PHYS 146

How to Write and Format Lab Reports

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Useful Resources

- The lab manual on eClass (especially Chapters 4, 5, and 6)
- The rubric on eClass
- Feedback from PHYS 144 lab reports
- The Anonymous Forums on eClass
- The sample lab reports in the Google Drive folder
- These slides

Plagiarism

- Do not take from the lab manual (or any other source) without proper referencing. This means adding quotation marks if you copy anything word-for-word (which you generally should not do).

- Most cases of plagiarism come from taking things from the lab manual. Be careful with equations and diagrams. If you use the diagram in the lab manual, you **MUST** clearly indicate it came from the lab manual.

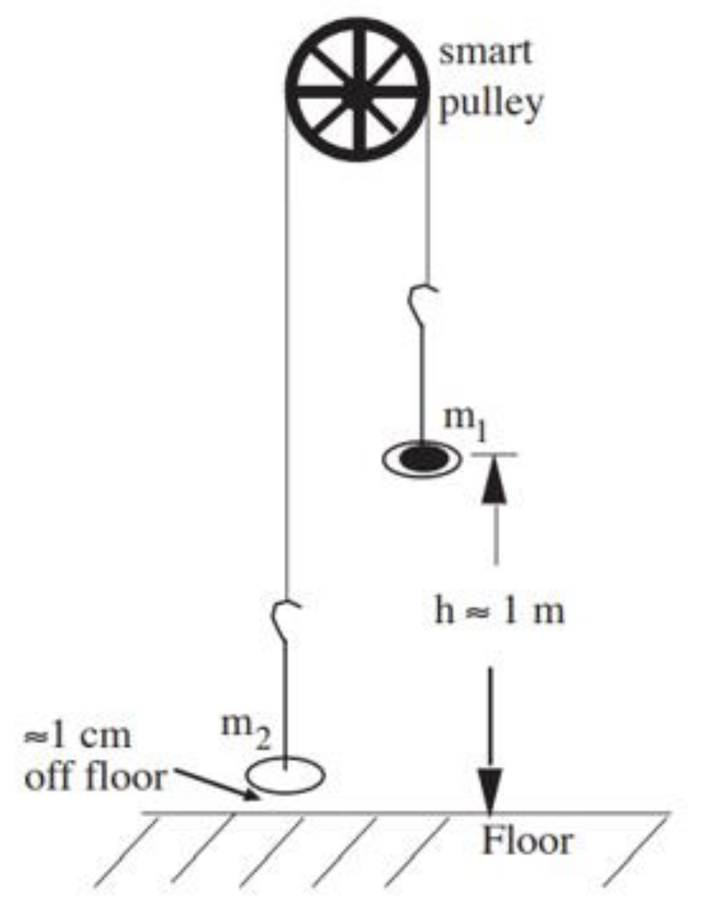

Figure 1: A diagram of the experimental set-up, taken from [1].

Presentation

- Please use paragraphs. If I cannot follow what you write because of excessive typos or a confusing flow of ideas, I cannot give you marks.

- Please use an equation editor. Compare:

$$\frac{P_0}{P_0 - P_1}\sqrt{\left(\frac{\delta P_0}{P_0}\right)^2 + \left(\frac{\sqrt{(\delta P_0)^2 + (\delta P_1)^2}}{P_0 - P_1}\right)^2}$$

vs

(P0/P0-P1)((dP0/P0)^2+(((dP0)^2+(dP1)^2)^(1/2)/(P0-P1))^2)^(1/2)

Presentation – Symbols

- Format symbols properly. *mp* is ambiguous. Is this m_p or $m*p$? If you write P0/P0-P1, it is unclear what the denominator is.

- Symbols only need to be defined once. If you have two formulas with m_p, you only need to state that m_p is the mass of the pulley once.

- Symbols are assumed to retain their original definition throughout the entire document. You should not use *m* for mass and then later use it for slope too.

- Make sure you are consistent. *X* is not the same as *x*.

Presentation – Organisation

- Organise your thoughts. Keep information on the same topic in the same place to make things as easy as possible for the reader. Do not just write a stream of consciousness. Compare:

  The mass of the bob was 5 g with an uncertainty of 0.5 g. I measured the length of the string to be 80 cm. I measured the mass of the bob with a scale.

  The mass of the bob was measured with a scale to be (5.0 ± 0.5) g. The length of the string was measured with a measuring tape to be (80.0 ± 0.5) cm.

- Refer to your equations, tables, and figures by the numbers you give them, rather than using phrases like “the equation” or “the image.”

Presentation – Organisation

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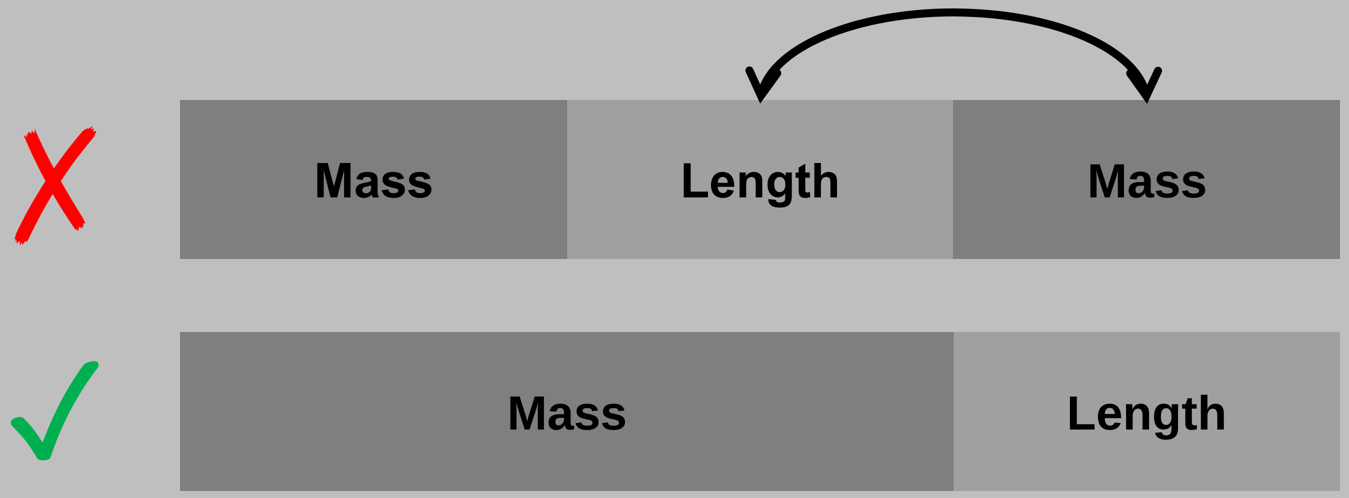

- Refer to your equations, tables, and figures by the numbers you give them, rather than using phrases like “the equation” or “the image.”

Presentation – Organisation

- Make sure things are in a logical order. Do not give a value before showing how you arrived at that value. Keep material on similar topics in similar places.

✗

Stuff about m_p
Stuff about m_f
More stuff about m_p
More stuff about m_f

✓

Stuff about m_p
Stuff about m_f

Methods

- Include a photo or diagram of the experimental set-up with labels.

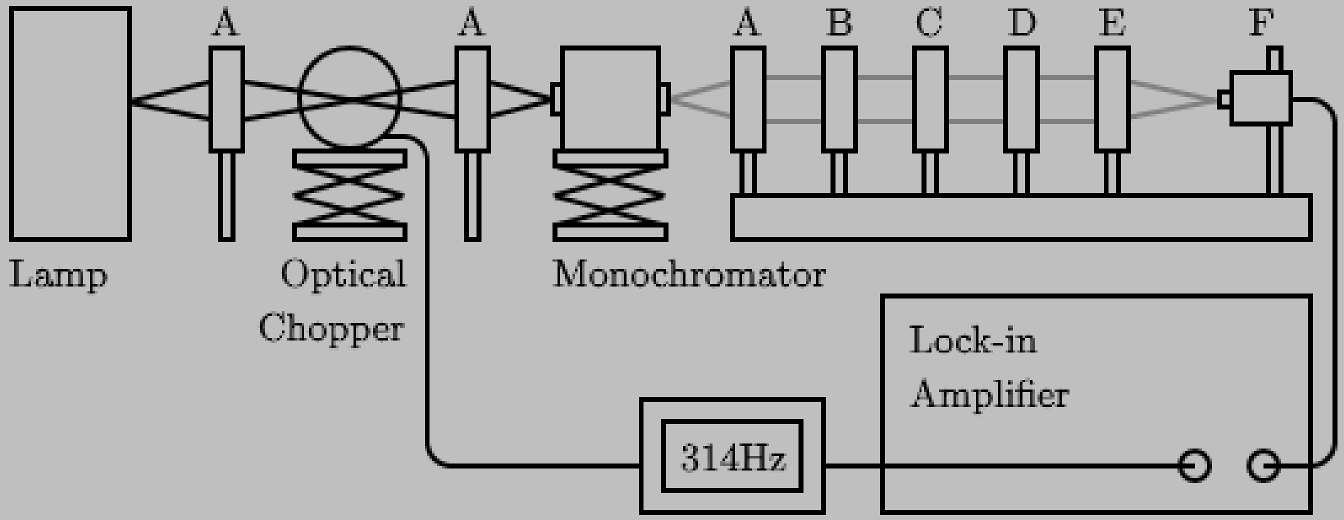

Figure 1: A diagram of the experimental set-up showing red light exiting the monochromator, where ‘A’ refers to a lens with a focal length of 10 cm, ‘B’ is the polariser, ‘C’ is a wave plate, ‘D’ is the analyser, ‘E’ is a lens with a focal length of 15 cm, and ‘F’ is the avalanche photodiode.

- Give details about the equipment you used (dimensions, models, etc.).

- Detail only the experimental steps you took (not necessarily what is written in the lab manual) to get your data. **No analysis at all here!**

Methods

- You can list your equipment as you go through your procedure.
- Describe your experimental set-up in words, and refer to your figure ("as seen in Figure 1"). Be specific about what you did. The reader should be able to not only reproduce your steps, but also make sense of your data.
- Make sure your labels are clean and legible (regarding text size and colour). Write the labels in a box or outside the photo if necessary.
- Give information about your steps in Tracker or Logger Pro.

Methods

- Make sure you have all of the images the assignment asks for. You can put additional pictures or diagrams in the Appendix, but the main ones must go in the main body of the assignment, if asked for.

- Use the correct grammar. You are writing about the steps you took. You are not writing steps for somebody else to take.

✗

Imperative Mood:

Measure the length of the string.

✓

Indicative Mood (1P, PST, ACT):

I measured the length of the string.

Methods

- Be detailed in how measurements were taken. What did you use to take the measurement? What would somebody need to know to make sense of your results or reproduce them?

- Make sure all of the equipment that you used is listed. Just because something was not placed at your lab table, like a balance, that doesn’t mean you didn’t use it.

- If the measurement is of a property of an object (its mass, its dimensions, etc.), you can give the value in the Methods section. You still have to include uncertainties and units.

Tables

- Give your tables numbers so you can refer to them easily. Include table captions explaining what the data is, and state where your uncertainties come from or if they are neglected.
- Any quantities you plot should be included in your table.

Table 1: Times measured from analysing the frames of the recorded videos in Tracker for each oil drop. The uncertainty in V was estimated from the reading of the voltage on the apparatus, and the uncertainty in the times was taken as the reciprocal of the video frame rate, $F = 15$ s. The 'falling' direction was the direction the oil drops moved under the influence of gravity, which appeared as rising in the videos.

Drop	Voltage V / V (± 1)	Direction	Time t / s (± 0.067)	
			Initial	Final
1	301	Falling	32.259	40.195
		Rising	40.323	56.787
2	301	Falling	24.131	33.139
		Rising	3.009	20.931

Tables

- The table caption should go above the table, not below.
- This is so that the reader can look at the column headers and the caption at the same time, instead of having to scroll to find information.

Table 1: Times measured from analysing the frames of the recorded videos in Tracker for each oil drop. The uncertainty in V was estimated from the reading of the voltage on the apparatus, and the uncertainty in the times was taken as the reciprocal of the video frame rate, $F = 15$ s. The 'falling' direction was the direction the oil drops moved under the influence of gravity, which appeared as rising in the videos.

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Tables and Graphs

- Your table headers and axis labels should have three pieces:
  1. The variable name (if applicable)
  2. **The symbol or equation**
  3. The units (if applicable)

Velocity, v (ms^{-1})

- Putting the symbols in table headers and axis labels helps the reader easily associate equations, data, and graphs.

- If your data has a constant uncertainty, put it in the header.

Graphs

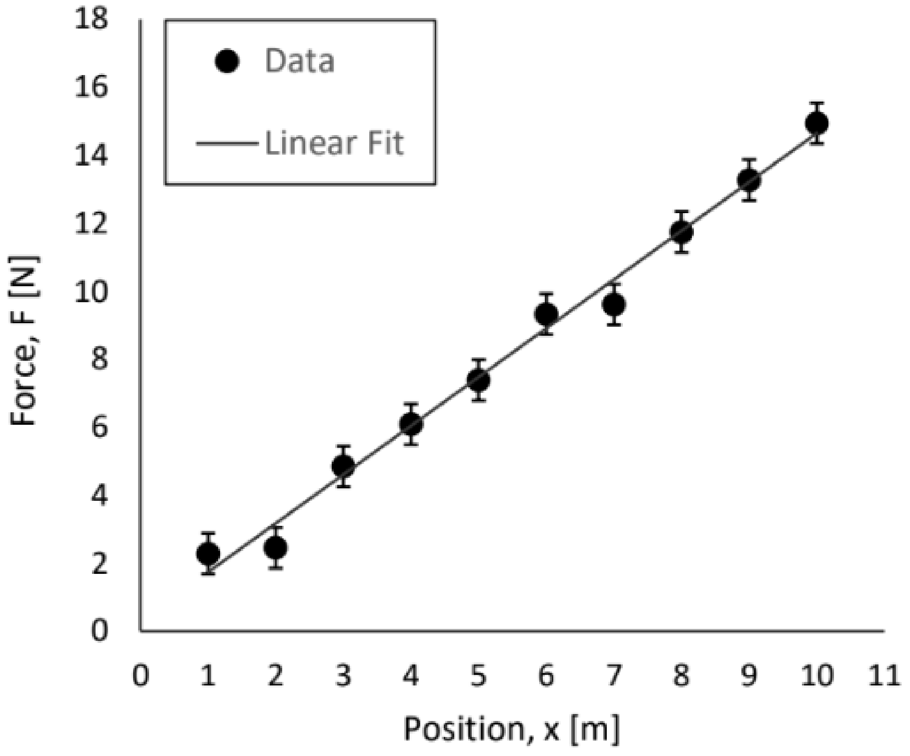


Figure 1: A plot of force against position of the raw data from Table 1. As calculated by Excel's LINEST function, the slope of the trend line is 1.43(5) Nm^{-1}, and the intercept is 0.3(3) N. Hooke's Law predicts the intercept to be 0, which is within the error range of the calculated intercept, and the slope is consistent with the accepted value of the spring constant of titanium, 1.45 Nm^{-1}.

- No title at the top
- No gridlines
- Remove extra empty whitespace
- Descriptive axis titles, if possible:

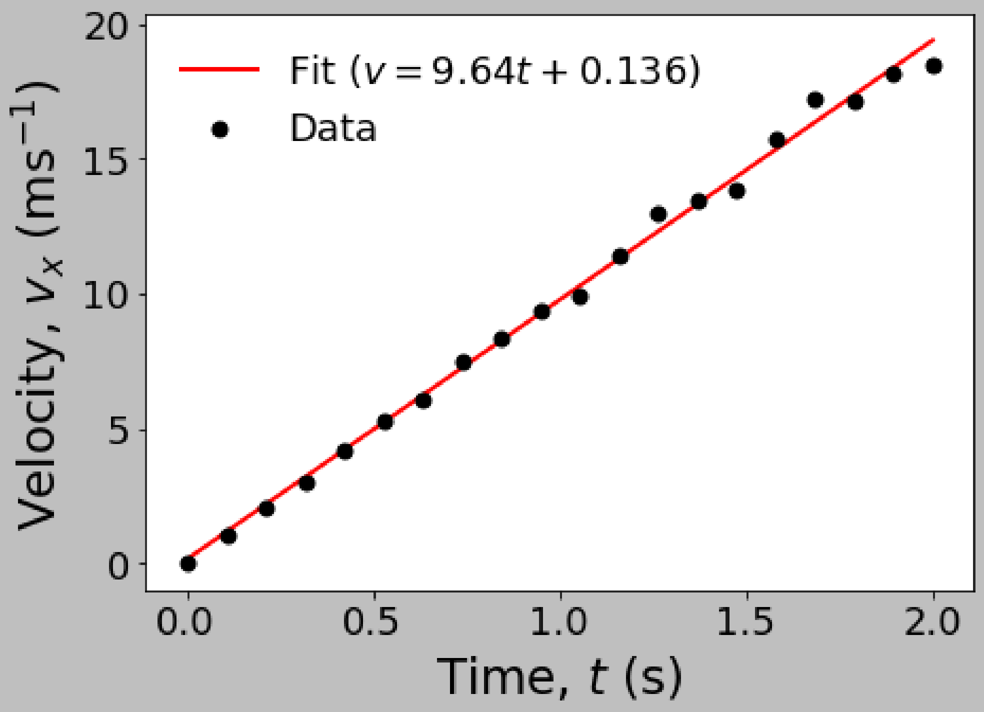
Name, *symbol* [units]

- Error bars (if appropriate)
- Legend (if appropriate)
- A detailed caption with information on what the plot shows, where the data comes from (Table #), and the important features of the plot

Graphs

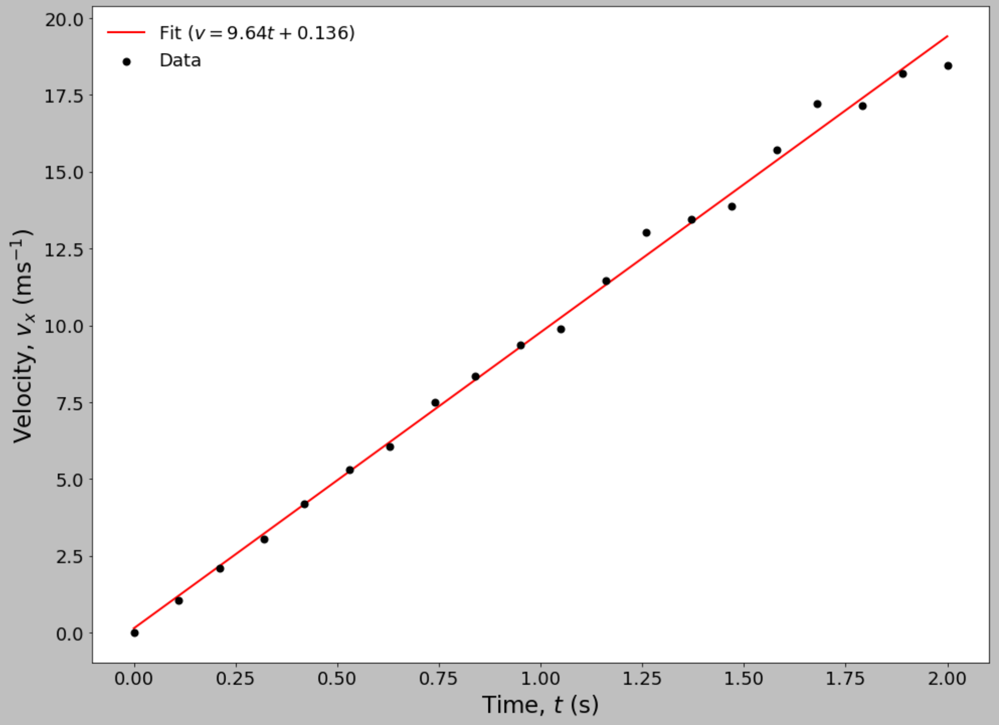
- Make sure the text on your graphs is legible.

✓



vs

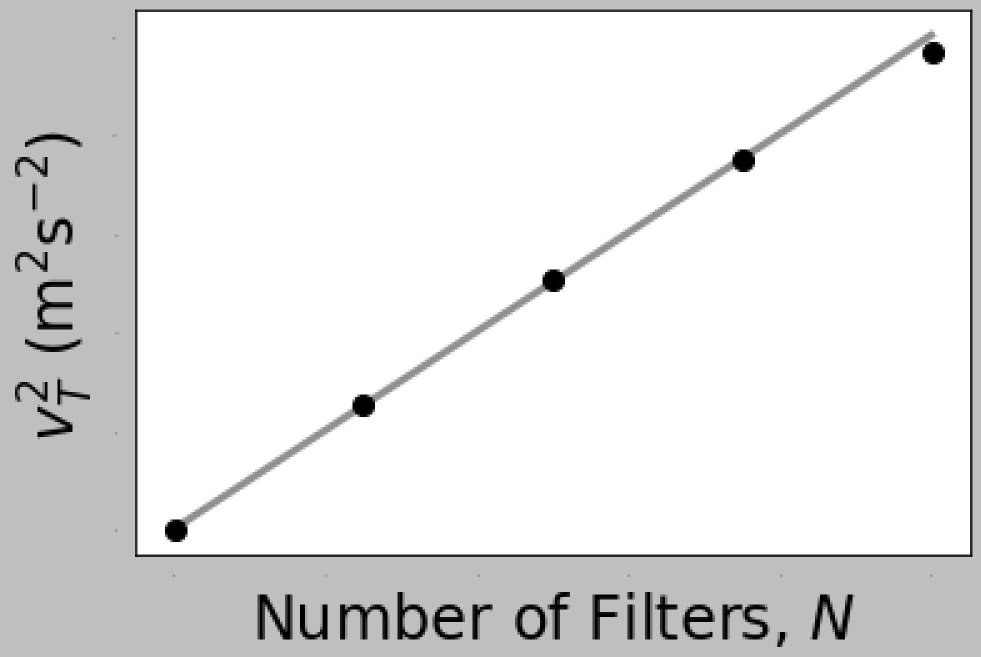
✗



Graphs

- Try to format the math properly in your axis labels and legends.

✓



vs

✗

Calculations

- Give the full steps of your calculations. Show fully simplified formulas and plug numbers in. I have to be able to see that you arrived at the correct expression and that you put the correct values in the correct places.

✗

The error in the mass of the pulley was calculated with:

$$\delta m_p = \sqrt{\left(\frac{\partial m_p}{\partial s}\right)^2 (\delta s)^2 + \left(\frac{\partial m_p}{\partial M}\right)^2 (\delta M)^2}$$

This gave a value of +/- 0.5 g.

Also, don't start plugging numbers in too early! Leave things symbolic for as long as possible, and simplify before plugging anything in.

✓

The error in the mass of the pulley was calculated as below:

$$\delta m_p = \sqrt{\left(\frac{\partial m_p}{\partial s}\right)^2 (\delta s)^2 + \left(\frac{\partial m_p}{\partial M}\right)^2 (\delta M)^2},$$

$$\delta m_p = \sqrt{(g\delta s)^2 + (\delta M)^2},$$

$$\delta m_p = \sqrt{(9.81 \cdot 0.05)^2 + (0.01)^2}.$$

With this, the mass of the pulley is (6.3 ± 0.5) g.

Significant Digits

- This is one of the most common ways to lose marks (and one of the easiest ways to annoy your TA).

- Significant digits should always be taken into account everywhere, including graph captions, and can lead to you losing a lot of marks if you don’t follow the rules.

- Please review the rules on page 31 of the lab manual concerning significant digits. If you have any questions about the rules, ask!

- There is a practice sheet in the Google Drive folder if you need it.

Significant Digits

- “s.f.” = Significant Figures. **Please** review the rules on pages 30 and 31 the lab manual, in particular:

- In introductory labs, uncertainties have only one significant figure, such as 0.2 or 0.001. Not 1.2374. (The uncertainty in the uncertainty is an advanced topic.)
- A value should have the same number of decimal places as the uncertainty: 62.4 ± 0.1 cm. Obviously, if the measurement is reported as 62.4 ± 0.01 cm, it would be pretty weird because it implies that we are more certain about our error than we are about the actual value. Bizarre. Similarly, 62.4 ± 1 cm does not make sense, because it says that our measurement is more precise than its uncertainty.
- The value and its uncertainty should have the same units. Measurements are reported in the format $x \pm \delta x$, followed by the unit. Here x is the value and δx is the uncertainty.
- A value and its uncertainty should use the same power of 10. These last two rules are there to avoid confusion – if you use different units and different powers of 10, you will be likely to get into a nasty mess.

Units

- Uncertainties have units too.

✓ $\delta g = 0.04\ \mathrm{ms}^{-2}$

✗ $\delta g = \pm 0.04$

- ln(E) does not have units of J or ln(J). Logarithms and their arguments are dimensionless quantities.

- When you square a quantity, the units get squared as well.

- Do unit checks to make sure your units always come out correctly.

Units

- You should know how to correctly find the units of the slope and the y-intercept:
  - **Slope:** The slope will have units of the y-axis divided by units of the x-axis:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

  - **Intercept:** This is a value on the y-axis, and so will always have the same units as the y-axis.

- Make sure you use the correct calculator setting according to what units you are using for angle values.

Uncertainty

- The notation you should follow is:

$$g = (9.72 \pm 0.04)\ \text{ms}^{-2}$$

- By writing this, you are saying the value of *g* can be anywhere in the range [9.68, 9.76] ms^{-2}. This will allow you to conclude whether or not your value of *g* is consistent with a known or accepted value.

Uncertainty

- Uncertainties are **always** needed **everywhere** (even in captions).

- Write uncertainties using the proper notation, **not** in a phrase.

✓

$$g = (9.72 \pm 0.04)\ \mathrm{ms}^{-2}$$

✗

The value of g is 9.7191 ms-2 with an uncertainty of 0.041 ms-2.

- Do not include the ± symbol when talking about an uncertainty alone.

✓

$$\delta g = 0.04\ \mathrm{ms}^{-2}$$

✗

$$\delta g = \pm 0.04\ \mathrm{ms}^{-2}$$

Error Propagation

- “Error” is not the same as “error propagation.” Uncertainty is calculated in different ways depending on where your value comes from.

Value	Uncertainty
Measurement	Estimated from Device
Fit Parameters	LINEST
Equation	Error Propagation
Multiple Measurements	Standard Deviation
Mean of Values	Standard Deviation of the Mean

Used for error bars on graphs

Error Propagation

- Anytime you calculate a value using an equation, you should do error propagation to find the uncertainty in your calculated value.

- You can use the formulae in Table 6.1 on page 32 of the lab manual. However, I strongly suggest you instead use the general error propagation formula (Equation (6.4) on page 32):

$$\delta f(x, y, z, \ldots) = \sqrt{\left(\frac{\partial f}{\partial x}\delta x\right)^2 + \left(\frac{\partial f}{\partial y}\delta y\right)^2 + \left(\frac{\partial f}{\partial z}\delta z\right)^2 + \cdots}$$

Agreement

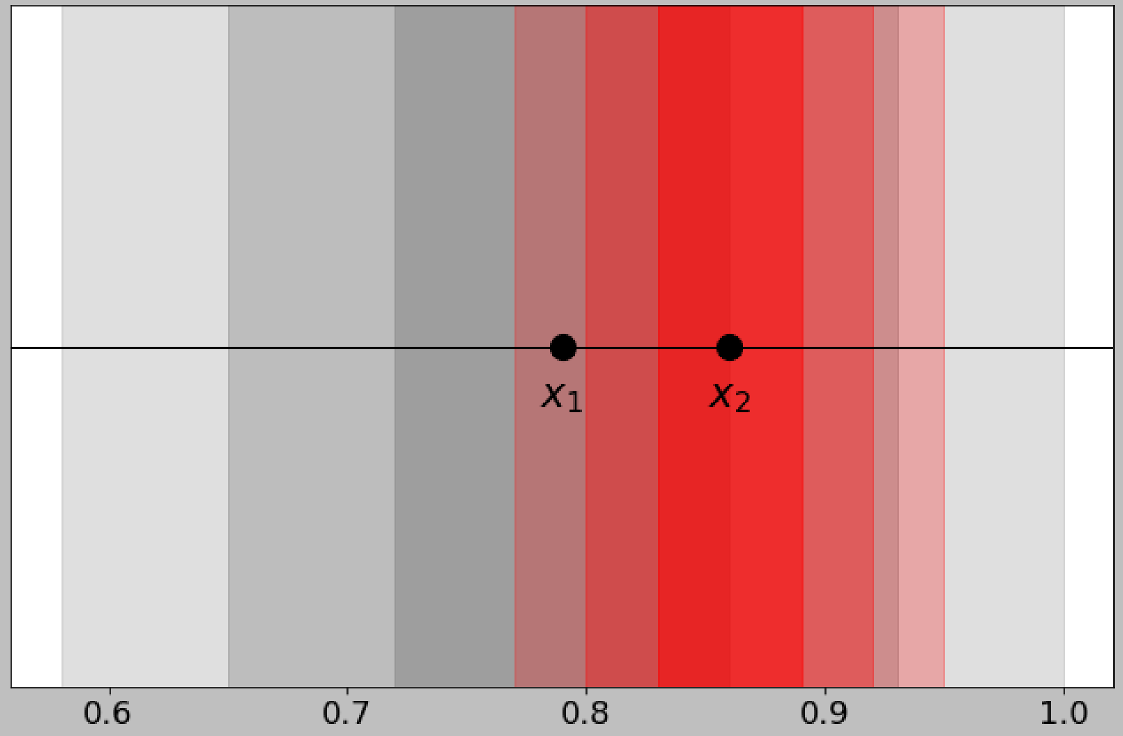
- You must explicitly mention whether or not your measured value agrees with a theoretical value (or another measured value) according to Section 4.3.4 on page 18 of the lab manual:

    1. **Within one error interval:** Good agreement
    2. **Within two error intervals:** Modest agreement
    3. **Within three error intervals:** Poor agreement
    4. **More than three error intervals:** No agreement

- Comparing (9.72 ± 0.04) ms^{-2} to 9.81 ms^{-2}, we have poor agreement.

Comparing Values

- To compare two values that both have uncertainty:



x_1 = (0.79 ± 0.07)
x_2 = (0.86 ± 0.03)

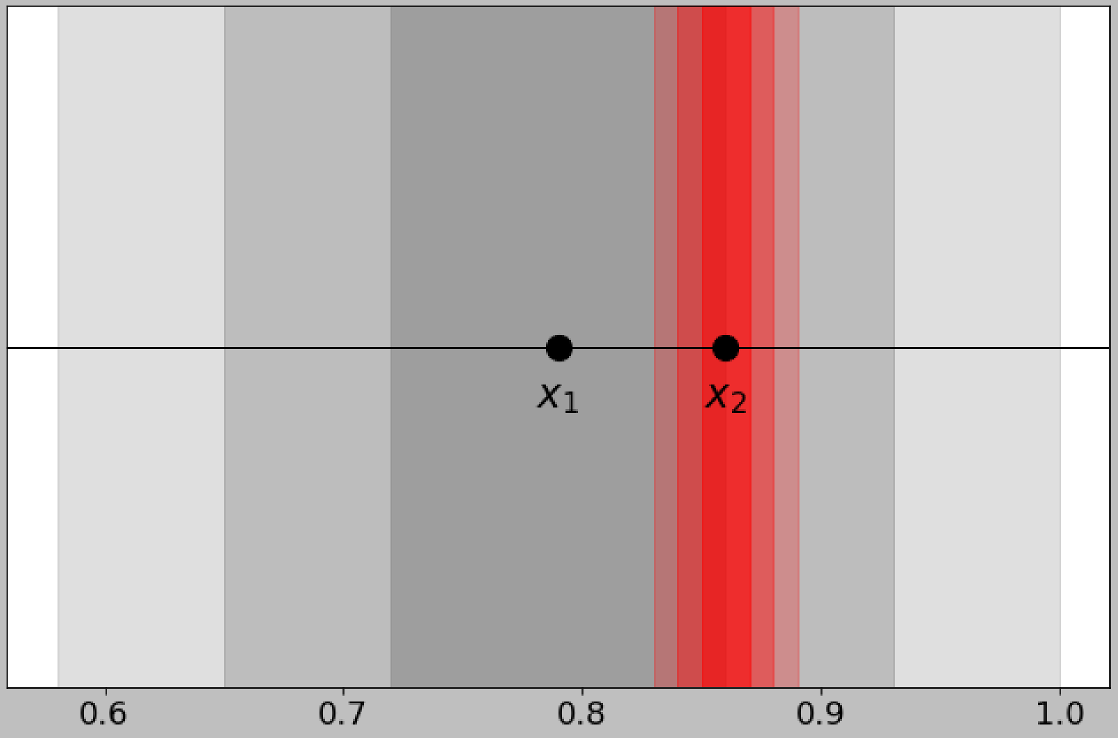
- x_2 is **within one error interval** of x_1, and x_1 is within three error intervals of x_2: good agreement.

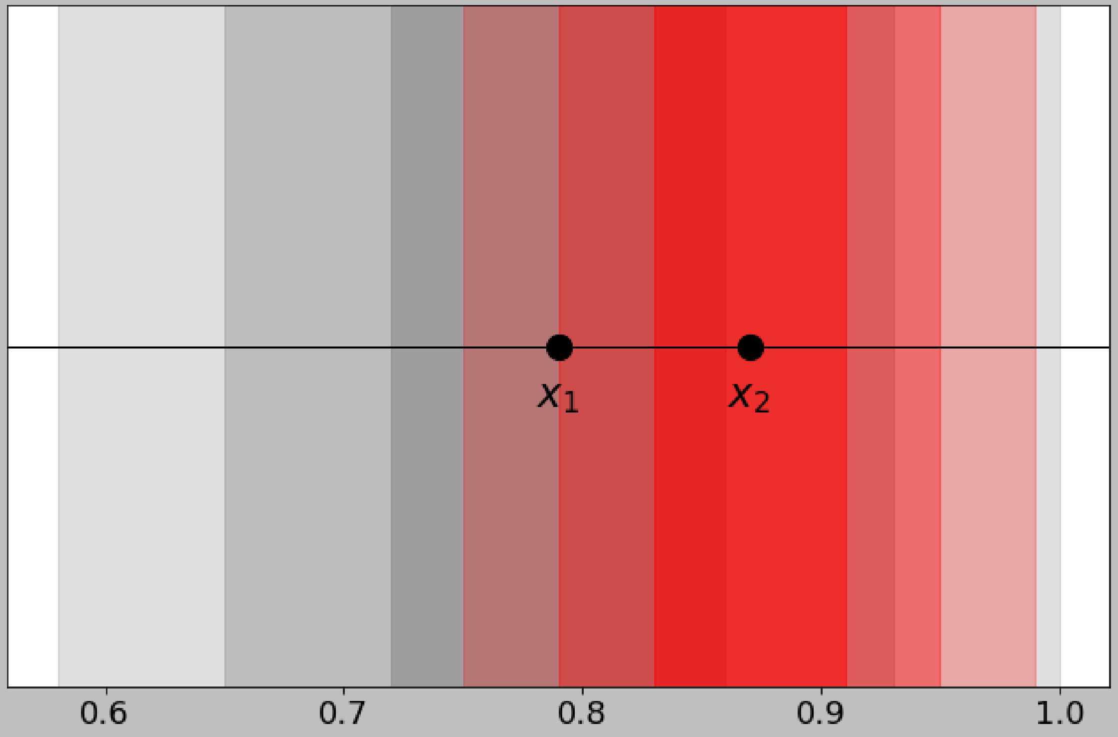
$$\Delta x = |x_1 - x_2| = 0.07$$

$$\delta(\Delta x) = \sqrt{(\delta x_1)^2 + (\delta x_2)^2} = 0.08$$

- (0.07 ± 0.08) has good agreement with 0, so the values have good agreement.

Comparing Values





x_1 = (0.79 ± 0.07): No agreement
x_2 = (0.86 ± 0.01): Good agreement
Δx = (0.07 ± 0.07)
Good agreement

x_1 = (0.79 ± 0.07): Modest agreement
x_2 = (0.87 ± 0.04): Modest agreement
Δx = (0.08 ± 0.08)
Good agreement

Sources of Error

- If you have a large error (50%+), you should acknowledge this. If your calculated value was $\beta = -1 \pm 3$, then the value -2 does lie within one error interval, but it's a bit misleading to claim there is "good agreement" when your calculated value could be as high as +2.

- Make sure the connection between your experiment and your suggested improvement is made clear. Each suggestion should have two pieces:
  1. Statement about what you had difficulty with,
  2. Detailed suggestion for how to make it better next time.

Sources of Error

- Mention realistic sources of error coming from either limitations of the equipment, or from external forces that you cannot control.

One possible source of error while measuring the magnetic field of the source coil was the influence of an external magnetic field from a strong magnet installed one floor below the lab room. This influence could have prevented observations of small deviations due to higher order multipole behaviour very near to the coil, making the coil only appear to be a dipole.

- Use these sources of error to suggest realistic improvements.

- Human error is **NOT** a valid source of error.

Sources of Error

- Be detailed with your improvements. Justify **why** you are suggesting what you are suggesting, and make sure your suggestions are relevant:
  - “I could use a device.” What kind of device? Be reasonable.
  - “I could have used better materials.” What materials? What was wrong with the materials you did use? How would other materials avoid those problems?
  - “This was a problem.” Ok, so what is the improvement?
  - “I noticed A and changed it to B.” That’s good, but irrelevant.
  - “I did a good job at C.” That’s good, but irrelevant.

- Try not to suggest things that will introduce even more problems, even if it solves the problem you mentioned.

Sources of Error

- You should explicitly point to evidence in your data. You cannot say that something was a major source of error if its effects cannot even be seen in your data. If you got a value of *g* that was higher than the accepted value, do not claim that this was due to air resistance, as this is not justified.

- Judge what is actually a significant source of error that is worth mentioning. If something had such a small effect that it only makes a difference at the 10th decimal place, the reader probably does not need to know about it, and you definitely should not claim it as the main reason your results were off.

Sources of Error

- You cannot reuse sources of error. If you already took something into account in an uncertainty value and, even when doing this, the results still don't agree, you cannot claim this thing as a reason why your results don't agree. You already accounted for it.

- Do not use the word "if." Something either happened or it did not.

- "We might have thrown the ball." Did you? If you did, retake the video. This is human error. Sources of error are things outside of your control.

Sources of Error

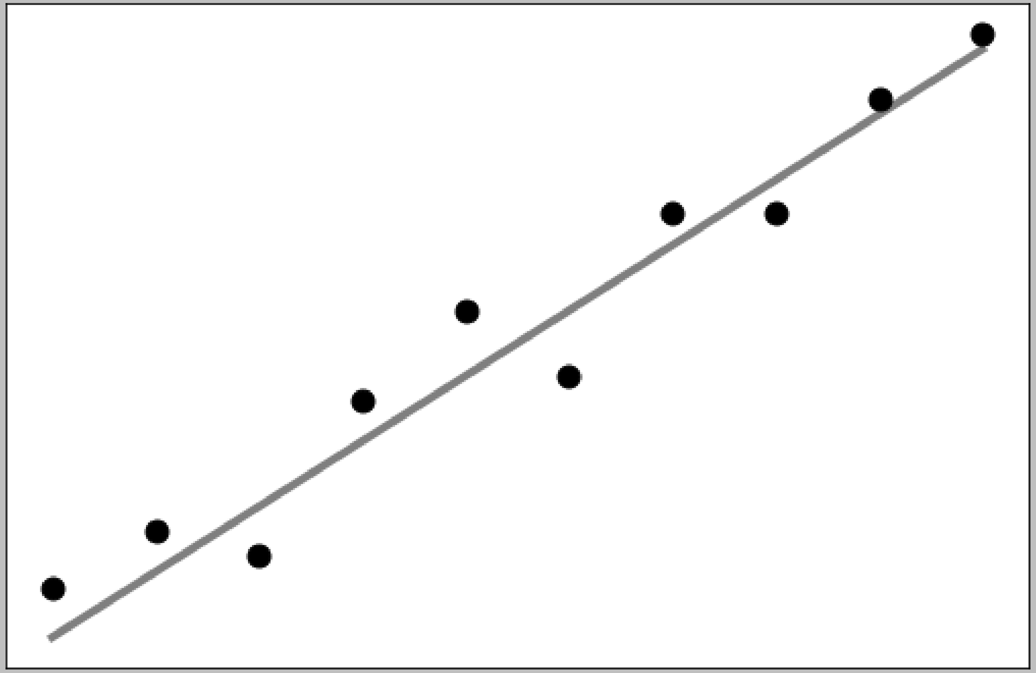
- You should mention if something is a random error or systematic error. Will it affect one data point, or all of your data points? More data points will not help improve your results if the errors are dominated by systematics.

- Be specific in the ways a source of error will affect your data and results (in particular for systematic errors). Will it increase or decrease your data for a certain variable? How would this change your final result? Follow the error through from the beginning to the end.

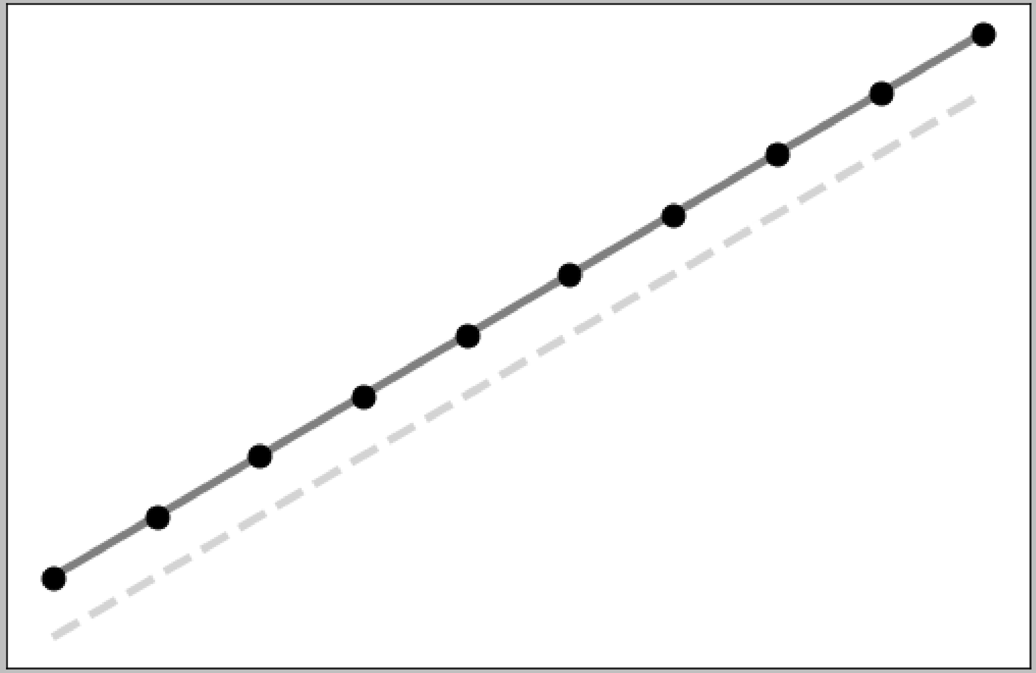
Types of Error

- Random error affects individual points. Systematic errors affects every point. Your experiment may have both types of error.

Random Error

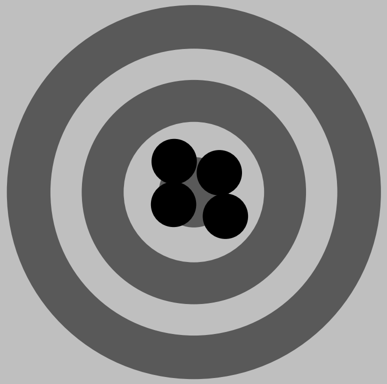


Systematic Error

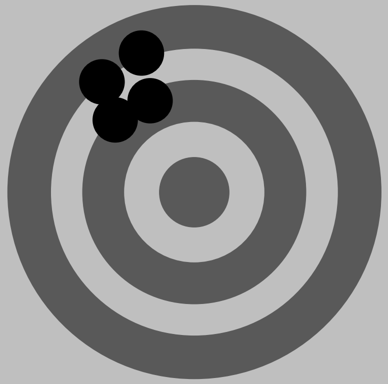


Precision and Accuracy

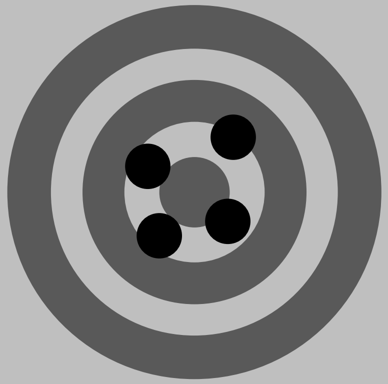
- Just because your errors from one method were smaller, that does not necessarily mean the method was better. You might have had systematic errors. Precision and accuracy are independent concepts:
  - **Precise:** Small errors
  - **Accurate:** Close to the true value



Precise
Accurate



Precise
Not Accurate



Not Precise
Accurate

Not Precise
Not Accurate

References and Acknowledgements

- **References:** For specific resources that you used directly that another person should be able to find (like a textbook or the lab manual). Include enough information for the source to be found.

- **Acknowledgements:** For general help you received, either from a resource or a person, but did not implement directly. They can also be used for internal resources that another person might not have access to (like these slides). Acknowledgements can be written in sentences or a paragraph. It might be safer to make Acknowledgements its own section so you don't forget about it and so I can award points correctly.

References and Acknowledgements

- These sections are required for your lab report, even if you have no acknowledgements. They do not count towards the page count.

- There is no required formatting style, but please be consistent and clear. I should be able to easily find whatever you reference.

- It is best practice to number your references and use those numbers in your report to indicate where you took information from:

[1] Foster, K., *et al*. 2023. *Lab Manual PHYS 146*. Edmonton: University of Alberta, Department of Physics.

Appendix

- You can include appendices for pieces of work that do not fit into the main body of your report. These (might or might not) include:
    1. Long data tables (though a sample data table is needed in the main body of your report)
    2. Figures to show the experimental set-up (in addition to the main one)
    3. Additional plots with outliers included / removed

- The appendix does not count towards the page count.