Guide to Writing Physics Lab Reports

Preamble

When completing a full report for a laboratory experiment in the Physics Department at John Abbott College, please follow the style in this guide, with minor variations possibly required by your teacher. The table of contents below lists the sections of a formal lab report. You do NOT need a table of contents in your report.

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Title

There is no need for a separate title page. At the top of your first page, include a short, descriptive title (more than just “Lab #4”). Also include your name, the date the experiment is performed, the date the report is submitted and your teacher’s name. If this is a group report, list all names alphabetically. If this is an individual report but the data was collected in a group, list group members’ names on a separate line.

Abstract

The abstract is a concise, 1 paragraph summary of your entire report. Your teacher may set a word limit. Aim for one sentence per report section, for a total of 5-7 sentences. In some cases, two sections can be efficiently combined into one sentence. Your abstract should include:

- Objective of the study
- A short situating statement (e.g., theory being applied or tested)
- Brief methodology (what did you do?)
- Summary of key results:
    - Quantitative as well as qualitative
    - Compare to theoretical predictions where appropriate, with uncertainty.
- Conclusion(s)

> *The Abstract is NOT just an introduction. It must include your key results and conclusions. Think of it as a plot summary of a movie, including the spoilers.*

The abstract goes at the beginning of your report, but it should be the last thing you write. It gives readers an overall idea of your report without having to read the entire thing. This is very helpful when you are doing research and need to choose from hundreds of scientific articles.

Here's a simple example:

> This study models the acceleration of falling objects near the surface of the Earth. According to theory, near-Earth acceleration due to gravity alone should be 9.81 m/s^2. Several massive objects are dropped and the time of descent recorded. The results show an acceleration of 9.73 ± 0.03 m/s^2, which is 2.7 standard errors less than predicted by theory. This suggests that to model the near-Earth acceleration of massive objects, other factors, such as air resistance, must be considered.

Introduction

The introduction sets the scene, helping your reader understand the rest of the report. It states the broad objective(s) of your study, explains the relevant theory, and ends with a research statement, hypothesis or question showing how your objective could be attained with an experiment.

Objective:

The objective can take different forms depending on your type of study and it may be expressed as a question or as a statement. In JAC physics, there are two main types of studies:

1. Most experiments you will do are **confirmatory studies**. In these, you conduct experiments to **test** if **a theory** can be used to adequately model a certain system.

Confirmatory studies apply theory to see when it works and when it breaks down.

✓ Do objects fall at the constant rate of acceleration of 9.81 m/s^2 near the surface of the earth at John Abbott College?

✓ This goal of this study is to model the acceleration of falling objects near the surface of the Earth at the location of John Abbott College.

Confirmatory studies do not find things that you already know.

✗ The objective is to observe that objects freefall at a constant rate near the surface of the earth.

✗ This goal of this study is to find $g = 9.81 m/s^2$ near the surface of the earth at the location of John Abbott College.

2. **Exploratory studies** conduct experiments to **find new relationships**. In such cases, you can't assume the form of the relationship nor that the relationship exists. Instead, you must collect and analyze data to discover if a relationship exists and if so, what it is.

Exploratory studies collect and analyze data to find new relationships.

✓ How does a water balloon's range vary with the extension of the rubber slingshot that launches it?

Exploratory studies are not done just to teach *you* more stuff.

✗ The objective of this study is to learn more about the physics of a rubber slingshot used to launch water balloons.

Relevant Theory

This is the longest part of your introduction. This is where you will show & explain any theory used in your study, in your own words. Often this includes deriving a theoretical relationship, explaining each step.

DO	DON'T
✓ Write the theory for a reader who is at your math and physics level in cégep but has never studied this specific topic before.	✗ Skip over derivations, assuming the reader will "figure it out."
✓ Write your theory as if the experiment has not yet happened. No spoilers!	✗ Include experimental data or your procedure (e.g., equipment or set-up).
✓ Label all equations using a number placed to the right of the equation in parentheses.	
✓ Define all variables and symbols.	
✓ Include a labelled and captioned diagram to support your explanation, if useful.	

TIP:
Look at your textbook to see how they explain new theory.

Research Question / Hypothesis / Research statement

Finish the intro with 1 - 2 sentences explaining how the objective may be achieved, based on the theory you described.

Do provide a summary of the relationship to be tested (or developed).

✓ According to the theoretical relationship for objects dropped from rest ($h= ½ at^2$), if objects freefall at a constant rate, a graph of an object's initial height (h) vs. time-in-the-air squared (t^2), will result in a linear graph with an intercept of zero.

✓ As shown by the relationship $h=½at^2$, a graph of h and t^2 for a freefalling object will have a constant slope whose value is half the acceleration due to gravity. This value can then be compared to $½g = 4.905\ m/s^2$.

Don't describe the set-up, equipment used, or your procedure.

✗ We will drop objects from rest and measure their initial height and the time it takes for them to reach the floor. We will then graph h vs t^2 and check if the results are linear, thus showing that objects fall at a constant rate.

Don't assume your results will match your hypothesis.

✗ The value of $g = 9.81\ m/s^2$ will be found by calculating the slope of a h vs t^2 graph.

Materials & Methods / Procedures

This section describes the experiment and the equipment used in sufficient detail so that another person could repeat the experiment and obtain similar results.

If the procedure was given to you, direct your reader to the source, and describe any deviations you made. If you are writing the procedure yourself, keep things as simple as possible, using the table below to guide you.

DO	DON'T
✓ Describe all required materials, including quantities.	❌ Explain things the reader doesn't need to know. E.g., which buttons to push on the software.
✓ Include one or more labelled and captioned pictures or diagrams of the set up and refer to them in your procedure.	❌ Tell the reader to "record" data each time something is measured. Anything measured must be recorded, there is no need to say this.
✓ Ask your teacher if they prefer a paragraph or a numbered list of steps. Published scientific articles use paragraph form.	❌ Include instructions for how to analyze the data. The analysis and calculations will be shown in the next section.

Results

This section could consist of any or all of the following, depending on the experiment:

- clear visuals of the results obtained (graphs/tables)
- the results of any statistical testing performed on the results
- a sample of each important calculation that was done

Focus only on results related to the objective. Do not interpret the results as this should be done in the discussion section.

Reporting uncertainties

All experimental quantities, measured or derived, must include an uncertainty estimate.

Measured quantities: Estimate the uncertainty using whatever information you have available. Digital devices usually report their own uncertainty. Other instruments will require you to estimate using common sense and your knowledge of how the tool operates.

Derived (calculated) quantities: Ask your teacher if error propagation is required in your course.

- If it is not required, your teacher will provide a spreadsheet or app that will calculate uncertainty. You must still report these in your results section.
- If you propagate the error yourself, follow the rules you have been taught. It is likely that every piece of calculated data will have its own uncertainty.

Show uncertainty using either of the two equivalent formats shown below:

		Benefits	Best places to use it
A)	**4.32 ± 0.07 m/s**	Easy to understand	• In column header when all values have the same uncertainty.
B)	**4.32(7) m/s***	Shorter and neater	• Within equation • In table column when each value has a different uncertainty. • When writing numbers as part of a sentence.

*Number in parentheses is uncertainty of the preceding place value. Same as saying 4.32 ± 0.07 m/s.

Rules for rounding uncertainties and sig figs:

- First round the uncertainty to a single digit.
    - ± 0.02134 m becomes ± 0.02 m.
- Then round the data value so only its final digit is uncertain.
    - 3.03219 ± 0.02 m becomes 3.03 ± 0.02 m or 3.03(2) m.

Tables

Data is rarely presented in its raw form. It is usually formatted into a table and/or a graph. Tables should be made in your Word editor, as Excel is good for graphs but not for presenting tables.

Table 1 is a good example of a well formatted table.

Current (mA) ± 0.03 mA	**Resistance (Ω) ± 17 Ω**	**Voltage (V)**
1.02	4703	4.80(14)
2.46	4703	11.57(15)
3.66	5597	20.5(2)
5.87	5597	32.9(2)

Table 1: Voltage values of the one-resistor circuit as calculated from current and resistance. The experimental current and resistance values were measured using a multimeter and the voltage was calculated using Ohm's law.

✓ Has a label and a useful caption.

✓ Has headers with full names and units in parentheses.

✓ States the uncertainty of each variable, even the calculated voltages.

✓ The last significant digit shown in the data agrees with the reported uncertainty.

✓ Is neat and easy to read

Table 2 below is *not* a good example of a table because it has the problems listed below:

I	**R**	**V**
1.02 mA	4703	4.8
2 mA	4703	11.57
3.66 mA	5597	20.5
5.873 mA	5597	32.87

Table 2: Current, resistance and voltage.

✗ Caption is not useful. What is the current, resistance and voltage of? What else should the reader know?

✗ Header includes neither full name nor units in the headers.

✗ Does not provide the uncertainty of the values

✗ Sig figs appear random.

✗ Would look neater if units were removed from current column.

Graphs

In physics, the most commonly used graph is a scatter plot with a trend-line. Create graphs in Excel and import them into your report. Do not use screenshots as the quality is too low.

Figure 1 below is a good example because it:

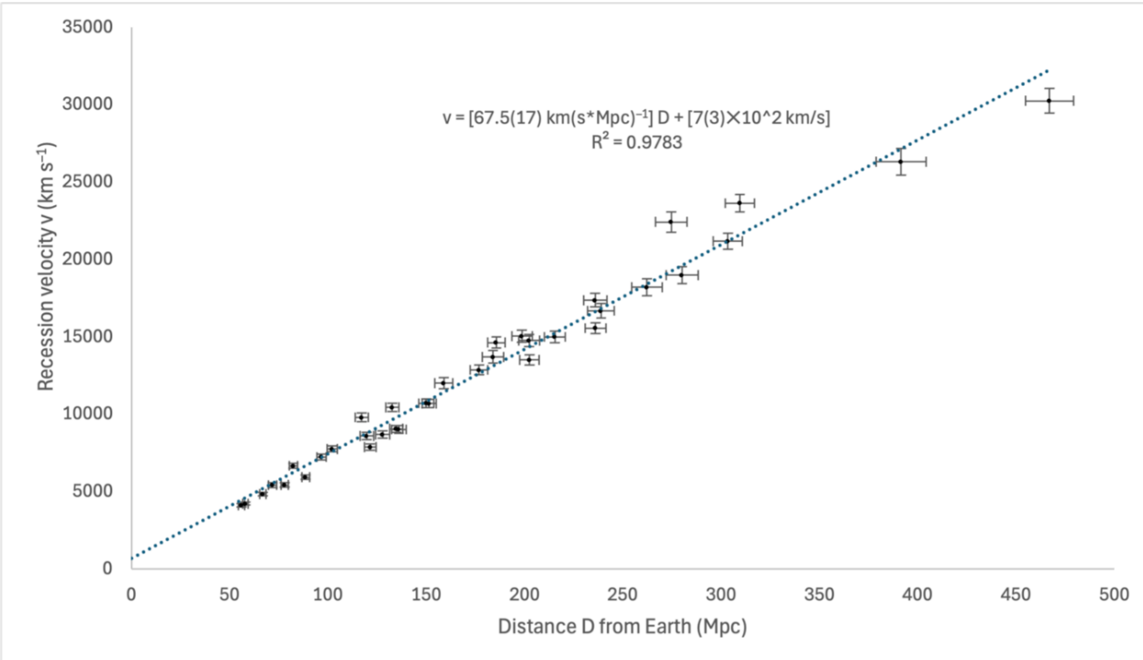

Figure 1: Recession velocity *v* (km/s) compared to distance *D* (Mpc) from Earth for supernova observed by the Hubble Space Telescope. From the slope, we find a Hubble Constant of 67.5 ± 1.7 km/s/Mpc.

- ✓ Is captioned as a sequentially numbered figure followed by a useful description that helps the reader understand the context and key result.
- ✓ Does not include a title on the graph itself.
- ✓ Has axes that are labeled with the variable name followed by the unit in parentheses.
- ✓ Uses a scatter plot format without connecting each data point
- ✓ Uses an appropriate curve-of-best fit to find a relevant relationship. *Note, choose an appropriate function, if one exists. Don't make something linear, if it is not linear!
- ✓ Displays the best fit equation using the appropriate variables, not the default x & y.
- ✓ Includes custom error bars if you have calculated the uncertainty of each variable.
- ✓ Is neat and easy to read
    - Does not have too many grid lines cluttering the space
    - Choice of spacing of axes values makes it easy to read.
    - Axes values allow full range of data to be displayed and maximized.

Figure 2 below is poor because it:

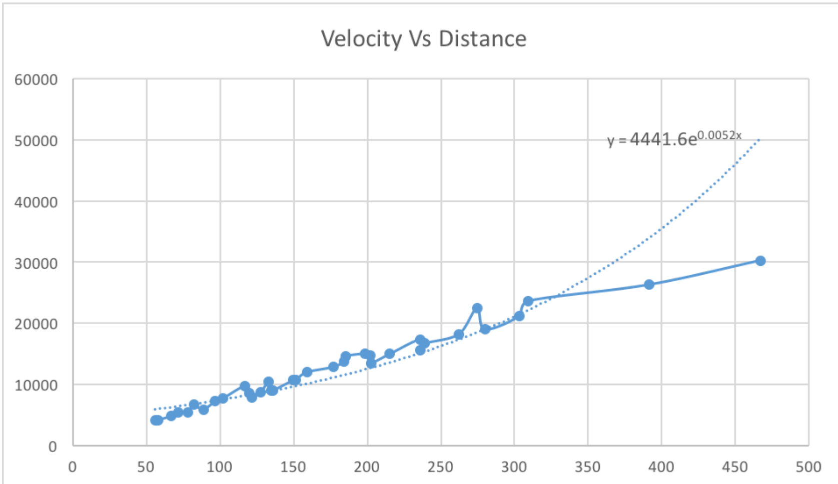

Figure 2: Velocity vs Distance.

- ❌ Has a useless caption that restates what should already be on the axes.
- ❌ Includes a title. Only a caption is needed.
- ❌ Has unlabeled axes.
- ❌ Connects each data point to the next. Do NOT do this!
- ❌ Uses a curve-of-best fit that clearly is not the best choice.
- ❌ Displays the equation using generic x & y instead of the real variables, v and d.
- ❌ Data is condensed into bottom half of graph. Top half is empty.

Sample Calculations

DO	DON'T
✓ Provide **one** example for **each important type** of calculation including any error propagation.	❌ Show how you calculate an average or other basic math.
✓ Use MS Word or another equation editor.	❌ Write equations by hand and then insert their images.
✓ Incorporate the calculations into your narrative. As you "talk" your reader through your analysis, explain and include each sample calculation.	❌ Dump all sample calculations together in the same place.

Discussion

In this section, you reflect on your results and what they tell you about your hypothesis and ultimately your objective or research question. If doing a confirmatory study, you will have made predictions, tested them experimentally, and now you must discuss the results of those tests: Were your predictions accurate or inaccurate and what does this mean for your hypothesis? To answer these questions, you must consider the uncertainties of your data. In some cases, your teacher may ask for a rigorous treatment of experimental uncertainties

> "Examining the relationship between height *h* and the square of the time (Figure 2), we find that the data are well-described by a linear function with a slope equal to 4.57(6) m/s^2. This corresponds to a downwards acceleration of 9.14(12) m/s^2. This value is 5.6 standard errors below the accepted value of 9.81 m/s^2, a deviation we attribute to air resistance effects that were not included in our model."

The difference between an experimental result and its predicted value is considered *significant* when you can be 95% confident that this difference is not a coincidence.

Example: You measured a value of 7.63(3) m/s, and are questioning whether this differs significantly from the theoretical prediction of 7.80 m/s. You calculate your 95% confidence interval to be 7.57 m/s – 7.69 m/s. The predicted value does not lie within this range therefore the difference is *significant*.

Do not claim two values are different without using a valid statistical test.

❌ We found that g = 9.75(8) m/s^2 which is lower than 9.81 m/s^2. This may be caused by air resistance.

Do claim two values are different, when it is significant. Then, suggest the most important, reasonable sources of error, and explain how each could cause this difference.

✓ The predicted value of $g = 9.81\ \mathrm{m/s^2}$ differs significantly from the measured value of 9.75(2) m/s^2 (95% confidence interval 9.71–9.79 m/s^2). This discrepancy in the hypothesized model may be caused by air resistance because . . .

Do not blame random factors. Make sure your proposed sources of error could have caused this difference. Do not blame human error (mistakes).

❌ We found that g = 10.7(4) m/s^2, which is significantly different from the predicted value of 9.81 m/s^2. . .This difference may be caused by air resistance.

Air resistance couldn't have caused the experimental value to be higher than 9.81 m/s^2. Something else must be responsible for the model not working.

❌ We found that g = 10.7(4) m/s^2, which is significantly different from the predicted value of 9.81 m/s^2. . . This difference may be caused by calculation errors or a misuse of the ruler.

Mistakes must be found and corrected prior to finishing the experiment and report.

Do refer to key results, Figures and/or Tables in your discussion to provide evidence for the claims you make. And always remember that you are **not proving**. All experiments have uncertainty and thus we can never be 100% certain, we can just be more or less uncertain.

❌ We proved Newton's Laws to be correct.

✓ Our results show that Newton's Laws adequately describe the motion of the cart on an inclined plane.

✓✓ Our results fail to show any deviation from Newton's Laws for the motion of a cart on an inclined plane.

Important things to do in the Discussion:

- Use experimental results to critically assess the viability of the model under investigation (e.g., it's not really Newton's laws that are being tested, it's the way they've been applied in a particular context).
- Link the discussion / analysis directly to experimental data; (anything that goes against predicted results must be thoroughly discussed). Furthermore, assess that it's the *model* that fails the test unless there are readily identifiable reasons that the experiment was flawed (in which case no conclusion can be drawn).
- Interpret results in context of uncertainties and frame your findings using your data and results. You **CANNOT** prove that two things are the same—you can only *fail to show that they are different*. A failure to find significant differences *can*, however, be interpreted as evidence supporting a model.
- Refer to specific Tables and Figures to provide evidence for all claims.

Consider the following as a reasonable discussion:

> As predicted, the height (h) vs. time-in-the-air squared (t^2) was linear as shown in graph #2. However, the intercept differed meaningfully from the predicted value of zero. Instead, instead, it was equal to the height from which the object was dropped (see Table 4).
>
> Our graph had a slope of 4.4(2) m/s^2 with a 95% confidence interval of 4.0 m/s^2 – 4.8 m/s^2 which does not contain the predicted value of 4.9 m/s^2, or half of g = 9.8 m/s^2. Because the predicted value fell outside of our 95% confidence interval, this difference is significant and thus we find that our measured value of acceleration is below the value predicted by our free-fall model.
>
> This can be interpreted in several ways: the gravitational acceleration at John Abbott College is unusually small, or the proposed theoretical model was insufficient to adequately describe what we observed. The latter is more likely, as air resistance was not considered in deriving the expected acceleration and if it was not negligible, then it would have had the effect of . . .
>
> Future experiments should explore whether including friction in the model can . . .
>
> To reduce experimental uncertainties, future experiments should consider . . .

Conclusion

The conclusion is a short paragraph (3–5 sentences) answers your objective / research question, restating the key evidence that support that answer. Include a statement of any key difference between what your results showed and what your hypothesis (e.g., your model) predicted. There is nothing new in the conclusion; you are summarizing the key parts of your discussion.

For example, if you had earlier written:

> As shown by the relationship $h=½at^2$, a graph of h as a function of t^2 for a freefalling object is expected to have a constant slope whose value is half the gravitational acceleration. This value can then be compared to $g = 9.81\ m/s^2$.

Then your conclusion could state:

> As predicted by our model, the graph of height (h) versus time-squared (t^2) was linear. Its slope, 4.4(2) m/s^2, has a 95% confidence interval that does not contain the predicted value of 4.9 m/s^2, or half of $g = 9.8\ m/s^2$. This suggests that the proposed hypothetical model, while accurate in its linear prediction, did not fully describe the motion of a free-falling object and future models should account for the effects of air resistance, which may not be negligible as was originally assumed.

References

References are included in a report to give credit to the original source of an idea (including genAI if its use is permitted by your teacher) and to allow the reader to refer to the original source for any needed clarification. There are several methods of citing sources of information accepted by the scientific community.

In a Formal Lab Report it is common to cite the work in the text when direct quotes or images are used and to compile an alphabetical list of sources at the end of the report. The Cite It! Module on the JAC Portal can be used to help you format your references appropriately. Consult your teacher about citation style (e.g., APA, MLA, Chicago, Vancouver). Don’t forget that any online resource used must be referenced, including the date you accessed the material.

Graphic Overview of How to Tell Your Story