An experiment is a question which science poses to Nature, and a measurement is the recording of Nature's answer. *Max Planck*

Experimentation is the least arrogant method of gaining knowledge. The experimenter humbly asks a question of nature *Isaac Asimov*

VCE PHYSICS PRACTICAL INVESTIGATION

INFORMATION BOOKLET

2020

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I never allow myself to become discouraged under any circumstances. … After we had conducted thousands of experiments on a certain project without solving the problem, … we had learned something. For we had learned for a certainty that the thing couldn't be done that way, and that we would have to try some other way. We sometimes learn a lot from our failures if we have put into the effort the best thought and work we are capable of. *Thomas Edison*

If we knew what we were doing, it would not be called research. *Albert Einstein*

1. **What will you be doing?**

From the Study Design, Unit 4 Area of Study 3:

> Students access primary quantitative data, analyse and evaluate the data, identify limitations of data and methods, link experimental results to science ideas, reach a conclusion in response to the question and suggest a further investigation that may be undertaken.
>
> The student is expected to analyse and evaluate an investigation involving one continuous independent variable. Findings are communicated in a scientific poster format or as a practical report.
>
> A logbook must be maintained by the student for record, authentication and assessment purposes.

It will be your task to :-

- select a topic of your choice,
- plan how you will undertake the investigation,
- carry out observations and measurements,
- maintain a log book for
  - your plan and any refinements,
  - data and its analysis,
  - any difficulties and their solutions,
  - preliminary conclusions
- prepare a PowerPoint slide explaining:-
  - what you planned to do,
  - how you went about the task,
  - what you found out, and
  - commenting on how effective your plan was and where your investigation could have been improved or extended.

Working as a pair or on your own?

You can do your Practical Investigation on your own or with someone else. There are plusses and minuses to each arrangement. Working with someone else means that you have a sounding board for your ideas. Working individually means you can work at your own pace.

If you do work in a pair, remember whilst planning and execution of the investigation is a joint and collaborative effort, you must each analyse the data and prepare your own poster. The only feature identical in each poster must be the data. All writing and data analysis, including graphs, must be your own individual work.

It never occurred to me that there was going to be any stumbling block. Not that I had the answer, but [I had] the joy of going at it. When you have that joy, you do the right experiments. You let the material tell you where to go, and it tells you at every step what the next has to be because you're integrating with an overall brand new pattern in mind. *When asked how she could have worked for two years without knowing the outcome. Barbara McClintock*

2. What do you get out of the Practical Investigation?

Benefits:

- Sense of ownership of the task,
- Opportunity to work independently on a topic that interests you,
- Your success does not depend on how well you do in a test, but rather on you being:

focussed organised careful

thoughtful analytical thorough

But, there may be worries:

- Being unsure about being on the right track,
- Being stuck when the results don't make sense.

However, problems aren't a negative, they are an opportunity for you to reveal your capabilities to:

- analyse the possible causes, and
- suggest solutions.

Your teacher is there as a resource and a mentor.

3. Deciding on a topic

For the Unit 4 Area of Study, 'Practical Investigation' you have to choose a topic related to any of the physics content you have covered this year. This includes:

- Motion,
- Fields,
- Electrical Energy,
- Waves and Light,
- Light and Matter.

To stimulate your ideas about possible topics you might like to think about the following questions:

- Do your hobbies, sporting activities or musical interests have aspects you would like to investigate?
- Are there particular topics from this year's course that sparked an interest?
- Are there investigation topics from previous years you would like to pursue further?

You may wish to get together with some classmates to brainstorm some possible topics.

You may wish to look through some lists of topics for one that catches your eye. See Appendix 1.

Once you have a short list or a possible topic in mind. You should give it a clear title and preferably a couple of questions that you would like to find answers to. This helps focus your curiosity.

You will need to submit it to your teacher for their approval. They will be concerned about the following matters:

- Does the topic have sufficient depth for a Year 12 investigation?
- Can an independent continuous variable be identified?
- Is the topic practicable? that is,
  - Does the school have the equipment?
  - Can you make a good start and obtain preliminary measurements in the first double period?
  - Can it be completed in the class time available?

4. Identifying variables

In thinking about your topic, you need to explore the full range of both the dependent and independent variables. For example, if you were about to investigate the motion of a parachute, the terminal velocity of the falling parachute would be an obvious dependent variable, but you should also mention other dependent variables, even if you may not subsequently investigate them, for example, the distance travelled before terminal velocity is reached, or the time taken, or possibly the average acceleration.

Similarly, there are likely to be numerous factors that will affect your dependent variables. It shows your insight into the topic if you can list a good number even if they might not be significant or that you choose not to pursue them.

Appendix 2 has more details about the different types are variables.

5. Formulating a plan

You will need to prepare a detailed plan.

This may be done under test conditions, assessed with feedback provided. If you are working in a pair, each person would need to prepare a plan.

A plan should include some or all of the following:

- Title
- Dependent variables
- Independent variable
- Controlled variables
- Physics equations that you plan to use to calculate the value of relevant quantities from your measurements, possibly with sample calculations.
- Equipment and instruments that you will need, including data loggers. See Appendix 4 for list of available equipment.
- Equipment layout
- Procedure: A description of your plan including details of the range of values you will investigate for your independent variables as well as the number of trials for each data value. Any data analysis software, e.g. Tracker, that you plan to use should also be mentioned.

Once your plan is approved you will need to complete an equipment request form, see appendix 3, so that the equipment can be compiled and purchased if needed. There may be the occasional special item that you wish to bring from home. Appendix 4 has a list of available equipment and instruments with the school.

I built the solenoid and with great expectations late one evening I pressed the switch which sent a current of 40 amperes through the coil. The result was spectacular—a deafening explosion, the apparatus disappeared, all windows were blown in or out, a wall caved in, and thus ended my pioneering experiment on liquid hydrogen cooled coils!
[Recalling the result of his experiment, on 31 Mar 1930, to maximize the magnetic field by cooling the coils of an electromagnet in liquid hydrogen to reduce their resistance.] Nicholas Kurti

6. A Timeline

These are the steps in the process with a typical timeline from first being briefed on the task, defined as week 1, to submitting the poster or report and logbook.

Normal teaching of other topics will continue in weeks, 1, 2 and 3 of this timeline.

- Booklets are distributed and task outlined: *A period at the beginning of week 1*
- Brainstorming of topics: *A period at the end of week 1*
- Possible topics due by: *Monday of week 2*
- Topic approved by: *Tuesday of week 2*
- Preparation of a plan *(under test conditions)*: *Wednesday of week 2*
- Feedback on plan provided: *Friday of week 2*
- Equipment request form is submitted: *Monday of week 3*
- Requested equipment is assembled: *Friday of week 3*
- Experimental phase begins: *Monday of week 4*
- Progress and logbooks are monitored regularly: *Weeks 4 and 5*
- Final data analysis is done, conclusions drawn: *Early part of week 6*
- Poster is compiled from logbook material: *Later part of week 6*
- Poster and logbook are submitted: *End of week 6*

7. Hints for the students

- Do some quick measurements at the beginning to clarify if your equipment is working, and your technique is OK.
- Do repeated trials across a large range of values.
- Analyse data progressively, look for patterns and gaps. Don't 'stockpile data' for later analysis after all the equipment has been packed up and put away.
- Record uncertainties of instruments and measurements as you go.
- Take photos of experimental set up for your poster or report.
- This is real research, expect teething problems, so record difficulties and solutions in the log book.
- Seeking help from the teacher, is not a sign of failure, it is a sensible response to problems.

8. Using the log book

It is compulsory that you maintain a log book. It may be hard copy or electronic, but not loose sheets of paper. Your teacher will want to view it regularly.

What to put in it?

- The plan, including photos of set up
- All your data,
- Any difficulties and solutions,
- Graphs, their analysis and interpretation (pasted from Excel),
- Uncertainty calculations,
- Comments, ideas and possibilities,
- Discussion of results,
- Draft comments on conclusion.

Leave plenty of space for later annotations. Number and date the pages. At the end of each day write down what you plan to do the next day.

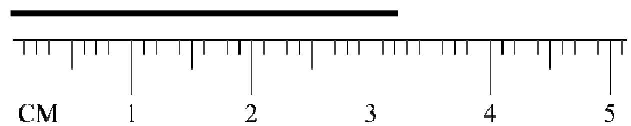
It will be a significant component of your assessment. It will be the supporting document to your poster or report.

9. Taking measurements and analysing data

Taking measurements

All measurements require a scale. The lines or graduations on the scale limit the measurement. They define a boundary or an uncertainty of value within which the measurement sits.

For example, the ruler at left has graduations 1 mm apart. The uncertainty of the resolution of the scale is ½ of this division, that is, 0.5 mm.



The length of the thick line is closer to 32 mm.
So the full description of this measurement is 32 ± 0.5 mm.

For digital scales, the uncertainty is ½ of the last digit. For example, a top load balance that gives a reading of 18.7 g has an uncertainty of 0.05 g to give a measurement of 18.7 ± 0.05 g.

Depending on your investigation, you may also need to know how to determine the percentage uncertainty of a measurement and the uncertainty in a quantity calculated from one or more measurements.

More information on these is in Appendix 5 and links to resources can be found in Appendix 6.

Analysing data

The ultimate goal of your investigation is to find out how your dependent variable depends on each of the independent variables. This is best described by a graph and possibly a mathematical relationship that summarises the graph for each independent variable.

To have a meaningful graph, you are likely to need at least seven values for each independent variable and also across a reasonable range of values.

Also to ensure the measured values of you dependent variable are reliable, several readings or trials should be undertaken. The actual number will be constrained by factors such as:

- how easy it is for you to repeat measurements, and
- the overall amount of time you have to complete the investigation,

but as a guide, three trails is desirable, and possibly more, if there is obvious variation in the readings due to human judgement, say measuring time with a stop watch, or vagaries in your equipment.

This range of readings is important as it gives you two important pieces of information:

- the average value for the dependent variable, which you will plot, and
- the spread of readings, which will determine the uncertainty of the average value and the size of the error bar on the graph.

A line of best fit on the graph summarises the relationships between the variables. If the line is straight or curved, it may be possible to describe the line with an equation.

More information on this and links to resources can be found in Appendix 6.

10. Assembling a poster or writing a report

The categories and their content are largely the same, regardless of whether you are working on a poster or a report.

Title	Question under investigation is the title
Introduction	Explanation or reason for undertaking the investigation, including a clear aim, a hypothesis and/or prediction and relevant background physics concepts
Methodology and/or method	Summary that outlines the methodology used in the investigation and is authenticated by logbook entries Identification and management of relevant risks, including the relevant health, safety and ethical guidelines followed in the investigation
Results	Presentation of collected primary data/evidence in appropriate format to illustrate trends, patterns and/or relationships
Discussion	Analysis and evaluation of primary data Identification of outliers and their subsequent treatment Identification of limitations in data and methods, and suggested improvement Linking of results to relevant physics concepts
Conclusion:	Conclusion that provides a response to the question
References and acknowledgments	Referencing and acknowledgment of all quotations and sourced content as they appear in the poster

If writing a report, set up a document with these headings, along with the descriptors as a helpful reminder Your poster can be done as a PowerPoint slide and then printed as a pdf. See the example in Appendix 7. You should use a template with ready-made text boxes for you to insert your text, photos, tables and graphs. The text boxes can also include the descriptors as a check to see if you have done what is required.

The example is also available as a template slide at https://www.vicphysics.org/practical-investigations/ . It has text boxes already set up for you to insert your text. This address has other templates and examples of posters.

Note also, you don't need to wait until the last week to begin your poster or start writing your report.

You will have a clear idea of your plan after the first week, so why not fill that section of the poster or the report then. You can tidy it up later. You can also paste a picture of your equipment layout.

Similarly in week two when you have some analysis completed, paste a graph or two in the poster or report along with sample calculations and uncertainty calculations.

Word limit: In 2020 there is a word limit of 600 words, which is not much. There are just over 450 words on this page. So some suggestions are:

- Keep most of your words for the 'Discussion'
- For your Method, use a labelled diagram and dot points
- Introduction: Be succinct, assumed your audience is a capable fellow student who does not need to basics of physics spelt out.
- The conclusion does not need to be elaborate, a precisely worded sentence is enough.

Appendices

1. List of Possible Topics for Investigations

- The sporting impacts of a ball with a bat: How does the energy transfer from bat to ball depend of the ball speed, bat speed and the position on the bat of the point of impact?
- Forces and energies of a bouncing ball: How does the drop height and internal air pressure of a basketball affect the rebound efficiency and the impact force?
- Sweet spot of a tennis racket: How does the rebound efficiency of a tennis ball hitting a tennis racket depend on the speed of the ball and the position on the racket where it hits?
- Impact of a balloon: How is the impact time of a bouncing balloon affected by the internal air pressure or its diameter and added mass?
- The performance of a parachute. How do the terminal velocity and the time to reach it depend on the attached mass and the design parameters of the parachute?
- Investigate the drag on objects towed in water (consider changes with length, depth of water and other factors)
- Investigate the thrust of a propeller (either in air, or in water)
- Magnus Glider: Glue the bottoms of two light cups together to make a glider. Wind an elastic band around the centre and hold the free end that remains. While holding the glider, stretch the free end of the elastic band and then release the glider. Investigate its motion.
- Hovercraft : A simple model hovercraft can be built using a CD and a balloon filled with air attached via a tube. Exiting air can lift the device making it float over a surface with low friction. Investigate how the relevant parameters influence the time of the 'low-friction' state.
- Surface tension of a liquid. Use a top loading balance to investigate how the liquid's restraining force varies as an object is pulled from the surface and how the liquid's parameters might affect that.
- Rolling magnets: Investigate the motion of a magnet as it rolls down a metal inclined plane.
- Bouncing ball : If you hold a Ping-Pong ball above the ground and release it, it bounces. The nature of the collision changes if the ball contains liquid. Investigate how the nature of the collision depends on the amount of liquid inside the ball and other relevant parameters.
- How does the efficiency of a bicycle dynamo depend on the wheel speed and the resistance of the globe?
- How does the efficiency of a DC motor depend on the load and the voltage?
- A charged rod will exert a measurable attractive force on a metal sheet placed on a top loading balance. What factors affect the size of the force?
- Investigate what factors affect the penetration of sound through double glazed panels.
- Sound-absorbing tiles sometimes have perforated hardboard over an absorbent layer. Investigate the effect of changing the frequency and the size of the air hole.
- Flute: Drill a hole into the side of a tube that is open at one end and produce a sound by blowing the open end. Investigate the pitch and timbre of the sound of your flute and how they depend on the position and the diameter of the hole
- When a laser beam is aimed at a wire, a circle of light can be observed on a screen perpendicular to the wire. Investigate how it depends on the relevant parameters.

There are lists of topics at https://www.vicphysics.org/practical-investigations/

2. Variables

Independent variables: Aspects you can change.
Dependent variables: Aspects that change because you changed something else.
Controlled variables: Independent variables that you decide not to vary, they are held constant.
Types of variables:

- Continuous can be represented by a real number and plotted on an x-y graph, *e.g. drop height.*
- Discrete can be represented by an integer and can be plotted on an x-y graph, *e.g. numbers of strings on a parachute.*
- Categorical are qualitatively different, can be graphed on bar chart, *e.g. types of surfaces on which a ball is bounced.*

Resources

A Level Physics Online, https://www.alevelphysicsonline.com/practical-skills has a series of short Youtube videos on variables, uncertainty, percentage uncertainty and graphing.

3. Equipment Request Form

Name(s): ____

Title of Investigation: ____

Equipment and instruments requested:

Quantity	Item description	Provided	Returned

Equipment supplied by the student:

____

____

____

Software for datalogging or data analysis:

____

____

Labelled Diagram of equipment:

Signed:

____

4. Equipment available for use in Investigations

Measuring Instruments	Range	Scale	Uncertainty
Measurement: Length			
Metre ruler	100 cm	1 mm	+/- 0.5 mm
Tape measure	30 m	2 mm	+/- 1 mm
Micrometer	5 cm	0.01 mm	+/- 0.005 mm
Vernier callipers	10 cm	0.01 mm	+/- 0.005 mm
Measurement: Mass			
Bathroom scales	100 kg	1 kg	+/- 0.5 kg
Beam balance	300 gm	0.01gm	+/- 0.005 gm
Top-loading balance	5000 gm	1 gm	+/- 0.5 gm
Measurement: Time			
Stop watch		0.01 sec	+/- 0.005 sec
Event timer		0.001	+/- 0.0005 sec
Multi-counter		0.001 sec	+/- 0.0005 sec

Mechanics

Air track	Ultrasound	Data loggers
Ticker timer	Pressure gauge	Video capture software
Springs	Air pump	

Electricity and Magnetism

Ammeters	Signal generator	Electromagnets
Voltmeters	Electric motor	Transformer
Multimeters	Magnets	Induction coil
CRO		

Waves and Light

Ripple tank	Mirrors	Diffraction gratings
Lenses		

Ancillary Equipment

Stand	Wire	Fishing line
Boss head & clamp	String	Set of heavy masses
G clamp	Sticky tape	Slotted masses

Appendix 5 Taking Measurements and Uncertainty

Conventions when using Uncertainty

- Put units at the end e.g. 25 ± 1 s, not 25 s ± 1 s
- With large or small numbers using standard form, the power of ten and unit are both placed at the end, e.g. $(6.3 \pm 0.2) \times 10^{-8}$ m, not $6.3 \times 10^{-8} \pm 0.2 \times 10^{-8}$ m
- Uncertainties normally stated to one sig fig.
- A measurement should be quoted to the same decimal place as its absolute uncertainty, e.g. 2.60 ± 0.02 s, not 2.604 ± 0.02 s or 2.6 ± 0.02 s

Uncertainty in Repeated Trials

Set of temperature readings: 19.4, 19.6, 19.5, 19.8, 19.2, 19.1, 19.5 and 19.2 ºC. Average = 19.4 ºC
Range: = 19.1 to 19.8 ºC
Uncertainty = Larger difference from average = 0.4 ºC
So plotted data = 19.4 ± 0.4 ºC

Percentage Uncertainty

Percentage Uncertainty (PU) = (Uncertainty / Measurement) x 100 /1
e.g. PU for temperature data = (0.4 / 19.4) x 100/1 = 2.06 = 2 %

Combining Measurements: Uncertainty

a) When adding or subtracting quantities. Rule: Add uncertainties
e.g. Change in velocity of a bouncing ball on impact
Initial velocity = 6.26 ± 0.03 m s^{-1} , Final velocity = 4.85 ± 0.06 m s^{-1}
Change in velocity = 4.85 - (- 6.26) m s^{-1} = 11.11 m s^{-1}
Uncertainty = 0.03 + 0.06 = 0.09
So, change in velocity is 11.11 ± 0.09 m s^{-1}

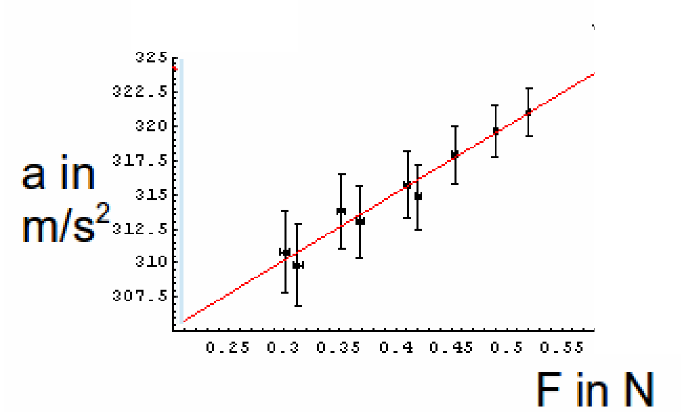
b) Multiplying or dividing quantities. Rule: Add percentage uncertainties
Problem: Drop height = 2.00 ± 0.01 m, Rebound height = 1.20 ± 0.03 m
What percentage of the initial gravitational potential energy is retained?
Answer: = $(mgh_{\text{rebound height}}) / (mgh_{\text{drop height}})$ x 100
= (rebound height / drop height) x 100 = (1.20 / 2.00) x 100 = 60.0 %
To calculate percentage error in this value of 60.0 %
Drop Height (PU) = (0.01/2.00) x (100/1) = 0.5%. Rebound Height (PU)= (0.03/1.20) x (100/1) = 2.5%
Energy Efficiency (PU) = 0.5% + 2.5% = 3.0%
So, the uncertainty in Energy Efficiency = 3.0% of 60 = (3.0 / 100) x 60.0 = 1.8
So answer is 60.0 ± 1.8, but rounding gives 60 ± 2.

See Appendix 6 for Resources.

Appendix 6 Analysing Data

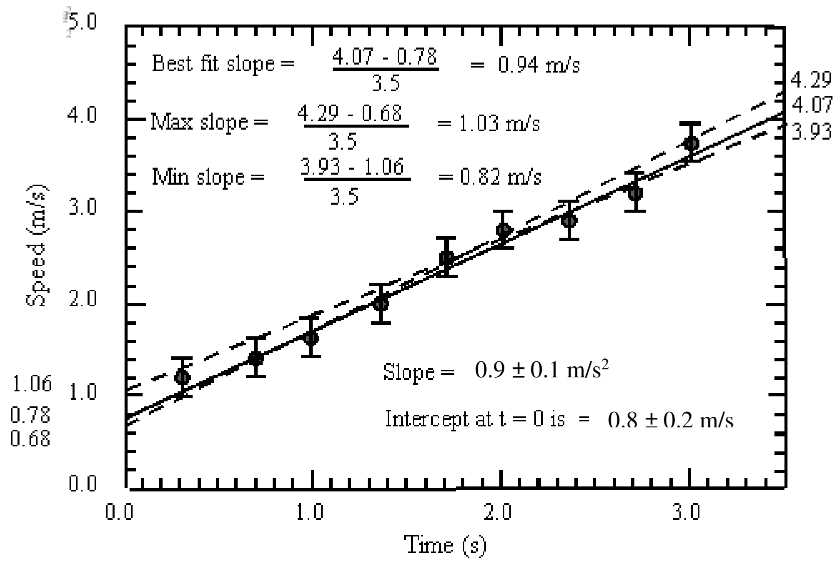
Uncertainty and graphs

- Uncertainty is represented on a graph by an 'Error bar' about each data point.
- Size of the error bar = uncertainty



Line Of Best Fit

- Draw smooth line through all the error bars.
- Avoid forcing line to go through a maximum number of data points.
- It gives different pairs of readings different rather than identical weightings.
- As many data points above the line as below the line.
- Max and min values for gradient of line of best fit, also for intercept.



Resources

A Level Physics Online, https://www.alevelphysicsonline.com/practical-skills has a series of short Youtube videos on uncertainty, percentage uncertainty, variables and graphing.

https://www.youtube.com/watch?v=T78cXi-72Eg An 11 min Youtube video on uncertainties, hand written, but a good description. It is UK production for A level and is part of the Science Shorts series of 18 videos. There are also videos on Standard form, and Proportionality and Graphs.

https://www.youtube.com/watch?v=6XZsfV5FCwc An 18 min Youtube video that effectively covers the material in this appendix and also appendix 6. It is also UK based and refers to the IB.

https://www.youtube.com/watch?v=KFzN4CYjtoI This 13 minute Youtube video features a person talking to camera explaining data analysis with large hand held cards. It is simple, effective and covers the topic.

Using Excel to analyse data

https://www.mtholyoke.edu/courses/mpeterso/phys103/labs/ExcelHandout.pdf An 8 page pdf guide to using Excel in a Physics Lab. An impressive resource.

Youtube videos:

https://www.youtube.com/watch?v=5O00O8CqVQ4 Calculations, graphing and trendlines (10 min)

https://www.youtube.com/watch?v=alTdv8LG6Xk Physics 101: Lab 1 Data analysis and presentation. 28 mins

Title of Physics Practical Investigation

Student's Name

Introduction

Explanation for undertaking the investigation, including a clear aim. (One sentence should be enough.)

Relevant background physics concepts. (Just definitions and equations should suffice.)

Methodology

Summary that outlines the methodology used in the investigation and is authenticated by logbook entries.

- Description of independent and dependent variables, including which are continuous,
- Equipment and measuring instruments,
- Sketch of equipment layout as well as a photo,
- Identification and management of relevant risks …

Results

Presentation of collected data/evidence in appropriate format to illustrate trends, patterns and/or relationships.

- Selection of data showing number of repeated measurements and range of values,
- Sample calculation,
- Sample determination of uncertainty and error bars,
- Graphs with descriptions, at least 2, but less than 5,
- Analysis of graphs including lines of best fit, gradients and intercepts,
- Effect of uncertainties.

Discussion

- Analysis and evaluation of primary data
- Identification of outliers and their subsequent treatment
- Identification of limitations in:
  - Data, both in the range of values and number of repeated measurements, and
  - Experimental method, and so
  - Suggested improvements and
  - Further aspects you would like to investigate,
- Linking of results to relevant physics concepts.

Conclusion

Provide a precise and detailed response to your question. Need only be a short paragraph.

References and acknowledgements

Rarely needed in student physics investigations.