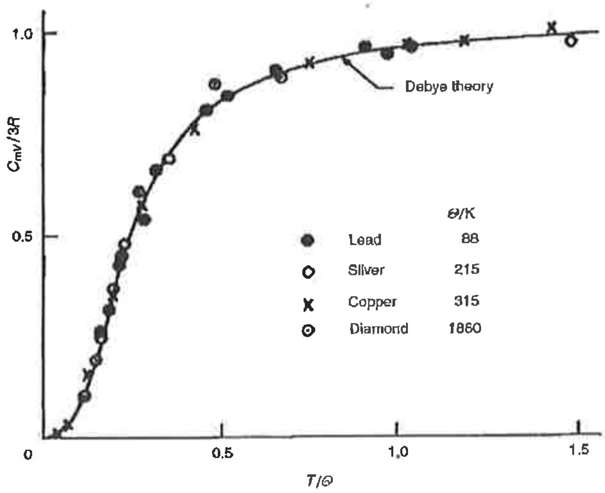

Figure 2. Molar heat capacity, C_{mV}, in units of $3R$, versus T/Θ for lead, silver, copper and diamond

All values of a physical quantity (either measured, derived from graph slopes or intercepts, or by application of a formula) have uncertainties associated with them. It is important to give some indication of the precision or reliability of the measurements in order to be able to draw significant conclusions from the experimental results. Use the methods given to you during the introductory lectures on error calculation to assess and estimate them properly.

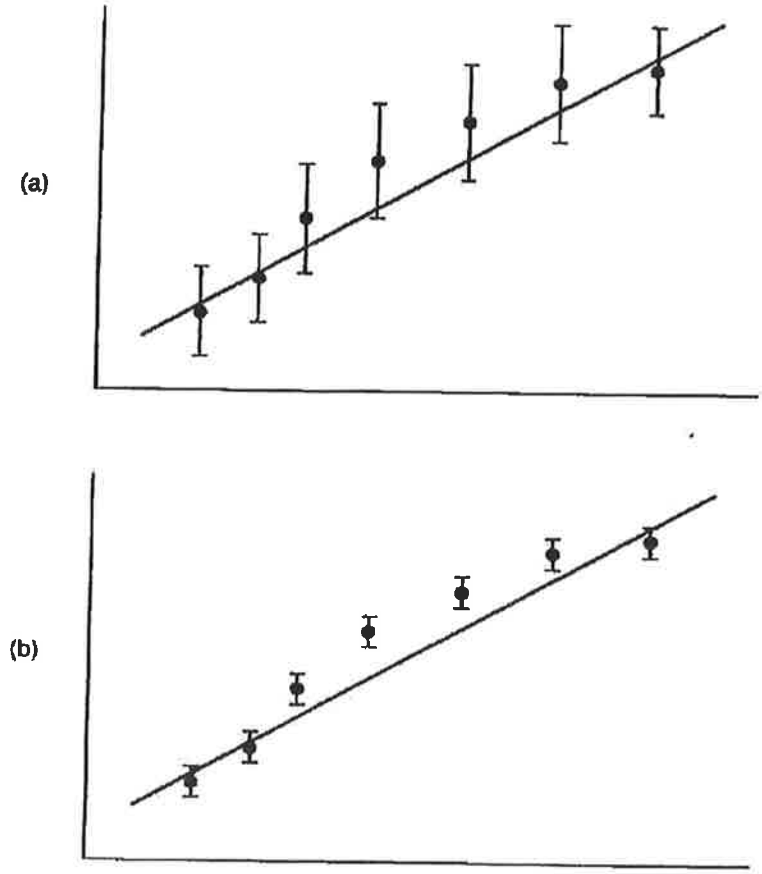

Figure 3. The deviations in (a) with respect to the theoretical straight line are not significant, whereas in (b) they probably are

In your results, do not give excessive precision – six or seven significant figures for quantities known with less than 1% accuracy are nonsense. Do not forget to give the units associated with each measurement, and make sure that the number you quote are *reasonable*.

Discussion

Having presented the results, in this section you should discuss them in relation to the theory presented in the introduction. Focus your attention on questions like these: Are your results in good agreement with the theory? What have you learned from the measurements? Why did the experiment or a particular part of it fail? Have you seen anything unexpected? What are the weaknesses and strengths of the experimental approach employed and how could the experiment be improved?

When your results are not in good agreement with the theory or with results obtained using a similar set-up, try to understand the possible reasons for this discrepancy, providing evidence to back-up your claims. Avoid using general statements such as *"the discrepancy between the measured and theoretical value may be due to human error"* or *"the results agreed with theory within the limits of experimental error"*.

Conclusions

Although this section is often combined with the previous one, you can end the report with a brief summary of the main conclusions, picking the most important and interesting results and what you learnt from them.

Appendices

At the end of each report, you must append a full printout of the *MathCad* worksheets used in treating the raw data to obtain your results. There should be clear evidence supporting statements made and conclusions drawn in the main body of the report. In experiments requiring interfacing, you must also include a copy of the code you wrote for this purpose. Where appropriate, include comments so that the code can be easily understood.

References

References (books, articles, etc.) used in the experiment or in the preparation of the report should be listed at the end. They should be quoted in the text either by number or by author and year as indicated above. For a given reference, try to provide all the information required to allow someone else to find it (author, title, year of publication, journal or publisher, volume, page number). For example, for the references quoted in the above text:

George, S. (1989), 'Absorption spectrum of iodine vapor – An experiment', *Am. J. Phys.* **57**(9), 850–853.

Shanker, G., Gupta, V.K., Saraf, B. and Sharma, N.K. (1985), 'Temperature variation of modulus of rigidity and intenal friction: An experiment with torsional oscillator', *Am. J. Phys.* **53**(12), 1192– 1195.

Squires, G.L. (2001). *Practical Physics*. 4th Edn., Cambridge University Press, ISBN 0521779405, Cambridge, 212 pp.

Weiner, I., Rust, M. and Donnelly, T.D. (2001), 'Particle size determination: An undergraduate lab in Mie scattering', *Am. J. Phys.* **69**(2), 129–136.