School of Physics
UCD Dublin

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.

Reports I the advanced lab should be short and concise. They are judged on the basis of quality not quantity!

The purpose of the laboratory report is to demonstrate that you have carried out an experiment, made the appropriate measurements and performed the appropriate analysis to allow you to discuss and extract some conclusions from your results. Your deeper understanding of each of these elements will be assessed in the discussions with the staff member responsible. 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.

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 https://pubs.aip.org/aapt/ajp) for other examples of reports written in this format. You are also encouraged to consult other texts on experimental procedures in physics such as *Practical Physics,* by G.L. Squires.

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

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 and Theory

The introduction should describe the aims of the experiment and provide the context or motivation for the experiment. If the experiment was, for example, on Rutherford scattering you might mention the importance of the method in determining the structure of the atom. A short outline of the theory necessary for understanding the results should be presented including appropriate references. It is not necessary to derive equations but rather present a summary of the key equations. Describe in your own words the main theoretical concepts covered by these equations. 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

$$\boldsymbol{I\frac{d^2\theta}{dt^2}+\gamma\frac{d\theta}{dt}+C\theta=T_0e^{i\omega t}} \tag{1}$$

where ***I*****,** *r* 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 (Al-Juboori et al, 2021) 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).

II. EXPERIMENT

The experimental layout is shown schematically in Fig. 1. It was comprised of a cylindrical vacuum chamber of 50 cm diameter with 8 ports orientated toward the center of the chamber separated by 45°. Throughout all experiments, the vacuum chamber was kept at a base pressure of 3×10^{-6} mbar using a Leybold D&B rotary vane pump as a backing pump and an Edwards EXT250 turbomolecular vacuum pump. The laser pulse was introduced along the z-axis and was focused by a plano-convex lens mounted on an actuator, which controlled the lens-to-target distance. The fast gated camera observed the plasma at 90° to the z-axis, while the visible spectrometer was also at 90° to the z-axis but on the opposite side of the chamber from the camera. The three actuators used to control the x, y, and z movement of the target holder had a 100 μm step resolution. The different thicknesses of the targets were accounted for by the z-actuator, which moved in the direction toward/away from the laser beam. A Q-Switched Nd:YAG Continuum Surelite III-10 laser ($\lambda = 1064$, $\Delta t = 5.3 \pm 0.3$ ns and maximum laser energy of 670 mJ)[26] was used to generate the plasmas. A 2° wedge prism was used to separate the incoming laser beam into two separate beams as shown in Fig. 2. Two different focal length lenses of 100 and 125 mm were used to produce seed plasma separations of 1.66 and 2.16 mm, respectively. The maximum laser power densities were $4.60 \pm 0.9 \times 10^{12}$ and $2.94 \pm 0.6 \times 10^{12}\,\mathrm{W/cm^2}$ with the $f = 100$ and 125 mm lens, respectively.

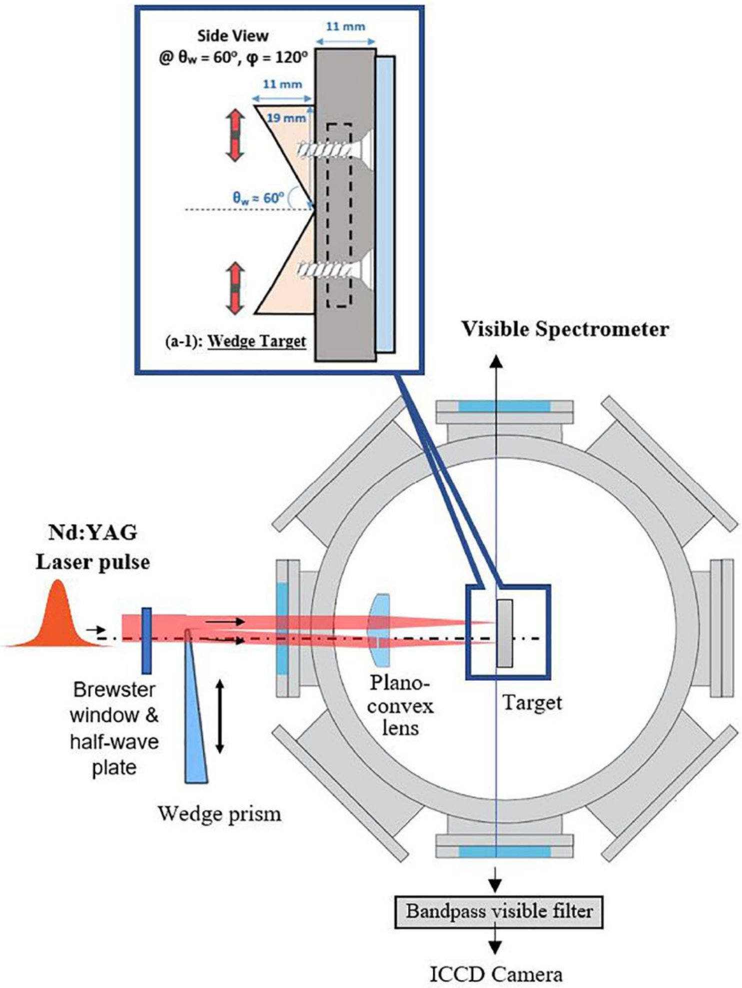

Figure 1 A schematic diagram of the experiment. The laser enters from the left of the figure and is split into two beams by the wedge prism before entering the chamber. Both beams are focused by the plano-convex lens onto the target. A closeup of the target is shown. The plasma generated is imaged by the ICCD camera shown at the bottom of the figure. The spectrometer views the plasma perpendicular to the laser and through the port shown at the top of the figure.

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 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 or graphs. Unprocessed raw data (if it is not too large) should included in the appendix. This allows the teaching staff to troubleshoot cases where the results do not make sense. Python code and Jupyter Notebooks 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. Individual data points should not be connected with lines (except in the rare cases where it is required for clarity). Theoretical fits to data should be done at higher resolution than the raw data so that the curve/line appears smooth. In the case of more than one set of data being plotted 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 or centimetres?).

Where appropriate, include the uncertainty in the experimental values as error bars. In Figure 2a there are clear deviations between the measured data and the theoretical straight line. However, they are all within the estimated uncertainty of the straight line fit and thus the data supports the theory. Whereas in Figure 2b the deviations from the expected behaviour are significant. Either the theory is incorrect, the data is measured incorrectly or perhaps the calculated uncertainty is underestimated. Thus plotting the experimental results with the estimated uncertainty 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.

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.

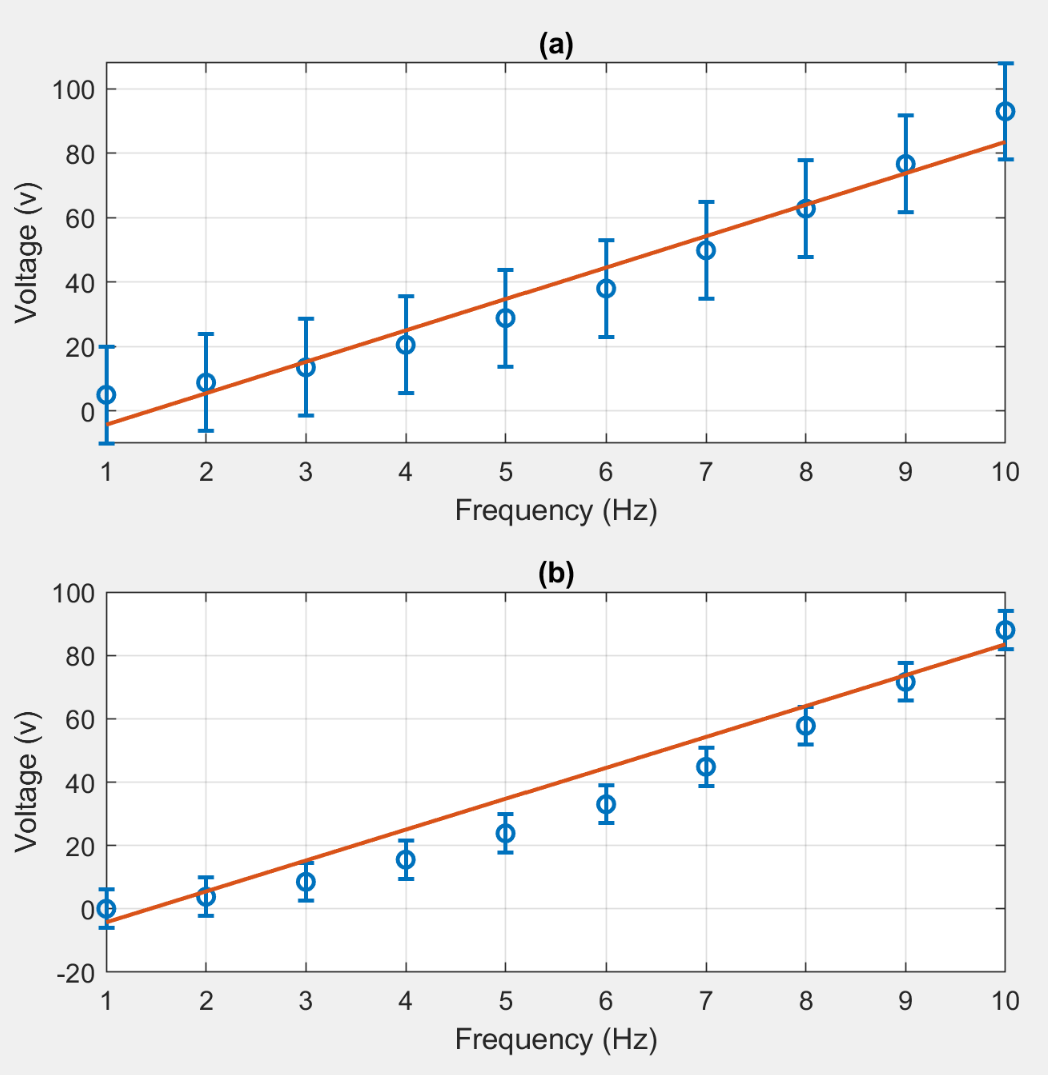

Figure 2 . The deviations in (a) with respect to the theoretical straight line are not significant, whereas they probably are in (b)

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 numbers 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 predicted results is due to human error*" or "*the results agreed with the 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 specifying what you learnt from them.

Appendices

At the end of the report you must include a copy of any Python codes or Jupyter Notebook pages that you used in treating the raw data, or code written to interface with various bits of equipment. These can be converted to pdf and imported into the report. Your code should be well documented in order to make it easy to interpret.

References

References and Citations are required in Academic Writing to:

- respect and acknowledge the thoughts, ideas and creations from other people's work
- give credibility to the arguments and conclusions in an assignment
- provide evidence for the ideas and arguments made in an assignment
- avoid plagiarising or representing another person's work as your own
- let others trace the sources and materials used to create your work*

*IMPORTANT NOTE: By including a reference list with information such as Book Title, Publisher, Publication Date, Journal Title, Website address etc., you are allowing your readers examine the evidence used in your assignment and read more about the topic.

The above paragraph was taken form the UCD library webpage https://libguides.ucd.ie/academicintegrity

References (books, articles etc) used in the experiments or in the preparation of the report should be listed at the end. They should be quoted in the text either by a number or an author and a year as indicated below.

There are a number of well-known approaches to citations such as the Chicago style or the Harvard style. These are well described in the library link above. My own personal preference is for the style followed by the American Physical Society (APS) journals such as this paragraph taken from the article by BP Abbott et al in Physical Review Letters 116 (2016) :

> In 1916, the year after the final formulation of the field equations of general relativity, Albert Einstein predicted the existence of gravitational waves. He found that the linearized weak-field equations had wave solutions: transverse waves of spatial strain that travel at the speed of light, generated by time variations of the mass quadrupole moment of the source [1,2]. Einstein understood that gravitational-wave amplitudes would be remarkably

Where each reference is given as a number in square brackets. At the end of the main text there should be a list of the corresponding references

[1] A. Einstein, Sitzungsber. K. Preuss. Akad. Wiss. **1**, 688 (1916).
[2] A. Einstein, Sitzungsber. K. Preuss. Akad. Wiss. **1**, 154 (1918).
[3] P. R. Saulson, Gen. Relativ. Gravit. **43**, 3289 (2011).
[4] K. Schwarzschild, Sitzungsber. K. Preuss. Akad. Wiss. **1**, 189 (1916).
[5] D. Finkelstein, Phys. Rev. **110**, 965 (1958).

For a given reference try to provide all the information required to allow someone to find it (author, title, year of publication , journal or publisher, volume, page number). For example , for the references quoted in the text above they would appear in the Harvard style as:

Al-Juboori, H., Malik, N. and Mccormack, T. (2021) *Phys. Plasmas* 28, 123515.

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 internal friction: An experiment with a torsional oscillator ", *Am. J. Phys*. 53(12), 1192-1195

Squires , G.L. (2001) Practical Physics 4th Ed, 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

Note these are in alphabetical order and follow a similar pattern in terms of the use of italics, word order , year etc

Please select one of the standard styles referred to above (APS, Harvard, Chicago) or some other internationally recognised style. Regardless of which style you pick please adhere to it closely.

Finally, a comment on the use of AI in the advanced labs

We remind you that our policy in the use of AI is contained in the module descriptors. In essence you must cite in your report the use of AI during the preparation, execution and reporting on the experiment. Students may use generative AI tools for limited support in this module. You may use AI for planning and researching your experimental work, debugging your own code or refining the language of text you alone have authored, but not to generate text, interpret experimental results, formulate scientific conclusions or write the code required in your computational physics project. Students remain fully responsible for the accuracy and reliability of their learning, and should be able to demonstrate their understanding of the experimental work undertaken during the discussions with staff which will follow each experiment. Specifically, students are expected to be able to explain and justify the theory, procedures, analysis and conclusions provided in their laboratory reports, as well as the structure and workings of any code used. Any use of AI must be cited appropriately, including details of the tools used and the prompts submitted