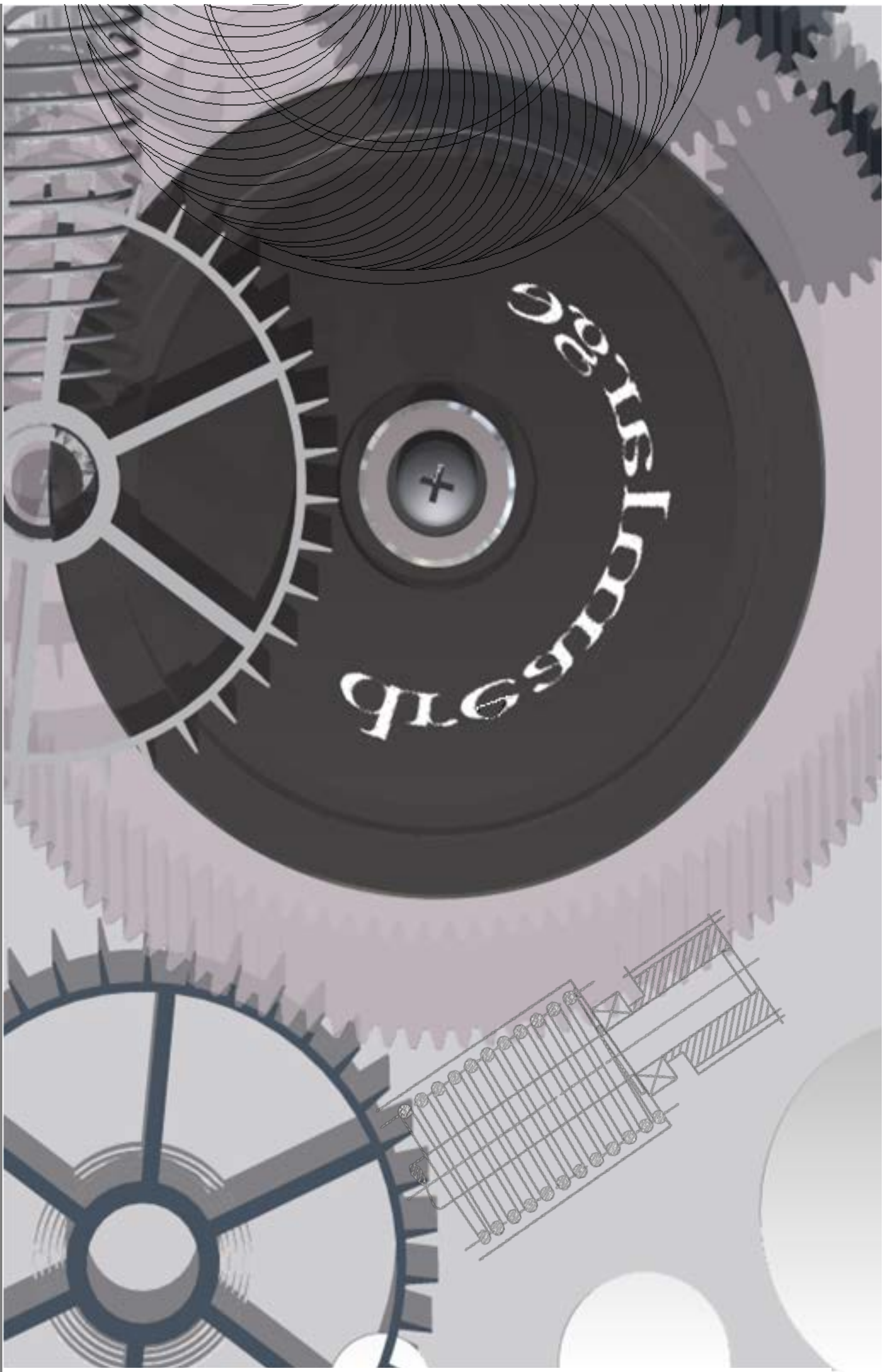
THE UNIVERSITY OF
MELBOURNE

PHYSICS HANDBOOK

2019

SCHOOL OF PHYSICS



PHYC10003

Physics 1

THE UNIVERSITY OF MELBOURNE

School of Physics

PHYC10003
Physics 1

Physics Handbook

Name: ____________________________

Student Number: ____________________________

2019

Subject Details

Class	**Who**	**When**	**Where**
Lectures	Lecturer 1: Email: Lecturer 2: Email:	1. 2. 3.	
Tutes	Tutor: Email:		
Labs	Demonstrator 1: Demonstrator 2:		3rd Floor Labs, David Caro Bldg

Welcome to PHYSICS 1 – PHYC10003

The Essentials

Resources

- **LMS** – the Learning Management System is *the* place to find all the information about this subject, including all the details and resources for lectures, problem solving classes and labs.
    - https://lms.unimelb.edu.au/
    - Log in regularly
    - Also check your unimelb.edu.au **email** regularly
- **Textbook** - Halliday & Resnick, *Fundamentals of Physics (11th ed.)*, Wiley, 2018

Classes

- **Lectures** – 3 one hour lectures a week, with resources and lecture notes posted on the LMS
- **Problem Solving Classes** (or tutes) - 1 one hour tute per week with a tutor, starting in **week 2**. The tutorial questions can be found in this book and should be attempted **before** the tute.
    - Attendance at lectures and tutes is *optional* but we know students do better when they attend.
- **Laboratory classes** – eight 2.5-hour lab classes during the semester, starting in week 2. (schedule is on the back page of this book)
    - Attending **ALL** labs and obtaining over 50% is a **hurdle requirement** and must be completed to pass the subject.
    - Read through the pracs (in this book) and do the PRELAB questions in this book AND via the LMS **before** attending class. This counts for 20% of your lab mark.
    - Check the start time and turn up to your lab session at least 5 minutes before. If you are more than 15 minutes late, you may not be allowed to start the lab for safety reasons.

Assessment

- **Homework** (15%) - an on-line homework assignment posted on the LMS each week.
- **Lab reports and performance** (25%) – participation and lab report for each lab.
- **Exam** (60%) – a 3-hour exam covering all of semester 1 at the end of semester.

Help

- Tutors in Laby Ideas Centre (underneath the Physics podium, David Caro Building)
- Director of First Year Studies – Jacinta den Besten dfys@physics.unimelb.edu.au Rm 225
- Laboratory Manager –Melaku Alemu fyl@physics.unimelb.edu.au Part I Labs
- First Year Laboratory Technician – Jude Prezens fyl@physics.unimelb.edu.au Part I Labs

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Introduction to Laboratory Work

Welcome

Welcome to the Physics 1 laboratory program where you will spend the semester performing the laboratory exercises (also known as 'Labs', 'Practical Classes', or 'Pracs') that will run alongside the lectures and tutorials, providing a practical exploration of physical concepts and an opportunity to develop your scientific methodology.

The aim is for you to broaden your understanding of the physics involved and develop the skills needed to be a successful experimental physicist.

Although the laboratory exercises investigate physics topics that may also be covered in lectures the lab exercises are designed to be completed at any time during the course. ***You may explore new concepts or re-visit ones you know well in the lab.*** While exploring the concepts you will be learning the analytical and critical skills of a Physicist.

It is very important that you read carefully the information in this manual before you start the Lab program. In particular, how to prepare for your Lab, what to do if you are unwell and how to be safe in the laboratory.

Physics Laboratories (summary)

- 8 Labs, one per week
- Starting in Week 2 of Semester 1
- You have 2.5 hours to complete the lab, allow ½ hour preparation before the lab
- Each lab has the following components
    - Pre-Lab Exercise (worth 20%)
    - Lab performance and logbook (worth 80%)
    - Demonstrator to guide your learning
    - Partner(s) to work with
- Attendance and passing is a hurdle requirement to completing the course

Help and Contacts

Help during the Lab – Demonstrator

Absences, timetables and enquiries – Laboratory Manager, Melaku Alemu (Part I Labs)
fyl@physics.unimelb.edu.au

Equipment – Damaged or broken equipment should be reported to the demonstrator immediately.

Concerns about labs and teaching - Director of First Year, Jacinta den Besten (Rm 225)
dfys@physics.unimelb.edu.au

Lost Property – See lab staff promptly

Preparation

It is essential to be properly prepared for each lab exercise. The timetable at the back of this book will tell you exactly which lab your group is undertaking each week. See below for how to check which lab group you are in.

Before your first class, you **must** read the **Safety Notes** (page I-15). Laboratory exercises may involve radioactivity, toxic materials and/or hazardous equipment, and it is essential that you are fully aware of the safety issues involved.

You must read the rest of this Introduction, including the sections on **assessment** and **logbook writing**. You will need to read **Appendix A** to learn about *uncertainty analysis* and **Appendix B** discusses the creation and use of *graphs*.

What class am I in?

Classes start in the **second week of semester one**. You will need to find out;

- which **lab group** you are in and
- which **section** of the laboratory you have been assigned to.

This information is available from the pre-labs web page (which is a link from the LMS page for the subject).

http://fyl.ph.unimelb.edu.au/prelabs

Your **lab group** will have a code like '**UAB2**'. The letters and numbers describe your group:

U is the *day*. **M** = **M**onday, **U** = T**u**esday, **W** = **W**ednesday, and **H** = T**h**ursday.

A is the *time* of day. **A** = **A**M (morning), **P** = **P**M (afternoon), and **E** = **E**vening.

B is the *subject*. A = PHYC10001 and **B = PHYC10003**, C = PHYC10005

2 is the group number, which tells you which section of the lab you will be working in. There are up to four groups doing the Physics 1 labs at the same time.

Pre-Labs

Before you come to your lab each week, you **must** complete the following:

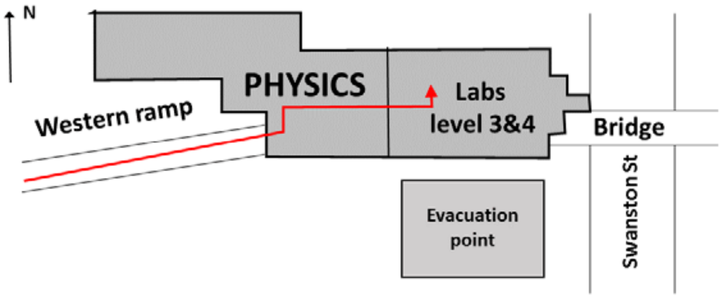
- You must read through the description of the Experiment for the week thoroughly so you are familiar with what you will be doing during the lab.
- You must complete any Pre-Lab Exercises that are in this book AND the online questions found at http://fyl.ph.unimelb.edu.au/prelabs and via the LMS.
- The online pre-labs need to be **submitted at least 10 minutes before your lab class begins.**
- Your pre-labs will be marked out of 10
    - 5 marks for completing them on time (**at least 10 minutes before your lab class begins)**
    - 5 marks for your correct answers to the questions.

Where do I go?

The first-year Physics laboratories are located on levels 3 & 4 of the Swanston Street extension to the Physics building, which is called the **Physics Podium**. The Physics I lab is on **level 3**.

When arriving for your practical classes, you should enter the laboratories via the big ramp. Follow the ramp straight up **into** the Physics Podium, and once inside go forward (towards the Swanston St exit), turn left into the area where problem solving classes run. You are now on level 2.

The entrance to the laboratories is via a stairwell, go up the concrete stairs (from level 2 up to level 3). Don't be worried as it looks like an emergency exit but this is the way to go. When you arrive for your first class there will be signs posted to show you the way.



What should I bring?

To the first practical class, you should bring:

- your Physics I **Physics Handbook** (this book!)
- your Physics I lab **notebook** (which will be your Logbook)
- a **calculator** (if you have one) – but you should use Excel as much as possible
- **pens** (for written work), **pencils** (for graphs and diagrams), **eraser and ruler**

All laboratory benches have a computer running Excel (and other useful software), and each laboratory has a printer. Any print-outs you create must be stuck into your logbook.

Attendance

Attendance is compulsory at *all* laboratory sessions. Laboratory work is a hurdle requirement: you must attend and complete your laboratory exercises satisfactorily in order to pass Physics I.

If you are unwell or cannot attend a lab session, you need to email fyl@physics.unmelb.edu.au as soon as possible (see the **Help and Contacts** section).

- If you present a medical certificate (or equivalent) you can be exempt from that prac. NOTE **A maximum of 2 medical certificates in each semester will be accepted for absences.** Further absences must be made up at another time during that same week and you will need to arrange this through the Lab Coordinator. Any further medical certificates will require you to make up your lab session/s at another time (but only in very extraordinary circumstances can this be in a different week of semester).
- If you do not have a medical certificate (or equivalent) for your absence, you **MUST** arrange an alternative time with the Lab Coordinator to attend a catch-up lab session in the same week.
- If you ignore the absence, you will receive *no* marks for that week (and a lower final mark for the subject because of this).

LABORATORY SAFETY – A BRIEF SUMMARY

Laboratory exercises may involve radioactivity, toxic materials and/or hazardous equipment, and it is essential that you are fully aware of the safety issues involved.

You are obligated to read and understand the **General Safety Notes** (later in this manual).

You must understand and follow all safety instructions and warnings for each laboratory exercise.

You must follow all the safety directions given by your demonstrator and other laboratory staff.

At your first laboratory session, your demonstrator will provide you with a declaration form which **you must sign**, asserting these responsibilities.

Much effort and thought goes into ensuring that the first-year laboratories are as safe as possible. If you have any safety concerns, you must immediately report these to your demonstrator or to another laboratory staff member.

These are the three most basic safety rules:

Adequate footwear and suitable clothing must be worn at all times.

This means no sandals or thongs. If your shoes are not closed-toe, you will not be allowed to stay in the laboratory.

Eating, drinking and smoking are not allowed in the laboratory.

This is especially important in the Radiation laboratories. The radioactive materials you will encounter in first-year Physics are extremely dangerous if accidentally ingested. If you are thirsty, there is a drinking fountain at the eastern end of the laboratories.

Mobile phones are not to be used in the laboratory.

Hazardous equipment may be in use nearby, and mobile phones can be a dangerous distraction or source of interference. If you need to receive or make an essential call, you **must** leave the laboratory to do so. If there is an essential reason for your phone to be on in the laboratory, it **must** be set to 'silent' mode.

REMEMBER:

If you bring food or drink into the laboratory, or if you wear shoes which are not closed-toe, or if you answer your phone in the lab, **you will be ejected and you will lose marks**.

Laboratory Work

You

For every lab session it is expected that you will:

- prepare adequately for your lab session – read manual and do pre-labs.
- arrive on time (5 mins before).
- work well with your partner(s) and work safely.
- consult with your demonstrator regarding any safety or physics issues.
- complete your **own** lab notes to be handed in at the end of the session.

Lab Partners

In every lab session you will:

- have one or two lab partners (they will change halfway through the semester).
- work in a team to conduct the experiments to collect data and discuss the results.
- talk together about the physics and discuss this with your demonstrator as needed.
- NOT copy each other's work, but write your **OWN** discussion, analysis and conclusions.

Demonstrators

During each lab session your demonstrator will:

- supervise your lab group for the full 2.5 hours.
- instruct and assist you in the correct use of the lab equipment.
- discuss concepts and ideas with you as a guide to your learning – they are not there to give you the answers!
- ensure the labs are run safely and everyone follows the safety procedures. You must read the **Safety Notes** and take note of your demonstrator's instruction on use of the equipment.
- assess your lab performance and logbook. Please take the time to discuss your notes for the lab with your demonstrator during the next session to learn how you can improve your experimental skills. See the **Assessment** section below as this describes what the demonstrator will be assessing you on.

Assessment of Practical Physics

Laboratory work is an important and essential part of first-year Physics. Refer to the **Laboratory Assessment Rubric** below to understand how you will be assessed for each lab.

Marks and Completion

- Laboratory assessment makes up 25% of your final mark for the subject. This consists of:
    - 20% of the marks from your submitted online prelab exercises (see **Pre-Labs** above) MARK out of 10 for each lab.
    - 80% from the completion of the labs according to the **assessment Rubric** below. Feedback is provided via the marksheet based on the rubric. MARK out of 20 for each lab.
    - the laboratory component of the first-year Physics course is a **hurdle** requirement. This means that if you fail to satisfactorily complete the laboratory component, you cannot pass.

Lab Performance

An essential aim for laboratory work is that you demonstrate your understanding of what occurs. Being able to follow directions to produce a result is important, but results are meaningless unless you can explain how they relate to the physics involved.

During your practical work, it is important to consider the following:

- **Prepare** – read the **entire** lab for that week and submit your online **Pre-Labs** before the session
- **Laboratory equipment** - use carefully, respectfully and safely. Set up correctly, check with your demonstrator if you are unsure. Make sure your bench is as you found it when you leave.
- **Lab partner(s)** – work **with** your partners and share the workload including using the computer, setting up equipment and discussing results
- **Demonstrator** – Check with your demonstrator if your group is unsure of the equipment or the Physics involved. See your demonstrator immediately if you feel anything is unsafe.
- **Measurements** - Ensure the accuracy and quality of your measurements. Think about how many measurements you should make, how best to use the available time, etc.
- **Method -** Consider possible flaws in the experimental procedure, whether the equipment you are using is appropriate, etc.
- **Results** – do they seem 'reasonable', or are they obviously in error?

Logbooks

During each weekly Experiment, you will be writing in your logbook as you go along. Please note, **your logbook stays in the laboratories at all times**: you don't take your logbook home to work on it later, so each week's logbook entry must be finished by the end of each session.

NOTE: it is better to have well thought out log notes and only finish 85% of the prac than rush to finish without demonstrating what you have learnt. Your demonstrator will give you guidelines on where you should be able to get to in your experiment.

The idea of your experimental log is to keep a sequential record of your actions, thoughts and results during the experiment.

How to write your log

Presentation

- Always use a **pen** to write your log, but use **pencil** (or Excel printouts) for graphs and diagrams.
- Your log does not need to be perfectly neat, only **clear and readable**.
- **Never** use white-out or correction fluid: simply put a line through what is incorrect and move on – apart from saving you time, this also shows your progress more correctly – making the logbook more useful to a reader.
- You should write fairly informally - it is an experimental diary for your own reference.
- At the start of each entry your log must clearly record the **date**, the **title** of the Experiment, and the **names** of your partner(s).

Recording your experiment

The logbook is a chronological record of everything that you do and think, written as you go along. Think of it like a diary entry, or a story; it should describe everything that you did differently from the manual and explain why you did it and what you think about it. There is a short example over the page of the things you might include. Definitely include diagrams of your experimental set up.

- **Don't leave writing this until the end** – it is very important (and time-saving!) to record your work as you go along. The skill to write a sensible, brief, and effective record of your work as you do it is one of the main aims in the first-year laboratory program.

- **Keep your description of the experimental procedure simple and clear**. Use simple, annotated diagrams to show how the experiment was set up, the measurements taken and any diversions from the manual description.

- **Be accurate and honest!** If you make a mistake in your setup and need to start again, your log should record this. If you misinterpret results and need to go back and re-analyse them, discuss your mistake in your log and explain where you went wrong. This is when you get to describe the awesome Physics you have learnt.

- **Graphs and Tables** – record data clearly and appropriately. Include labels, uncertainties and discussion where possible.

- **Analysis –** Consider the questions in the manual or asked by your demonstrator to guide the discussion of your results and the physics involved. The ✓ symbol indicates a good time to make a comment in your log book.

- **Uncertainties** - Remember that all measurements should be presented with their ± uncertainty values – **this is essential**! Read **Appendix A**: Uncertainties and see your demonstrator for how to present your data. Understanding the quality and validity of your results is a key learning goal in First Year Labs.

Summary

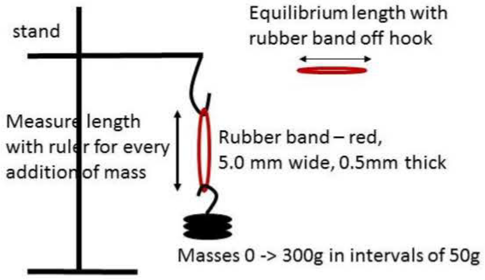
Every lab should have a **brief summary** at the end. This is a short paragraph presenting your final results and a quick discussion on how the experiment's actual outcomes relate to the original aims of the lab. As with all logbook keeping – this does not need to be formal – just a 'wrap-up" of what you did – in your own words!

Sample Logbook : Note this is a fictitious prac and log notes to demonstrate the many of the elements and detail you should include in your report.

Rubber Band **Partners:** Albert E, Marie C 1/1/1918

Observations and points to note:

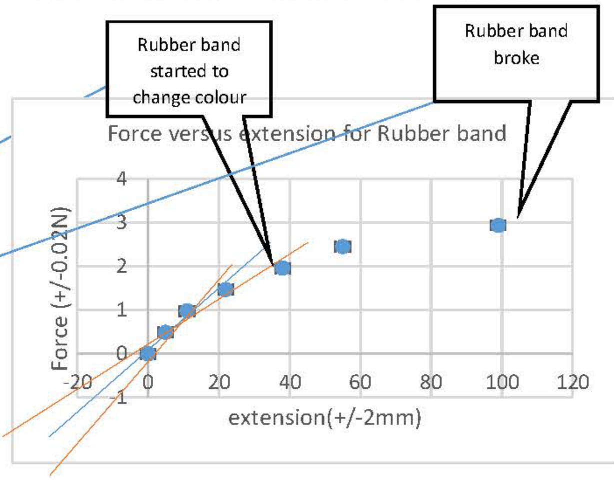
- the rubber band changed colour to white with larger masses
- at 300±5g the rubber band started to spilt and eventually broke
- It was really hard to measure the length of the rubber band because the hooks were in the way and made the measurement error larger => $\Delta L=\pm 1mm$. We had to remove the rubber band and make it flat to take our first reading.



- The masses had the uncertainty written on them. But to be more accurate, we decided to measure the mass each time on the scales to get a consistent uncertainty => $\Delta m=\pm 2g$

Data:

mass (+/-2g)	length of band (+/-1mm)	Weight Force	Extension
0	*50	0	0
50	55	0.49	5
100	61	0.98	11
150	72	1.47	22
200	88	1.96	38
250	105	2.45	55
300	149	2.94	99



Analysis:
At first we graphed the weight force with the length of the rubber band and the graph didn't go through zero. We then realised we had to subtract the natural length from the length of the band to get the extension.

Extension = length-equilibrium length(*)
Applied Force = mg = mass(kg) * 9.8

The first three/four points on the graph show a linear relationship and therefore we can say the rubber band is obeying Hooke's Law F = -kx up to 150g. We decided not to include any further data points above a weight of 1.5N.

The negative sign indicates the restorative force of the rubber band is in the opposite direction of the weight force of the masses. So in this case up,

$$k = \text{rise/run} = 1N/0.0013m = 7.7 \times 10^5 \text{ N/m}$$

We can then determine the spring constant, from the gradient which is $(7.7) \times 10^5$ N/m. To estimate the uncertainty we looked at the % uncertainty of the force (largest) which was = 2/50*100 = 4%, 4% of k = 0.3×10^5 N/m, so final k = $(7.7\pm0.3) \times 10^5$ N/m

This is a pretty large value which indicates that the rubber band can take lots of force per extension of it's length. Looking on the internet, similar rubber bands have a spring constant of around 8×10^5 N/m[1]. This is within the uncertainty of our results which means our value for k is valid and reasonable. It is lower than expected.

After the first 3-4 points the graph was not linear at all. This also coincided when the rubberband started to change colour. And at 300g, the rubber band completely broke! The change in colour may have indicated that the rubber band was changing in its structure and therefore no longer obeying Hooke's law.

The experiment could be improved by using smaller mass increments to get a better set of results earlier on. This would give us more data in the linear region. Measuring the length of the band was also difficult and could be improved by using a better hanging system as the data indicates we may have been underestimating the extension length from the low value of k.

Conclusion: In summary, we found that the rubber band obeyed Hooke's Law initially with a spring constant of $(7.7 \pm 0.3) \times 10^5$ N/m which is within the uncertainty limits of published data[1]. Despite this the rubber band diverged from it's linear relationship and eventually broke. It is theorised that a change in structure occurred at this time, eventually breaking the band altogether.

Reference: [1] www.rubberbandsRus.com

Experiment Assessment Rubric

	Meticulous	Excellent	Good	Requires Improvement	Poorly executed	Not shown
Participation and safety	Preparation meticulous; all details thoroughly covered; totally focused &engaged throughout *AND* All safety procedures followed, including set-up & clean up	Adequate preparation; focused & engaged throughout *AND* All safety procedures followed, including set-up & clean up.	Mostly focused & engaged *AND* no safety threats, but at least one safety procedure needs review.	Lab completed but engagement/focus minimal *AND* no safety threats, but at least one safety procedure needs review..	Lab incomplete; minimal engagement/focus *AND/OR* generally unsafe behaviour.	Not shown
Experimental skill	Meticulous & thorough experimental skill displayed at all times; effective & efficient use of time; teamwork evident throughout.	Experimental competence displayed throughout; effective use of time; teamwork evident.	Adequate experimental skill displayed; adequate use of time; some teamwork evident.	Limited experimental skill displayed; use of time inefficient; little teamwork evident.	Experimental skill very patchy; poor use of time; minimal teamwork evident.	Not shown
Recording[1]& analysis	Meticulous, clear & thorough recording of relevant data; including all uncertainties and full details of experimental arrangements; full & accurate analysis; links to all relevant concepts; graph/data conventions followed.	Clear recording of relevant data; including most uncertainties and most details of experimental arrangements; full analysis; links to many relevant concepts; graph/data conventions followed.	Adequate recording of most relevant data; including some uncertainties and adequate details of experimental arrangements; adequate analysis linked to some relevant concepts; graph/data conventions followed	Recording of some relevant data; some uncertainties and limited details of experimental arrangements; limited analysis linked to some relevant concepts; graph/data conventions partially followed	Recording of some data; incomplete details of experimental arrangements; little analysis; links to few concepts.	Not shown
Summary & evaluation	Clear & succinct summary of conclusions; fully justified by data/analysis; convincing explanation of discrepancies; critique of experimental procedures.	Clear summary of conclusions; mostly justified by data/analysis; explanation of discrepancies; critique of experimental procedures.	Summary of conclusions; reference to data/analysis; some explanation of discrepancies;	Partial summary of conclusions; minimal reference to data/analysis; attempted explanation of discrepancies; minimal critiques of experimental procedures	Limited summary of conclusions; no explanation of discrepancies.	Not shown

[1] Students are not expected to copy material directly from lab book or demonstrators board work, *unless* annotations or elaborations are necessary.

Experiment Feedback and Mark Sheet

Student Name: Peta Smith   Prac Title Pendulum

	Excellent Experimental Technique	----------	Poor Experimental Technique	Mark
Participation and Safety	☑ Well prepared and understood what to do ☐ Totally engaged throughout ☑ All safety procedures followed and checked with demonstrator ☐ Bench was tidy throughout and left how it was found	☐ Some preparation evident but needed assistance ☐ Mainly engaged with some periods of distraction ☐ No safety threats but at least one safety procedure needs review ☑ Bench was mostly tidy	☐ No preparation evident and needed lots of assistance ☑ Little or no engagement throughout ☐ Unsafe behaviour experienced ☐ Bench was left in a mess	3/5
Experimental Skill	☑ All equipment used properly with little to no assistance and learnt new skills quickly ☑ Used time efficiently and completed the experiment as directed by demonstrator ☐ Worked well as a team ☑ Demonstrated deep thought into the Physics concepts when talking with the demonstrator ☑ Produced accurate measurements	☐ All equipment used properly with assistance ☐ Generally efficient with time and completed over 80% of experiment as directed ☑ Helped with most aspects of the experiment ☐ Thoughts about Physics concepts demonstrated when talking with the demonstrator ☐ Measurements could have been made more carefully	☐ Required constant assistance or equipment misused ☐ Did not use time efficiently and did not complete the experiment as directed ☐ Did not help with the experiment ☐ Was not able to demonstrate thoughts about the Physics when talking with the demonstrator ☐ Measurements taken were inaccurate or sloppy	4/5
Recording and Analysis	☑ Clear diagrams and careful record of any changes in experimental technique ☐ All data and results recorded with units and uncertainties ☐ All data presented in an appropriately labelled table or graph ☑ Data analysed using correct physics ☐ Clear record of thoughts on accuracy of data and resulting physics concepts	☐ Diagrams provided with some omissions and some changes in experimental technique recorded ☑ Most data and results recorded with units and uncertainties ☑ Data presented in an appropriate table or graph but missing units or labels ☐ Data analysed using correct physics with some minor errors ☐ Some record of thoughts on accuracy of data and resulting physics concepts	☐ Diagrams not included and no consideration of experimental technique ☐ Some data recorded or no units or uncertainties included ☐ Data not presented in an appropriate form or illegible ☐ Data not analysed correctly ☑ Little to no record of thoughts on accuracy of data and resulting physics concepts	3/5
Summary and Evaluation	☑ Justification of data and analysis relevant to the appropriate physics concepts throughout ☑ Valid explanation of any discrepancies with theory or expected results ☑ Thorough critique of experimental procedures ☑ Finished with sucinct statement of findings	☐ Some justification of data and analysis relevant to the appropriate physics concepts ☐ Attempted explanation of discrepancies with theory or expected results ☐ Mention of possible improvements to experimental procedures ☐ Some attempt to state findings	☐ Little to no justification of data and analysis or irrelevant to the appropriate physics concepts ☐ No explanation of discrepancies with theory or expected results ☐ No mention of possible improvements to experimental procedures ☐ Limited statement of results	5/5

Things done well: Great conclusion and evaluation, insightful & demonstrated you thought about the Physics	Improvements to be made: Lack of team work hindered your performance. Remember it is not just about your logbook!

Total : 15/20

Marking Scheme: **5** – Meticulous, **4** – Excellent, **3** – Good, **2** – Requires Improvement, **1** – Poorly executed, **0** – Not shown

Safety Notes

The University of Melbourne has adopted the internationally recognized systems Safety MAP (ISO 12001) and Environmental Management System (ISO14001) to ensure a safe and environmentally-friendly workplace for all staff, students, and visitors. As a student of the University you are responsible for adopting safe work and study practices, and you are required to comply with all relevant University and Departmental rules and procedures.

Detailed information on University policy and procedures is provided in the Environment, Health and Safety Manual at

http://www.unimelb.edu.au/ehsm

The Laboratory Rules and Safe Work Procedures set out below must be adhered to always, and the direction of all staff and demonstrators must be followed. If you have any concerns about the safety or environmental impact of any aspect in these practical classes, please raise them with the staff member in charge. Report all injuries and incidents to the staff member immediately.

Medical status – voluntary notification

If you have any allergies or medical conditions that you think may be affected by chemicals, material or procedures to be used in these practical classes, fill in a "Medical Status - Voluntary Notification for Laboratory Classes Form" and give it to your demonstrator so that any risk can be assessed, and the work procedures modified.

This form is available from your demonstrator, or online at

http://webraft.its.unimelb.edu.au/640141/pub/firstyearlab/resources/medform.pdf

1. Safety Measures

Whilst in any of the laboratories the following rules should be remembered.

- Maintain a neat and clean bench and work area. Keep aisles and doors clear. Switch off and tidy up the equipment after use.
- Never run or throw objects in the laboratory. Do not adopt a casual attitude - be aware of the potential hazards and act accordingly.
- Never work alone in a laboratory - a colleague should always be within call.
- Adequate footwear and suitable clothing should be worn at all times in the laboratory.
- Eating, drinking and smoking is forbidden. After leaving the laboratory (especially Radiation), wash your hands thoroughly.
- All accidents, injuries, mishaps and "near misses" must be reported to your demonstrator immediately. This also includes breakages, faulty equipment, etc. If you are the cause of some mishap or accident, do not cover it up, tell your demonstrator immediately: in doing so you may save others from injury.

2. Emergency Procedures

If the emergency alarm bell sounds continually, the building MUST be evacuated. Switch off all equipment, clear walkways and leave by the suggested emergency exit route. This is:

the door at Eastern end of lab, and down stairs to the ramp area.

If this exit is not accessible, leave by the Western stairway.

If a fire occurs in the laboratory, alert people near you and others on your level. Turn off all equipment if safe to do so and leave the area immediately. Do not get in the way - your demonstrator will take control.

Note: (a) Remember that it is very easy to be overcome by smoke and fumes; these may be extremely toxic, especially if electrical equipment is involved.

(b) Furthermore, the application of an inappropriate type of fire extinguisher can be very dangerous. The two most common types of extinguishers are: water (or soda acid) which is most effective on ordinary combustibles, such as paper, wood, etc., and should not be used on electrical, oil or grease fires; and carbon dioxide which can be used on combustible, electrical and flammable liquid fires.

3. Accidents

If you are first on the scene of an accident and the casualty is in danger of further injury, observe the area for hazards and, ***if it is safe***, pull the casualty clear. However, do not move the casualty unnecessarily. If the cause of the accident is electrical and the casualty is still receiving the charge, first ensure that you will not be in danger of electric shock by attempting to help the casualty. Switch off the current at the wall and pull out the plug. If this is not safe, free the person by using something non-conductive (eg. dry wood, rubber, etc.). *Do not touch the casualty or you will receive a shock yourself*. Once the casualty is out of immediate danger, summon aid immediately by reporting the accident to (1) your demonstrator and (2) any lab staff (in eastern end of the labs) or the front office in the Physics building on level 1. There are number of people available who are qualified in First Aid - attempt to find one of them by asking your demonstrator.

4. Hazards

Trips and Slips

School of Physics has a duty of care to provide and maintain a safe laboratory space for students, demonstrators and staffs. Everyone is encouraged to identify all potential hazards, the associated risk and then eliminate or reduce those risks.

Common causes of trips

- **poor housekeeping - e.g. cluttered work spaces**
- **low, unseen objects - e.g. electrical cords, boxes, bags,**
- **passage or walkways being used for storage**

Common causes of slips

- **inappropriate floor surface - e.g. smooth, shiny tiles in a wet area**
- **slippery floor surfaces - e.g. oily, icy, wet or dusty**
- **poor housekeeping - e.g. spills not cleaned up immediately**
- **inappropriate footwear**

Electrical Hazards

Electrical energy is invisible, odourless and silent. Therefore, extreme care must be taken when working around electrical equipment and devices connected to mains electrical supply.

Effects of electric current

There are five effects of electric current flow: Thermal, light, magnetism, chemical and physiological. When electric current flow finds a path through living tissue the physiological effects can cause what is commonly known as electric shock. An electric shock can cause muscle contraction, ventricular fibrillation (heart), cardiac arrest, asphyxia(lungs) and burns.

For an electric shock to occur a person must be in contact with at least two points of electrical contact, one of which must be at raised voltage. This is called a touch voltage. Most electric shocks occur between hand and foot, or hand to hand. The amount of current that will flow through a body will depend on the difference in touch voltage between the two points and the resistance of the current path through the body. This is called the touch current.

The severity of an electric shock depends on several variables:

- The path the current flows through the body.
- The amount of current that flows through the body.
- The length of the time the current flows.
- Amount of moisture in the environment.
- Phase of the heart cycle when the shock occurs.
- Health of the person prior to the shock.

The mains electrical supply is 240 volts, alternating current. Such a supply is hazardous and can be lethal. Therefore, care must be taken at all time.

- Do ***not*** attempt to fix any electrical equipment yourself. This includes changing fuses.
- If an accident occurs, act quickly. Ensure that you will not be in danger of electric shock by attempting to help the casualty. Switch off the electrical supply at the wall and pull out the plug. If this is not safe, free the person by using something non-conductive (eg. dry wood, rubber, etc.). *Do not touch the casualty or you will receive a shock yourself*.
- Alert your demonstrator.

Remember the following:

- Be aware of live parts and take appropriate precautions.
- When working with live equipment, work one-handed, keeping the other hand at your side.
- Make sure all connections are clean, dry and secure.
- Always connect the supply voltage to your circuit last and then, at first, only connect on for an instant using circuit switches.

LASER Hazards

The Australian/New Zealand Standard *AS/NZS 2211.1:2004 Safety of laser products - Equipment classification, requirements and user's guide* define lasers as any device which can be made to produce or amplify electromagnetic radiation in the wavelength range from 180nm to 1mm primarily by the process of controlled simulated emission.

Lasers are classified and rated according to the hazard associated with their emissions:

- Class 1 and 1M lasers
- Class 2 and 2M lasers
- Class 3R lasers
- Class 3B lasers
- Class 4 lasers

Class 1 and 1M lasers:

CLASS 1 LASER PRODUCT

These types of lasers are safe under reasonably foreseeable conditions of operation. Class 1M can be hazardous if the beam is Magnified with optical instruments (hence the letter 'M' is added).

Class 2 and 2M lasers:

LASER RADIATION DO NOT STARE INTO BEAM CLASS 2 & M LASER PRODUCT

Class 2: Lasers that emit visible radiation in the wavelength range from 400nm to 700nm where eye protection is normally afforded by aversion responses, including the blink reflex.

Class 2M: Lasers that emit visible radiation in the wavelength range from 400nm to 700nm where eye protection is normally afforded by aversion responses including the blink reflex. However, viewing of the output may be more hazardous if the user employs optics within the beam.

NOTE: Higher power lasers exist, but are not used in the First Year Laboratories.

Reference: *Australian/New Zealand Standard: Safety of laser products. Part 1: Equipment classification, requirements and user's guide (IEC60825-1:2001, MOD)*

Chemical Hazards

Chemical hazards can be solids, gasses, liquids, fumes, dusts, fibers or vapors. Hazardous chemicals are not used in the First Year Physics Laboratories, but if you suspect a chemical spill or contamination, please seek your demonstrator immediately.

Radiation Hazards

Radiation can be divided into ionising and non-ionising radiation. Non-ionising radiation is also known as electromagnetic radiation. Ionising radiation includes X-rays, gamma rays, Alpha, beta and neutron particles. Non-ionising radiation includes radio-waves, microwaves and UV rays.

All types of ionising radiation produce changes in living cells, by actively dividing cells (e.g. blood-forming and reproductive cells) are particularly susceptible to damage. All doses of radiation, therefore, <u>must be kept as low as possible</u>.

Each of the radioactive sources is sealed or shielded to prevent the active material from dispersing into the surroundings, where it could be inhaled, ingested or absorbed. Take care not to break these enclosures. If any sources appear to be damaged, tell your demonstrator immediately.

When the sources are not in use, return them to the trolley. Radioactive sources <u>must never leave the laboratory</u>.

The dose received is directly proportional to the exposure time and inversely proportional to the distance squared. The main safety procedures are:

- Minimise your exposure time.
- Maximise the distance between yourself and the source.
- Where appropriate use shielding with lead blocks to reduce the intensity of radiation.

After leaving the laboratory, wash your hands thoroughly.

Experiment 1
Pendulum

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this manual, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

Welcome to your first experiment in Physics 1. Before coming to the lab, ensure you have read the Safety Notes, the appendices and this experiment and attempted all of the pre-lab exercises, both in these notes AND online. You will also find other resources for each lab on the LMS. Throughout the experiment we have provided suggestions and questions for you to consider to help you learn to write up your experimental log, indicated by ✓. As you progress through the semester, it will be expected that you will need these prompts less and less and will become an independent and capable experimentalist. Your demonstrator is always available to assist you with the experimental method and physics discussion.

Outline of Experiment

Every physics student learns about falling bodies and g, the acceleration due to Earth's gravitational field. The Earth's gravitational acceleration, represented by lowercase g, is known to everyone through familiar and dependable effects that touch nearly all aspects of life. But have you ever tried to accurately measure 'g'?

In the lab when trying to make instruments that measure g work, gravity can sometimes seem rather arbitrary. In this lab, you will use two techniques to attempt to determine g, often referred to as the acceleration due to gravity, or 9.8 ms^{-2}. As you will see, the principles behind the experiments are quite simple, but require careful attention to detail. Part of the analysis will require additional thought to overcome perceived errors and assumptions, and hopefully through this you will gain some understanding of how important it is to make experimental tests of things that you have been asked to remember and apply.

One of the "easier" ways to determine 'g' is to study the motion of a pendulum. A simple pendulum is an idealised body consisting of a point mass, suspended by a light, inextensible cord. When pulled to one side of its equilibrium position and released, the pendulum swings in a vertical plane under the influence of gravity. The motion is both periodic and oscillatory.

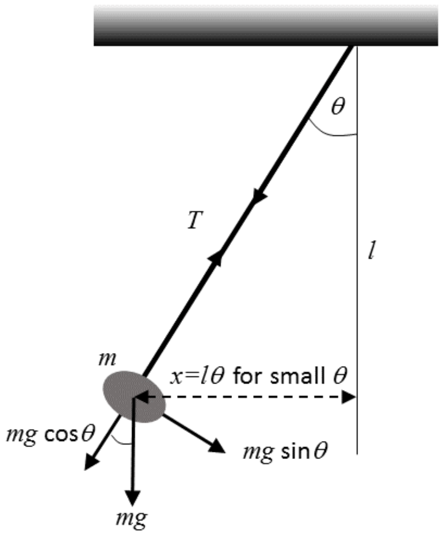
✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To become adept at using a digital oscilloscope
- To identify assumptions in theoretical models and the effects of these assumptions
- To determine the best mathematical model for fitting data
- To obtain an experimental value for the acceleration of gravity through analysing the motion of a pendulum

Introduction

In the figure to the right, the pendulum of length *l*, with an attached mass *m*, makes an angle θ, with the vertical.



The forces acting on m are *mg*, the gravitational force, and *T*, the tension in the cord. The tangential component of *mg* is the restoring force acting on *m*, tending to return it to the equilibrium position. Hence, the restoring force is given by:

$$F = -mg\sin\theta$$

Notice that the restoring force is NOT proportional to the angular displacement θ, but to $\sin\theta$ instead. The resulting motion is therefore not exactly Simple Harmonic Motion. However if the angle θ is small, we can use the small angle approximation $\sin\theta \approx \theta$ (expressed in radians).

Hence the displacement along the arc is $x=l\theta$ and for small angles, this is nearly straight-line motion.

$$F = -mg\sin\theta \approx -mg\theta = -mg\frac{x}{l}$$

For small displacements the restoring force is proportional to the displacement and is oppositely directed. The system is now behaving under Simple Harmonic Motion.

Using Newton's II Law; $\quad F = ma(t) = -m\frac{g}{l}x$

Which has a solution: $\quad x(t) = A\sin\left(t\sqrt{\frac{g}{l}}\right)$

Hence the period of a simple pendulum under the small angle approximation is: $\boxed{T = 2\pi\sqrt{\frac{l}{g}}}$

✓ **Pre-lab question 1**

What are the mathematical conditions for Simple Harmonic Motion (SHM)? Describe the motion of an object undergoing SHM.

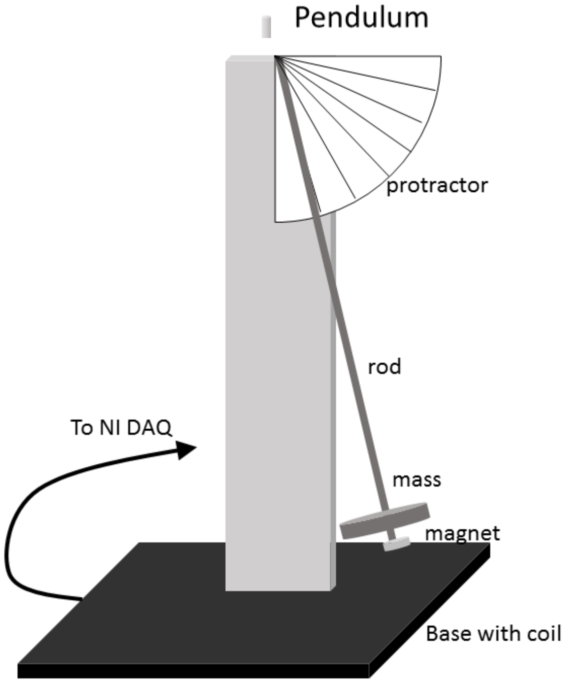
✓ **Pre-lab question 2**

Test the small angle approximation mathematically (remember to use radians). At what angle to you consider it to break down and why?

Section A: The approximation of sin θ=θ

Experimental Set-up

Set up the timing sensing equipment as shown in the diagram below. Your demonstrator will assist you in this key step. Note that as the magnet passes the sensing loop, a small voltage is induced in the coil, and a can be observed with the help of a digital oscilloscope.



Digital Oscilloscope

Set the pendulum swinging and adjust the voltage/trigger settings on the oscilloscope to record the induced voltage. By choosing a suitable length l and varying the angle θ, observe any resultant period variations.

HINT: You can use the “CURSOR” option to make accurate time measurements.

✓ What settings on your equipment will you use? How many measurements will you take? Note your experimental settings and why you chose them including all measurements to be taken and the settings on the oscilloscope. Include diagrams and a screen capture.

Data

✓ Record the period of the pendulum for each angle.

Analysis

✓ Graph the variation of the period T with the angle θ .

✓ Comment on the features of the graph and when the small angle approximation is no longer true. How did this compare with your first pre-lab question?

✓ How will this influence the rest of your experiment?

Section B: Determining a value for g

Experiment

In this experiment, you will study the variation of period with length of the pendulum to determine the value for g.

✓ Adjust the position of the mass to change the length of the pendulum. For a suitable range of lengths, determine how to calculate a value of g and write down how you went about your experiment. Comment on your sources of uncertainty.

Data

✓ Record the period of the pendulum for each length.

Analysis

✓ As you can see from the Introduction, $T \propto \sqrt{L}$.

In light of this, will you plot $T\ vs\ L$, $T\ vs\ \sqrt{L}$ or T^2 vs L? Which is likely to be the best mathematical model for this data and the easiest to determine a fit?

(hint: consider which variable is likely to have a systematic error in it, and consider the effect of a systematic error on your result…)

✓ Tabulate and plot your data. Use your plot to determine a value of 'g'. How does your value of g, with confidence limits or measurement uncertainties, compare to the known value of g = 9.80 ms^{-2} for Melbourne?

Section C(extension): Is the period really mass independent?

Experiment

In this part of the experiment, we would like to prove the statement that "the period of a pendulum is independent of the mass". A possible approach is to compare the periods by experimenting with the additional masses provided. (Do you need to know their actual weights?). In order to prove that the period is independent of the mass you will need to record your data with uncertainties.

Data

✓ Record any relevant measurements, including uncertainties.

Analysis

✓ When you changed the mass, did all of the other variables remain unchanged?

✓ Can you explain any discrepancy in your values of the period of the masses, with a possible variation in these other variables?

Conclusion

✓ Summarise your findings and how well they compare with the theory for all three sections.

Experiment 2
Gravity

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this book, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

Outline of Experiment

Last week you investigated gravity through the motion of a pendulum and were hopefully able to determine accurately the value of 'g' through the motion of the mass. This week you will be employing the equations of motion learnt in your high school education and using some data analysis techniques to find the value for g. It is important as scientists that we have multiple ways to determine our fundamental constants and environmental properties of note. Just as in any experiment we make more than one trial to arrive at a consistent result, we need to test the values of these properties in different ways to prove their validity.

At the address http://www.physicsclassroom.com/class/circles/Lesson-3/The-Value-of-g you will be able to find an applet to tell you the value of g in Melbourne.

The data results to this experiment should all be recorded and plotted in Excel. Please review Appendix B or ask your demonstrator how to use Excel if you're unsure.

✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To understand mathematical models for a linear relationship in order to determine the most accurate results.
- To relate data and the mathematical model to the physical aspects of the experiment.
- To estimate the overall uncertainty of the results and compare to the accepted value.
- To identify possible sources of uncertainty in the experimental method and offer reasonable ways to improve or minimise these.
- To obtain an experimental value for the acceleration of gravity through analysing the time of flight of a magnet falling under gravity.

✓ Pre-lab question 1

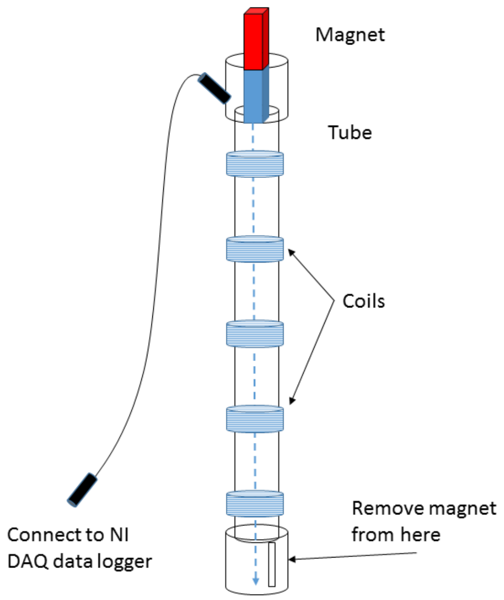
Derive $s = u\,t + \frac{1}{2}\,g\,t^2$ using integration for a body falling with constant acceleration a = g, with an initial velocity, u. (Knowing the equations of motion gives us a way of measuring the acceleration constant, g.)

Introduction

In this experiment, you will use "time-of-flight" techniques to measure the acceleration due to gravity, g. Time-of-flight techniques are very useful and are indispensable in the field of particle detection, where the energy of a particle can be determined by timing the particle's flight over a known flight path. Fast and accurate timing is required to measure the particle's energy.

Experimental Set-up

The "Gravitation System" apparatus consists of a Perspex pipe with several coils connected in series. A magnet is released at the top, and allowed to free-fall. As it does, it passes through each coil, inducing a voltage which is observed on the oscilloscope.



In the course of this experiment you will measure (distance, s; time, t) data as the magnet falls through the coils.

✓ Can you see how you might use the equation from Pre-lab question 1 to obtain g? As it has two unknowns (u and g) it may seem to be impossible. (note that u cannot be made to be zero as the timer starts when the magnet passes the first sensor, implying $u \neq 0$)

However, if you rearrange the equation by dividing through by t, you get: ${}^{s}/_{t} = \frac{1}{2}gt + u$

It should then be noted that the two 'unknowns' in this expression influence the structure of a graph of (s/t) vs t in very different, but well understood ways.

✓ If you were to graph s/t vs t for your data, how would you find a value for g? What else could you obtain from your graph?

Data

✓ Using the system, record 5 drops taking down the important parameters for your analysis. Think about what these may be and record this in your logbook.

✓ Is your data consistent with a linear interpolation or is there a distinct curve in it?

✓ If your line is not linear, use the information above to reconsider your data and re-plot your results (include your old data and plot in your lab book, these thoughts about the analysis of the experiment are an integral part of the experimental process).

✓ Does the graph of s/t versus t pass through the origin? If not, why not? Determine g with uncertainties (these uncertainties come from the limits of your measuring apparatus) and compare it with the 'known' value of g = $9.800 ms^{-2}$ for Melbourne. Use Appendix A to help you here.

Analysis

✓ Recalling your work from last week. You have now calculated g using 2 different methods. Which method gave you a better value of g? Why would this method be better?

✓ Where would the errors (systematic and random) come from in this experiment? Justify your answer. Could they be removed? If so, how?

Next Week

Your next experiment will look at the concept of Friction. The first part of the experiment will be directed, but you will have the opportunity to design a small experiment to explore another aspect of friction using the same equipment. So you are prepared, you may like to discuss some ideas with your partners and demonstrator when you have finished this lab.

Write some notes in your logbook for your demonstrator to review.

Experiment 3
Friction

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this manual, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

ADDITIONAL HAZARDS

In today's experiment, you will be moving a cart along the top ledge of your laboratory bench. It is important to move the cart **carefully** to prevent if falling over the edge.

Be aware that a loose rolling object is a potential hazard: it can damage equipment, or it can be stepped on or cause a person to trip.

Outline of Experiment

Friction is a force that we are constantly experiencing whether we are in motion or stationary. Today you will be investigating the properties of frictional forces between materials.

Before you begin you practical please read through the following information on friction and the different types of friction you may explore in the experiment: http://hyperphysics.phy-astr.gsu.edu/hbase/frict2.html

You will be using the datalogging system to determine the motion of a cart under a couple of different experiments, one of which you and your partner will design yourselves. You may find some ideas at the end of this lab or think of something on your own.

Appendix C will help you with the PASCO Capstone software so please familiarise yourself with the toolbars and functions available. You may wish to watch this video to find out how to use the software: https://youtu.be/5uuEQfQ8hnU

✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To use and interpret data logged from the PASCO carts.
- To critically argue the validity of all data and its meaning.
- To compare and relate the data from multiple graphs.
- To design and perform a secondary experiment which explores friction in a new context.
- To observe and quantify the amount of friction experienced when the cart is in motion.

✓ **Pre-lab question 1**

What is the difference between Static Friction and Kinetic Friction? Use a graph and/or equations if needed.

✓ **Pre-lab question 2**

How does Rolling Friction relate to static and/or kinetic friction?

✓ **Pre-lab question 3**

What is the general relationship between Friction and the mass of the object?

Section A: Friction with changing mass

In this experiment you will be using a pulley system to drop a mass connected to a PASCO Smart Cart which will move across a felt surface. You will be recording the position, velocity and acceleration of the cart with time as the cart moves along the felt surface with different amounts of mass. From the acceleration and a force diagram you will be able to determine the rolling friction coefficient of the cart.

This laboratory uses carts that carry a number of sensors to measure the position and force between the cart and an object in front of it. The information is then sent to the computer via Bluetooth. The carts do go into sleep mode when not being used. If your cart turns off, just press the On button again. The direction of the carts is shown on the top of the cart.

Note: Please be careful with the carts and ensure they do not fall off the benches.

Capturing motion using PASCO Capstone

- ✓ Start the PASCO Capstone software package.
- ✓ Select the first experiment type displaying a graph and table.
- ✓ From the **Hardware Setup** tab, select your cart number (check *your* cart number) and select which sensors you will need. See Appendix C for details on the menus and how to start a run.

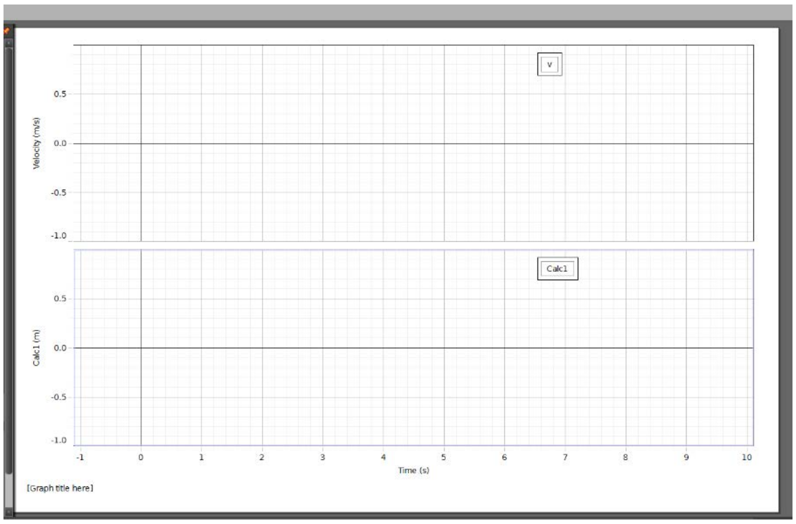


Figure 2: An empty graph

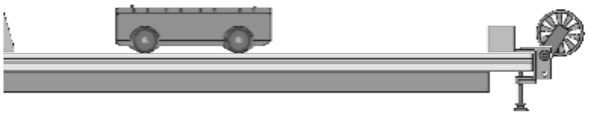
- ✓ In the graph page, click on the axes labels to choose which data you will plot. Add more graphs by selecting the Add new Graph button on the toolbar at the top of the graph (See Appendix C for information on Capstone Toolbars).
- ✓ Click the 'Record' button at the bottom of the screen to begin capturing data. You will be able to see the data appear on your graph.
- ✓ Move your cart backwards and forwards for a few seconds then click 'Stop'
- ✓ A position-time graph should now be displayed, showing the position of your cart as a function of time. Your cart will always start at a position of zero.

If no data is displayed, consult your demonstrator

- ✓ Repeat a few times until you are confident capturing data and have a feel for the movement of the cart.

Experimental Set-up

You will have the following set up in front of you;



- ✓ Before your first trial, predict the shape of the position/time, velocity/time and acceleration/time graphs. Discuss any assumptions you have made.

- ✓ Start with no extra mass on the cart.

- ✓ Start the cart in the middle of the track and once recording, gently push the cart backwards and then allow the cart to move towards the pulley before stopping the cart and stopping the recording.

- ✓ Comment on how well your predictions matched the data collected. What were the differences.

- ✓ Repeat this by adding one additional 250 g mass at a time. You may need to borrow some from another group.

Data

✓ Discuss the graphs you have recorded and how they relate to each other. What do you notice about the acceleration graph? Is this what you expected?

✓ Draw up a force diagram and determine the friction.

Section B: Experimental Design

Experiment

Design a *simple* experiment with the equipment provided that will explore another way friction plays a role with an object moving along a surface. There are some ideas below, or you may like to come up with your own.

- ✓ Repeat the above but with a varying incline.
- ✓ Turn the cart over to look at static or kinetic friction and determine their coefficient.
- ✓ Explore different surfaces.
- ✓ Change the mass over the pulley.

Make sure you record the method you employed for your experiment in your logbook, you may even plan this out the week before. Think about how you will define your variables, what assumptions you make and how you will ensure to minimise or eliminate uncertainties in your experiment. Please discuss your experiment with your demonstrator prior to collecting data.

Experiment 4
Moment of Inertia

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this manual, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

ADDITIONAL HAZARDS

Rotating and falling objects constitute a potential hazard. Keep your hands away from the spokes of the rotating wheel.

Make sure that the retort stand is securely clamped to the bench.

Outline of Experiment

In this Experiment, you will investigate certain features of rotational motion. In particular, you will measure the moment of inertia (I) for a rotating bicycle wheel through a conservation of energy treatment.

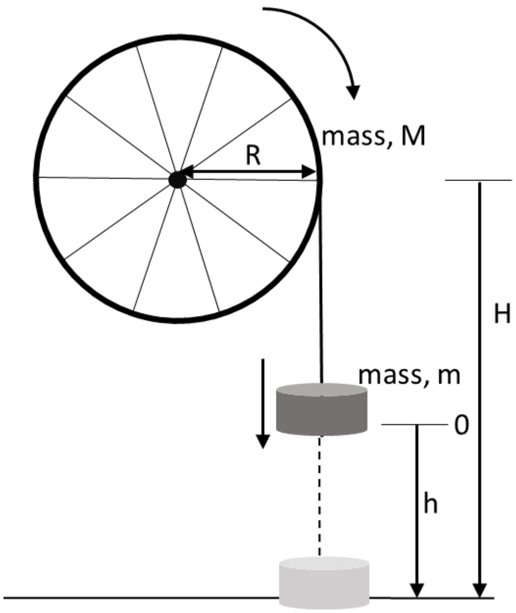
✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To be efficient in the use of Excel through generating functions and graphs.
- To work together as a team to record data efficiently and accurately.
- To determine the unknown quantity through graphical analysis and making a thoughtful conclusion regarding the results.
- To obtain an experimental value for the moment of inertia for a bike wheel.

Introduction

In this experiment you will make a series of measurements, graph the results and fit a line to these data points in order to calculate the moment of inertia. To do this we will be investigating the energy of the system and the known conservation of this energy.



The system consists of a mass, m, attached to the rim of a wheel by a string as shown in the diagram. As the mass is released, the wheel starts to rotate.

The total mechanical energy of this system at any given time must be the sum of the rotational kinetic energy ($\frac{1}{2}I\omega^2$) of the wheel, the translational kinetic energy ($\frac{1}{2}mv^2$) of the load, the gravitational potential energy (MgH) of the wheel, and the gravitational potential energy (mgh) of the load. Ignoring friction, the total mechanical energy is constant over the entire motion (i.e. it is conserved).

✓ Pre-lab question 1

Given that both the wheel and the load are initially at rest, write down an expression for the total mechanical energy E_{Total} of the system just before the load is released. This should be in terms of the initial height h of the load, the initial height H of the wheel's centre of mass, the mass m of the load, and the mass M of the wheel.

✓ Pre-lab question 2

Write down an expression for the total mechanical energy E_{Total} of the system just as the load reaches the ground. This should be in terms of the velocity v of the load, the angular velocity ω of the wheel, and the moment of inertia I of the wheel.

✓ Pre-lab question 3

Because the total mechanical energy is conserved, the value of E_{Total} is the same in both of your equations. Therefore, show that the following relation holds:

$$mgh = \frac{1}{2}(I + mR^2)\omega^2 \qquad \text{Eqn (1)}$$

Recall that the velocity of the load is equal to the velocity of a point on the rim of the wheel at all times: $v = \omega R$, where R is the radius and ω is the angular velocity.

Equation (1) is a useful one. It is in the form of a linear equation (y = mx), where mgh is y and ω^2 is x (as I, m, R are all constant). This means that if we can graph mgh versus ω^2, the graph should be a straight line, and the gradient 'm' of this line should be equal to ½ $(I + mR^2)$.

Experimental Set-up

Remember, our aim here is to measure the moment of inertia, I. Take measurements of m and R. Equation (1) above suggests that to calculate I, we must measure the final angular velocity, ω, of the wheel for various values of the drop height, h.

Over a range of heights from 0.6 m to 1.3 m (in 0.1 m steps), measure the time taken for the load to reach the ground. Remember to include uncertainties for all your measurements.

Data

✓ Record your measurements and calculations in Excel. Use the function application to complete any calculations as described in Appendix B, using a table similar to this:

h *(m)*	t *(sec)*	v *(ms^{-1})*	ω *(rad sec^{-1})*	ω^2 *(rad^2 sec^{-2})*	**mgh** *(J)*

✓ Plot a graph of mgh versus ω^2, with mgh on the vertical axis.

✓ Draw a line of best fit to your data points using Excel's **Add Trendline** function. See Appendix B if you need help with this.

✓ Using Equation (1) and the gradient of the trendline, calculate the moment of inertia.

Analysis

Be sure to consider the following points in your logbook:

✓ Is your line of best fit a straight line - why, or why not?

✓ Should the trendline's intercept the mgh axis at 0? What does this value tell you?

Note: Make sure to LABEL & print off your results graph and stick it into your logbook.

✓ Estimate the uncertainties in mgh and ω^2 using the half-range of their maximum and minimum values. Draw lines of maximum and minimum gradient on your graph, and use them to estimate the uncertainty in your value for the moment of inertia.

According to theory, the moment of inertia of a wheel which has its entire mass M located at its rim is $I = MR^2$ (where R is the wheel's radius). However, the moment of inertia of a solid wheel, which has its mass distributed evenly from the centre to the rim, is $I = \frac{1}{2} MR^2$. The mass of the wheel, M, will be given to you by your demonstrator.

✓ Compare your calculated value for the moment of inertia with the two values given by the expressions above. Based on your results, how would you characterise the mass distribution of your wheel?

✓ Are there discrepancies between what the theory predicts, and what you have actually measured and calculated? If so, try to explain them.

Conclusion

✓ Summarise and comment on your final results.

Experiment 5
Angular Momentum

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this book, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

ADDITIONAL HAZARDS

Rotating and falling objects constitute a potential hazard. Keep your hands away from the spokes of the rotating wheel.

Make sure that the retort stand is securely clamped to the bench.

Outline of Experiment

Whether you round a corner in a car or go on a carnival ride that spins, you will feel a force pushing you out of the circle you are travelling in. In this experiment you will be investigating this apparent force known as 'centrifugal force'. To do this you will be measuring the minimum velocity of a mass freely connected to a wheel. You can use the gravitational acceleration as 9.8 ms^{-2}. In section A, you will use the addition of vector quantities to measure the orbital velocity of a mass from a string. In section B you will find the minimal velocity of a mass to achieve "lift off" when in a circular path.

✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To compare and contrast methods and models to portray the best and most accurate representation of the data collected.
- To critically analyse and identify sources of error and uncertainty
- To explore the relationship between various aspects of circular motion through Newton's 2nd Law of Motion.

Introduction

Before beginning this lab please open up: http://hyperphysics.phy-astr.gsu.edu/hbase/corf.html#cent and read the sections on centrifugal force and centripetal force.

✓ **Pre-lab question 1**

Briefly explain the difference between centrifugal and centripetal forces. (hint: draw a diagram if needed)

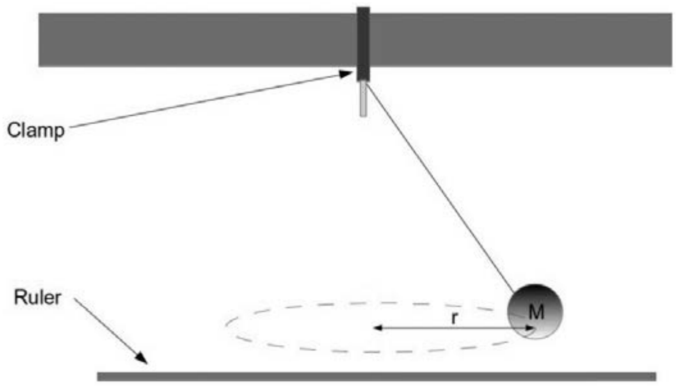
✓ **Pre-lab question 2**

Derive a formula to express the velocity of an orbiting object with gravity perpendicular to the orbital surface such as in Section A. (hint: draw a force-body diagram)

Section A: Measuring the Centrifugal Force Using Gravity

Experimental Set-up

In this experiment you will be measuring the velocity of an orbiting mass using two perpendicular "forces" in the form of gravity and centripetal. Don't take too long on this section.



✓ Set up a mass, M, on a string connected to a clamp hanging from the desk. Align the centre of a ruler along the ground with the mass hanging vertically.

✓ Swing the mass around the in a circular fashion so that the mass orbits at constant r.

✓ Measure the value of r and determine the angle of the string.

✓ Using the equation, you derived previously, calculate the velocity of the orbiting mass.

✓ Using a stop watch measure the period (and therefore velocity) of the orbiting mass and compare the value to that measured previously.

✓ Repeat this for various radii (4-5 should be enough)

Data

✓ Plot your results for radius versus velocity for both velocities in excel. (Velocity 1 calculated from the equation, Velocity 2 from the period.)

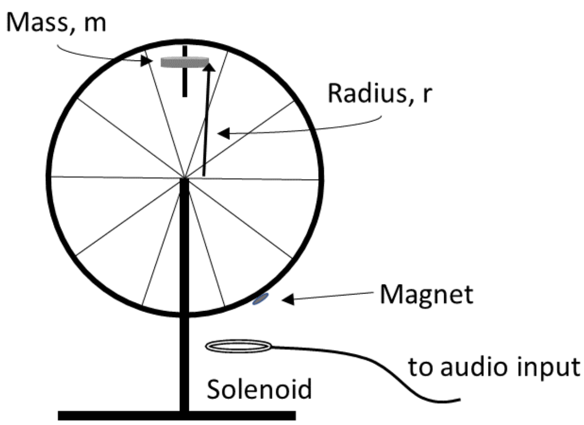
Analysis

✓ Comment on your results and consider any sources of error in your experiment.

Section B: Measuring the Centrifugal and Gravity equilibrium point

Experiment

The setup will be on your bench. Rotating the wheel will make the mass, m at radius, r sit with its centre of mass as far out as possible due to the centrifugal force.



✓ Open the program 'Scope' and make sure your coil is connected to the microphone input. A magnet on the wheel will induce a current in the coil.

✓ Rotate the wheel and measure the frequency using the oscilloscope. At a certain velocity the centrifugal force will equal the gravitational force, at this point the mass will start to drop as gravity is now the dominant force. You will be able to see (and hear) when your mass is reaching this point. The moment you start to hear the mass drop, stop the run and measure the period of the wheel.

✓ Determine the critical velocity at the equilibrium point between the gravitational force and centrifugal force.

✓ If you have time, adjust the position of the mass on your wheel to vary your radius. How would you expect you period to change with radius?

Analysis

✓ Derive a formula for the period such that the mass' centrifugal force equals its weight force.

✓ Use this formula to find yet another experimental value for the acceleration due to gravity, g. If you used multiple radii, you will be able to use a graphical method to determine g.

Conclusion

✓ Summarise your findings and how well they compare with the theory.

Experiment 6
Polarisation of Light

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this manual, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

ADDITIONAL HAZARDS

Over the course of this experiment, the lamps you use will become **very hot**. Take care not to burn yourself.

Outline of Experiment

From sunglasses, to calculator and computer screens, we use the physical property of polarisation daily. Polarisation is essential in much of our technology and lives and this extends to 3D movies and optical fibres and much more. In this experiment you will be investigating the wave-like property of polarisation in light, how polarisers (or polaroids) work and how some materials have optical activity and can rotate the polarisation of light.

✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To relate observations of physical phenomena with a theoretical model through graphical means.
- To consider how external conditions influence and experiment and incorporate this into the mathematical model.
- To develop an understanding of the nature of polarisation of lights with the use of polarisers.

Introduction

Before beginning your experiment go to the following link: hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polarcon.html and click on the words: Polarisation, linear polarisation, cross polarizers, reflection, polariser and optical activity to explore the ideas of this lab.

✓ **Pre-lab question 1**

Consider a linearly-polarised light wave with electric field magnitude E_0, incident on a polariser at angle θ to the transmission axis. Write down the magnitude E of the electric field that emerges from the polariser, in terms of E_0 and θ.

✓ **Pre-lab question 2**

Write down the intensity I of the electric field that emerges from the polariser, in terms of E_0 and θ.

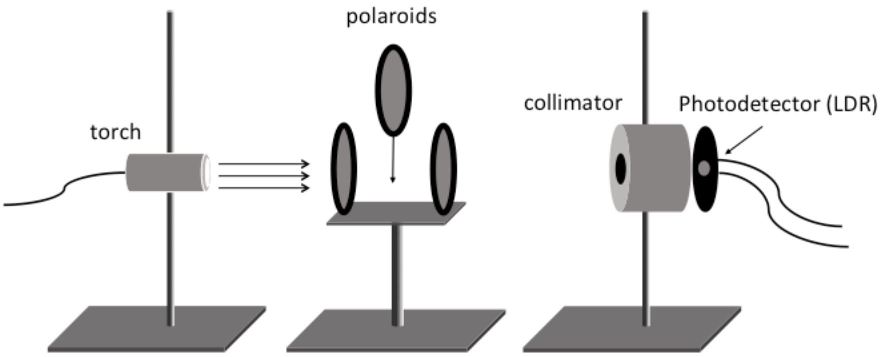
Section A: Investigating Polarisation

In this first experiment you will be investigating polarisation through consecutive lenses of variable polarisation axes. Using a voltage divider as an intensity meter you can measure the light intensity on a multimeter, with the units taken as arbitrary light units.

Experimental Set-up

Align a light source onto the photodetector connected to a multimeter.

Before turning on the light source measure the background voltage produced on the photodetector. Why is this important?



Turn on the light source (Your light source has 3 settings check to make sure you're on the highest intensity setting). Measure the maximum intensity (i.e. with no polarisers).

Place a polariser in front of the source and measure the intensity. What value would you expect this to be? Why?

Add a second polariser. Turn one of the polarisers and comment on the light passing through to the photodetector. Plot the angle versus intensity using Excel.

Align the two polarisers such that the measured voltage is minimised.

Add a third polariser between the other two. Rotate the middle polariser and comment on the results.

Data

✓ Plot the intensity vs angle of rotation for angles from 0 to 180 degrees for both two and three polarisers.

Analysis

✓ With two polarisers, could you completely block out the light? Why would you think that this may happen?

✓ With 3 polarisers, what did you notice when rotating the middle polariser? Why would this happen?

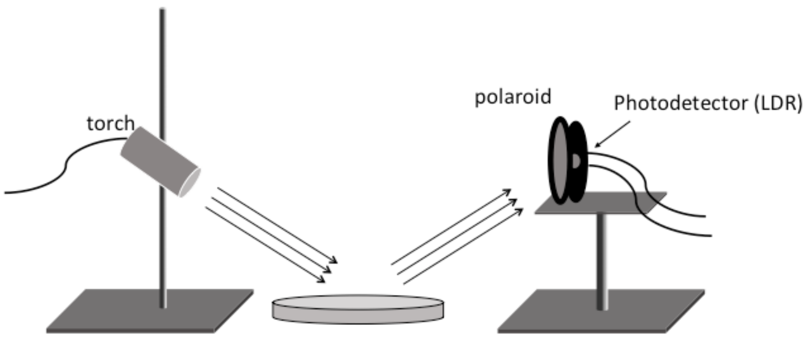
✓ Discuss your results.

Section B: Polarisation Through Reflection

If you have ever seen the surface of water through polarised sunglasses you will know that reflections can polarise light. In this section you will be investigating the reflection of polarised light and measuring the amount of polarisation from a reflected source.

Experiment

Fill a petrie dish with water and set up the following experiment. Angle the light source at approximately 35 degrees to the desk's surface.



Measure the background voltage produced.

Rotate the polariser until the voltage is at its minimum.

Calculate the level of polarisation of the water's reflection. Is it perfectly polarising? Why or why not?

Analysis

✓ Is water a perfect polariser or as good as one of the polarisers you have on your bench? Justify your response. You can do some measurements to justify this.

Can you think of any better ways to measure background light?

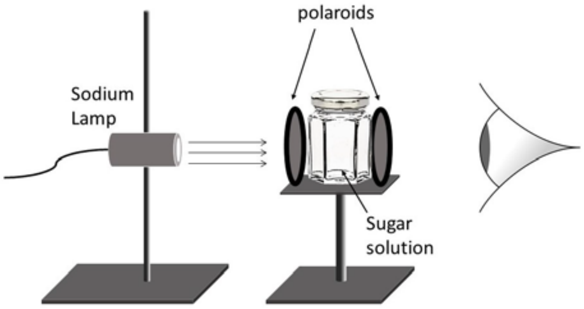
Section C: Optical Activity: Polarisation Rotation Through a Medium

Technologies such as LCDs rely on the rotation of polarised light through a medium. This can be done using solutions such as sugar dissolved in water. A material which rotates the polarisation of light is said to have optical activity. There is only one of these set up per lab, so you will need to take turns.

Experiment

Using a similar setup as Section A where the polarisers are cross-polarised, replace the middle polariser with a jar of sugar solution.

Using the final polariser rotate the angle until you see the light at a minimum again.



Using this we can find the concentration, C using the following formula:

$$\theta = CL\,\alpha$$

Where α is 66.47 degrees $dm^{-1}\ cm^{3}\ g^{-1}$, L is the length of the optically active medium and θ is the angle of rotation of polarised light through the solution.

Analysis

Discuss your results and compare to the concentration supplied by your demonstrator.

Conclusion

Write a final, short summary of your results from all the sections in this lab.

Experiment 7
Wavelength of Light (with a ruler)

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this book, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

ADDITIONAL HAZARDS

Do not, under any circumstances look directly into the lasers as they can cause eye damage.

Outline of Experiment

In this experiment you will achieve the seemingly impossible and measure the wavelength of light using a ruler! This is a very famous physics experiment and illustrates the kind of lateral thinking required to adapt available equipment to produce a more accurate measurement using clever design. We use our knowledge of interference (which you do not need to have covered in lectures before the lab – we only need the most basic theory included below) and the conveniently spaced grooves on a metal ruler to produce an interference pattern where we can measure or know everything except the wavelength of the light source (which we will then be able to work out). We will be using laser diodes as a light source because we will want to use a single wavelength.

✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

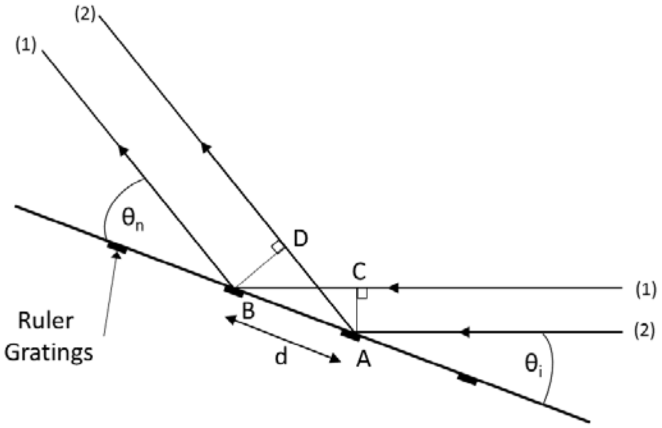
Learning Goals

- To undertake the careful setup of the experiment and obtain accurate results.
- To work efficiently as a team in your groups, sharing and contributing to all tasks.
- To use Excel efficiently for manipulating data through formulas.
- To critically compare results with the accepted value.
- To measure the wavelength of laser light using a ruler as a diffraction grating.

Introduction

Explore the idea of wave interference and diffraction grating at
https://en.wikipedia.org/wiki/Diffraction_grating

The light from the laser diode may be considered as parallel rays that are scattered (reflected) from the metal ruler in the spaces between the dark markings. In the diagram **below,** rays (1) and (2) are scattered from adjacent spaces.



Section A: Wavelength of Light

✓ **Pre-lab question 1**

Write down an expression for the path difference (AD – BC) in terms of θ_n, θ_i and d from the above figure.

✓ **Pre-lab question 2**

What is the physical condition for constructive interference? What does this mean for rays (1) and (2), which have the same wavelength?

✓ **Pre-lab question 3**

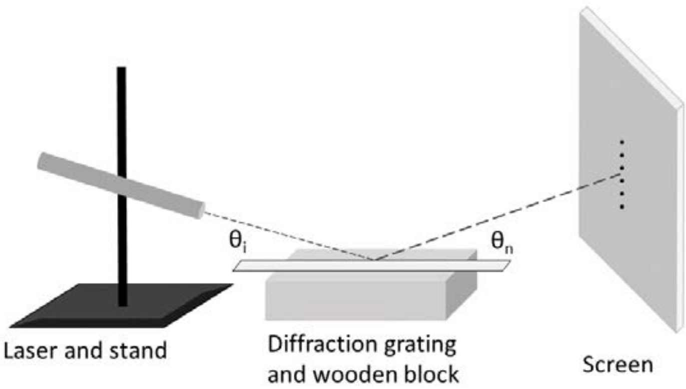
Equate these expressions to get a relation describing the structure of the interference pattern produced in this process. Check this with your demonstrator if you are uncertain about the equation that you have produced.

✓ **Pre-lab question 4**

Why do we want a light source of only one colour (wavelength) for this experiment? What would happen if we used a white light source? (if time permits you can experiment with this during the lab).

Experimental Set-up

Set up the experiment shown in the diagram. Using the spacings on the ruler create a diffraction pattern on the screen (Check with your demonstrator once you think you have the correct pattern). Observe and record the interference pattern that is produced on the screen (rough sketch of the pattern produced). (To indicate the relative intensity of the diffracted beams, you may wish to draw dots of varying diameter.)



✓ What do you notice when you change between the lines of 1 mm spacing and 0.5 mm spacing?

✓ Which will you use to get the best measurement for calculating the wavelength λ?

✓ Check that the laser beam is correctly aligned so it hits the spacings you chose.

Data

✓ Record the following quantities (include at least a rough estimate of your uncertainty – talk to your demonstrator if unsure):

- ✓ The length between ruler and screen is measured to be L_n
- ✓ The length between laser and ruler is measured to be L_i
- ✓ The height of the laser is measured to be X_i
- ✓ The height of the maxima, X_n

✓ The integer n labels the order of the diffracted beam, with the central (brightest) beam having n = 0. The quantities n should be the first in your table.

✓ Calculate the values θ_i and θ_n.

Analysis

✓ You should have an expression relating n to λ, d, cos (θ_n) and cos (θ_i) from Pre-lab question 3. Given that λ, d and cos (θ_i) are constants, how might you obtain λ from this data?

✓ Plot cos(θ_n) vs maxima (n), for experimental values. Use this to determine a value for the wavelength, λ.

Conclusion

✓ In your conclusion discuss how your wavelength value compares with the known value for these laser diodes (your demonstrators will tell you). Think about how you might improve the precision and accuracy of your measurement.

Experiment 8
Vibrations

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this manual, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

ADDITIONAL HAZARDS

Keep noise levels to a minimum. Some frequencies may cause discomfort and even nausea for some people. If this is the case, you may request ear plugs and please see your demonstrator immediately if you are unwell.

Outline of Experiment

Today you will be looking at **standing waves** of sound in pipes. The most common use of this phenomena is in musical instruments such as the clarinet and flute.

In this experiment you will observe and compare standing waves in a pipe (open at both ends) with standing waves in another pipe (closed at one end). You will explore the resonant frequencies (also known as 'modes of vibration') of the waves in each pipe and learn about harmonics. Finally, you will calculate the speed of sound in air using pipes both closed at one end and open at both ends.

This experiment is divided into two sections. In the first section you will measure the characteristics of standing waves. In the second part, you will aim to accurately determine the speed of sound.

✓***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To work well as a team completing the experiment and analysis efficiently and accurately.
- To demonstrate competency in the use of a digital oscilloscope and signal generator.
- To use different methods to confirm resonances and minimise false data.
- To demonstrate the behaviour of standing waves in pipes and determine the speed of sound in air.

Introduction

Before Starting the lab please visit these pages on harmonics in an air column. http://hyperphysics.phy-astr.gsu.edu/hbase/waves/opecol.html

http://hyperphysics.phy-astr.gsu.edu/hbase/waves/clocol.html

We will use the signal generator in the Scope Program connected to a loudspeaker to produce sound waves. The frequency of any sound wave (f) is determined by its source, and it will not change as the sound wave propagates through the air. The frequency is the 'rate' at which the wave repeats (so it is in units of Hertz – which is just inverse seconds). The time between 'peaks' (or troughs) at a fixed point in space, is called the period (T).

✓ **Pre-lab question 1**

Write down the equation relating frequency and the period.

The **wavelength** of a sound wave (written as **λ**) is the length of a complete wave. This will be the distance between maxima (or minima) if you consider a sound wave frozen in time.

The **speed** (just as it is normally) is the rate at which the wave moves. We could calculate it in the usual way, by dividing the distance travelled by the time taken.

✓ **Pre-lab question 2**

Write down an expression for the speed (v) in terms of the wavelength (λ) and the frequency (f).

This relation is true not only for sound waves but for **any** kind of wave, including water waves, radio waves and light.

Standing Waves in Pipes

A continuous sound wave moving along a pipe will be reflected at both ends of the pipe, whether the ends are open or closed (see appendix C). This means that after a very short time the pipe will contain **two** travelling waves, one moving along the pipe in one direction and the other moving in the opposite direction. These two waves will have equal speeds (as speed is determined by the properties of the air) and the same frequency (as determined by the source of the wave), and they will therefore also have the same wavelengths.

We can simply add the disturbance of air due to each of these two separate waves at each point in the pipe to produce a 'net' disturbance. The two travelling waves combine together to form a **standing wave**. Because the end point of a pipe defines a fixed maximum or minimum position (depending on if it is open or closed, and whether you are referring to the displacement or pressure) for a standing wave to form, the wavelength of the sound applied needs to relate to the length of the tube in a specific way.

✓ **Pre-lab question 3**

In terms of pipe length L and wavelength λ, write down a formula for the resonant frequencies of open and closed pipes.

Section A: Modes of Vibration

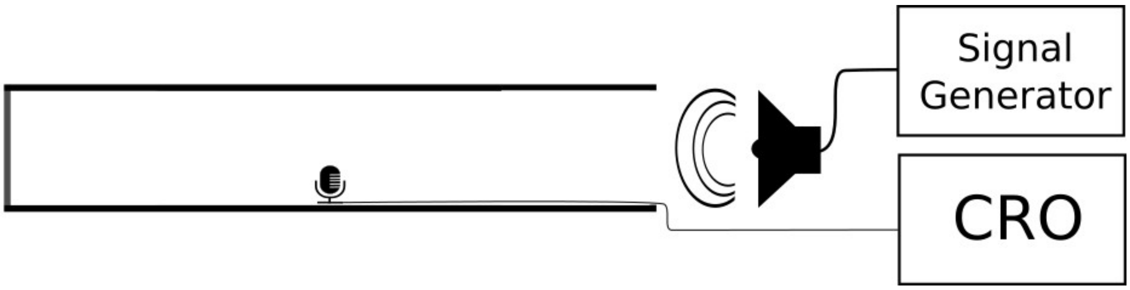
In the experiments below, we will use a loudspeaker to produce sound waves, and observe resonance in a tube/pipe. The motion loudspeaker is driven by a sinusoidal electrical signal, and therefore produces sinusoidal waves that move along (through) the pipe. When the wave reaches the other end of the pipe, some of it will be reflected, whether the end is open or closed. The reflected wave can then interfere with the original wave. Under certain conditions, a resonance can occur.

Experiment 1: Pipe open at one end

Procedure:

✓ Close one end of the cardboard tube (post pack) with lid provided and place the open end directly next to the loudspeaker above as shown in the diagram.

✓ Measure the length of your cardboard tube (post pack).



✓ Set the signal generator (use the Scope program) to SINE mode and a frequency of 150 Hz

✓ Adjust the output control so that you can hear the sound.

✓ Gradually increase the frequency until you hear a distinct increase in volume (i.e. loudness). You will also see an increase in amplitude of the signal on the oscilloscope. This point is called a resonance, and the frequency f_n at this point is called a resonant frequency of the pipe.

✓ By carefully varying the frequency, identify all resonances in the range 150-2000 Hz. You may like to use the sweeping function or make some predictions for the resonant frequencies you are looking for.

Data

✓ Record the resonance frequencies in your logbook.

Tips:

If you are unsure about hearing an increase in volume, move the pipe away from the speaker. If the sound doesn't become immediately less loud, it is not a resonance. You might find it useful to rapidly move the pipe in and out of line with the speaker.

Watch out for **false resonances**, which are due to the characteristics of the speaker rather than of the pipe. There is likely to be one at around 250 Hz. Again, the test is to check for a change in volume as you move the pipe away.

Experiment 2: Pipe open at both ends

Repeat the procedure as for experiment 1, this time using the same tube with the lid taken off so that it is open at both ends. (Be sure to replace the lid when you have finished this section.)

Analysis

✓The lowest possible resonant frequency (where n = 1) is called the fundamental frequency of the pipe. In general, the resonances are called harmonics (or modes). For example, the standing wave corresponding to n = 3 is called the 'third harmonic' (or the 'n = 3 mode'). The integer n is sometimes called the harmonic number or the mode number. You now have enough data to interpret how sound waves interact with open and closed pipes. As a starting point, use the expressions you obtained in the Pre-lab exercise relating the resonant frequency series.

Section B: Speed of Sound in Air

✓Using your equations derived in the pre-lab questions, calculate the speed of sound using both your closed and open pipe.

Consider these questions in your discussion:

- ✓ How do the resonant frequencies compare with the length of the tube?
- ✓ In measuring the length of the pipe did you include some confidence limits?
- ✓ Is the speed of sound in the lab 340 ms^{-1}? What might affect this?
- ✓ Look back at your table of measurements for the two pipes. How did you identify the fundamental frequency?
- ✓ How does the fundamental frequency of a pipe open at both ends compare with the fundamental frequency of a pipe open at one end, when the two pipes have the same length?
- ✓ Were all of the resonances you observed generated by the pipe?

Problem Solving Sheet Sets
Weeks 2-13

Introduction

The following Problem Solving Sheet Sets are sets of problems on the Physics covered in lectures in the previous week and are designed to help your understanding of the topics covered each week. You will be working through these problems in your Problem Solving classes with your tutor. It is expected that you attempt the problems **BEFORE** your Problem Solving classes. These problems are **in addition** to your weekly homework assignments which can be accessed on the LMS and are submitted online.

The following problem sets include;

- ✓ Discussion questions
- ✓ Problem solving questions
- ✓ Mini challenge questions
- ✓ Past Examination questions
- ✓ Short answers

Complete solutions will be posted on the LMS (https://lms.unimelb.edu.au/) at the end of the week and will be discussed during the Problem Solving class.

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Physics 1 (PHYC10003)

Week 2: Introduction to Kinematics

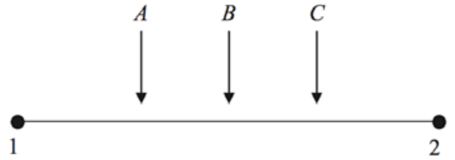
Discussion Questions

1. Most cars have a speedometer, an odometer and a clock.

(a) How could you use these to determine the instantaneous speed of the car?
(b) How you could use these devices to determine the average speed of the car?

From: Tutorials in Introductory Physics - Homework

2. An object moves along the line from point 1 to point 2 in time Δt.



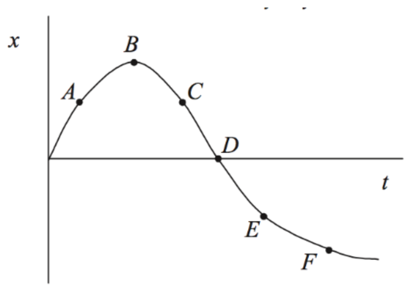
(a) If the object is getting faster, and Point B is halfway between points 1 and 2, which points A, B or C could correspond to the location of the object at $t = \Delta t/2$?
(b) If the object is getting slower, which points A, B or C could correspond to the location of the object at time $\Delta t/2$?

From: Tutorials in Introductory Physics - Homework

3. The figure shows a position-vs-time graph for a moving object. Positive values of x are to the right. At which lettered point or points;

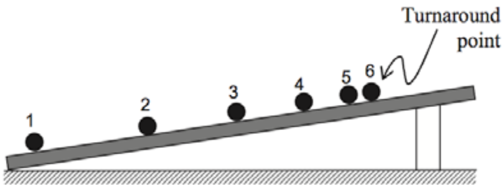
(a) Is the object moving the fastest?
(b) Is the object moving to the left?
(c) Is the object speeding up?
(d) Is the object slowing down?
(e) Is the object turning around?

Take the positive x-direction to be to the right.



From: Physics for Scientists and Engineers

4. The diagram below represents a strobe photograph of a ball as it rolls up a track. (In a strobe photograph, the position of an object is shown at instants separated by *equal time intervals*).



(a) Draw vectors on the diagram that represent the instantaneous velocity of the ball at each of the labeled locations. If the velocity is zero at any point, indicate that explicitly.
(b) Sketch vectors that represent the velocities at points 1 and 2 side-by side and label them $\overrightarrow{v_1}$ and $\overrightarrow{v_2}$ respectively.
(c) Draw the vector that must be added to the velocity at point 1, $\overrightarrow{v_1}$ to equal the velocity at the later time, $\overrightarrow{v_2}$. Label this vector $\Delta\vec{v}$.
(d) Would your answer to (c) change if you were to select two different consecutive points (eg points 3 and 4) while the ball was slowing down? Explain.
(e) Sketch a position vs time graph for this motion. Take the positive direction to be up the track. Sketch a velocity vs time graph for this motion.
(f) Sketch an acceleration vs time graph for this motion.

From: Tutorials in Introductory Physics Problem-solving questions

Problem-solving questions

5. The quantity called *mass density* is the mass per unit volume of a substance. Express the following mass densities in SI units.

(a) Aluminium, $2.7 \times 10^{-3} kg\ cm^{-3}$

(b) Alcohol, $0.81\ g\ cm^{-3}$

6. The minimum stopping distance for a car travelling at a speed of 30 m s^{-1} is 60 m, including the distance travelled during the driver's reaction time of 0.50 s. Assume the car brakes with constant acceleration.

(a) What is the minimum stopping distance for the same car travelling at of 40 m s^{-1}?

(b) Draw a position-vs-time graph for the motion of the car in part (a). Assume the car is at $x_0 = 0$ in when the driver first sees the emergency situation ahead that calls for a rapid halt.

From: Physics for Scientists and Engineers

7. A red train travelling at 72 km/h and a green train travelling at 144 km/h are headed toward each other along a straight, level track. When they are 950 m apart, each engineer sees the other's train and applies the brakes. The brakes slow each train at the rate of 1.0 m s^{-2}. Is there a collision? If so, answer yes and give the speed of the red train and the speed of the green train at impact, respectively. If not, answer no and give the separation between the trains when they stop.

From: Fundamentals of Physics

Mini-challenge questions

8. Careful measurements have been made of Olympic sprinters in the 100-metre dash. A quite realistic model is that the sprinter's velocity is given by

$$v_x = a(1 - e^{-bt})$$

Where t is in seconds, v_x is in m s^{-1} and the constants a and b are characteristic of the sprinter. Sprinter Carl Lewis' run at the 1987 World Championships is modelled with $a = 11.81\ \mathrm{ms}^{-1}$ and $b = 0.6887\ s^{-1}$.

(a) What was Lewis' acceleration at $t = 0$ s, 2.00 s and 4.00 s?

(b) Find an expression for the distance travelled at time t.

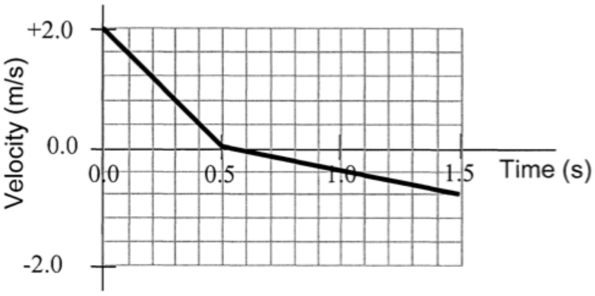
(c) Your expression from part (b) is an equation that you can't solve for t. Use 'trial and error' to find the time needed to travel a specific distance. To the nearest 0.01 s, find the time Lewis need to sprint 100.0 m. His official time was 0.01 s more than your answer, showing that this model is very good, but not perfect.

From: Physics for Scientists and Engineers (Problem 2.80)

Examination questions

9.

(a) A particle is launched up a uniform slope at time $t = 0.0$ s, and it begins to slide up the slope. A plot of its velocity as a function of time is shown in the figure below. The positive direction corresponds to motion *up* the slope and in what follows, ignore air resistance.



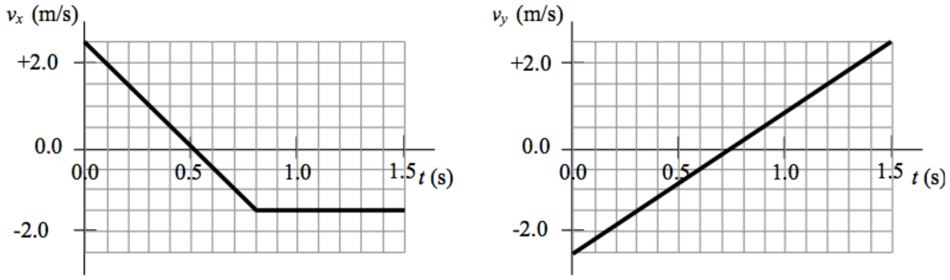
(i) Describe the motion of the particle after it is released. In particular describe the motion *before*, *at* and *after* 0.5 s have elapsed after release.

(ii) What distance does the particle travel in the 0.5 s after it is released?

(iii) Draw a clearly labelled plot of the acceleration of the particle as a function of time.

10.

(b) A bee starts from a position given by $\vec{r}_0 = 9.0\,\hat{\imath}$ m and moves in the xy-plane with x and y-components of velocity given in the figures below.



(i) What is the *speed* of the bee at $t = 0$ s?

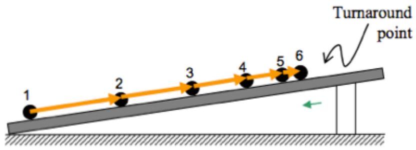
(ii) In what direction is the bee travelling at $t = 1.0$ s?

(iii) What is the displacement of the bee between $t = 0$ s and $t = 1.5$ s?

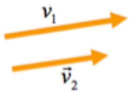
(iv) What is the position of the bee at $t = 1.5$ s?

Short Solutions

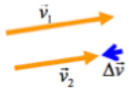
1a Simplest answer: read the speedometer; others possible.
1b Divide distance (from odometer) by time (from clock)
2. (a) A (b) C
3. (a) D (b) C,D,E,F (C) C (d) A,E,F (e) B
4a



4b

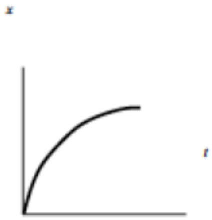


4c

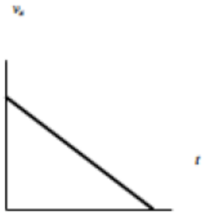


4d) answer doesn't change

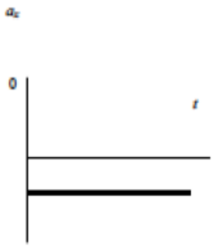
4e



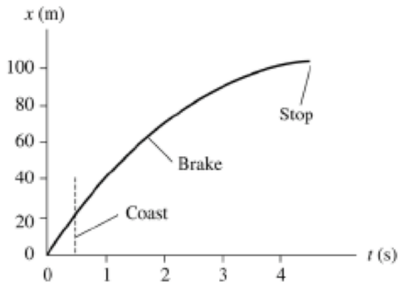
4f



4g



5a) 2.7 x 10^3 kg m^{-3}
5b) 810 kg m^{-3}
6a) 100 m
6b)



7 Trains collide. Speed of green train (red has stopped) 36 km h^{-1}.
8a) 8.134 m s^{-2} ; 2.052 m s^{-2}; 0.5175 m s^{-2}
8b) $x = \frac{a}{b}(bt + e^{-bt} - 1) = 17.15(0.6887t + e^{-0.6887t} - 1)$ metres
8c) t = 9.92 s; x = 100 m

9 (i) The particle initially slides up the ramp with decreasing speed. At 0.5 s it stops momentarily, then slides back down the ramp with increasing speed.
(ii) 0.5 m
(iii) Graph required, noting that the acceleration is <u>negative</u> **at all times.**

10bi 3.5 m s^{-1}; 10bii angle of 150° to *x*-axis (anticlockwise)
10biii –0.65***i*** (m) 10biv 8.35***i*** (m)

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Halliday, Resnick and Walker, Fundamentals of Physics Extended, John Wiley (8e).

Working Space

Working Space

Physics 1 (PHYC10003)

Week 3: Vectors and Two Dimensional Motion

Discussion Questions

1. You are in a lift rising at constant velocity. You drop your keys; it happens that when they hit the floor they are as high above ground level as when they left your hand. The keys fall dead on the floor without bouncing. Make a sketch graph showing the height above ground of the keys *and* the lift against time. Start from before the keys are released until after they hit the floor.

Mazur, Peer Instruction: A User's Manual, Prentice-Hall, (1997)

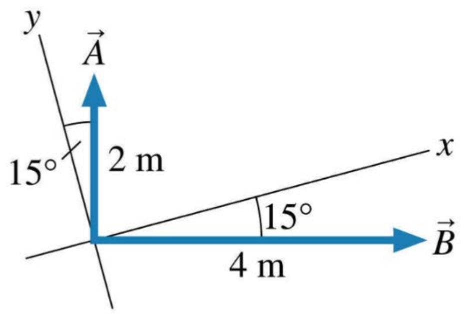
2. An object is held in place by friction on a slope. The angle of inclination is increased until the object starts sliding. If the surface is kept at this angle, the object

(a) slows down.
(b) moves at uniform speed.
(c) speeds up.
(d) none of the above

Mazur, Peer Instruction: A User's Manual, Prentice-Hall, (1997)

Problem-solving questions

3. The figure shows vectors $\vec{A}$ and $\vec{B}$. Find $\vec{D} = 2\vec{A} + \vec{B}$. Write your answer in component form.



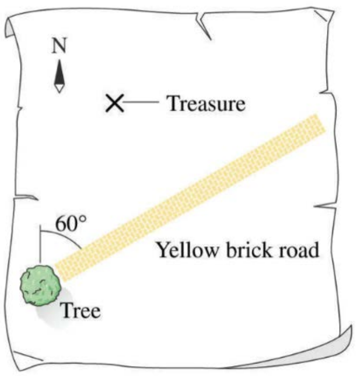
From: Physics for Scientists and Engineers - A Strategic Approach (Problem 3.28)

4. The treasure map in the figure gives the following directions to the buried treasure:

'Start at the old oak tree, walk due north for 500 paces, then due east for 100 paces. Dig.'

But when you arrive at the tree's location, you find an angry dragon just to your *north*. To avoid the dragon, you set off along the yellow brick road at an angle 60° east of north. After walking 300 paces you see an opening through the woods. Which direction should you go, and how far, to reach the treasure?

From: Physics for Scientists and Engineers - A Strategic Approach (Problem 3.40)

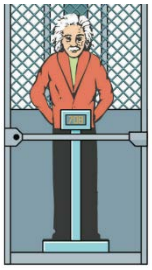


5. A sailboat is travelling east at 5.0 m/s. A sudden gust of wind gives the boat an acceleration $\vec{a}$ = (0.80 m/s^2, 40° north of east). What are the boat's speed and direction 6.0 s later when the gust subsides?

From: Physics for Scientists and Engineers - A Strategic Approach (Problem 4.5)

6. A ball thrown horizontally at 25 m/s travels a horizontal distance of 50 m before hitting the ground. From what height was the ball thrown?

From: Physics for Scientists and Engineers - A Strategic Approach (Problem 4.11)



7. In the figure, a passenger of mass m = 72.2 kg stands on a platform scale in a lift. We are concerned with the scale readings when the lift is stationary and when it is moving up or down.

(a) Find an expression for the scale reading in terms of the passenger mass (*m*), the lift acceleration (*a*) and the acceleration due to gravity, *g*.

(b) What is the reading if the lift is at rest or moving up at a constant 0.5 m s^{-1}?

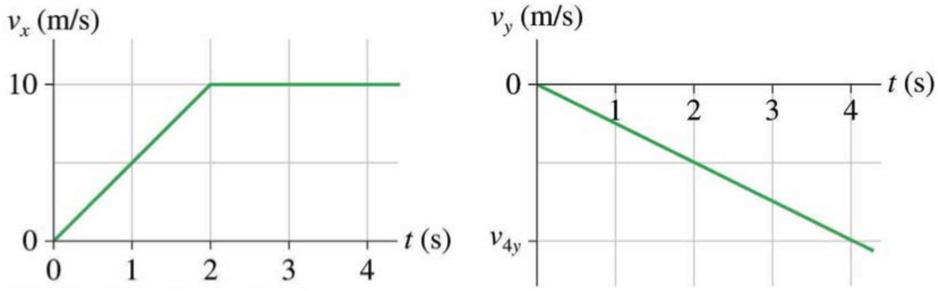
(c) What are the readings when the lift accelerates up and down at 3.20 m s^{-2}?

(d) During the upward acceleration in part (c), what is the magnitude F_{net} on the passenger, and what is the magnitude $a_{p,car}$ of his acceleration as measured in the frame of the lift? Does $\vec{F}_{net} = m\vec{a}_{p,car}$?

Walker, Fundamentals of Physics 8/e, Sample Problem 5-8

Mini-challenge questions

8. A particle starts from rest at $\vec{r_0} = 9.0\hat{\jmath}$ m and moves in the xy-plane with the velocity shown in the figure. The particle passes through a wire hoop located at $\vec{r_1} = 20.0\hat{\imath}$ m then continues onward



(a) At what time does the particle pass through the hoop?

(b) What is the value of the y-component of the particle's velocity at *t* = 4s.

(c) Calculate and plot the particle's trajectory.

From: Physics for Scientists and Engineers - A Strategic Approach (Problem 4.39)

Past examination questions

9.

(a) A particle is travelling along a flat surface with a velocity described by 3***i*** – 4t^2***j*.** At *t* = 0, it has a position at (0, 0).

(i) Calculate the *speed* of the particle at time *t* = 2.0 s.

(ii) Calculate, using (***i*,*j***) notation, the *acceleration* of the particle at *t* = 2.0 s.

(iii) Calculate, using (***i*,*j***) notation, the *position* of the particle at time *t* = 2.0 s.

(b) A sailing boat travelling NE at 5.0 m/s is spotted by an ocean going kayak travelling at 2.5 m s^{-1} due South. Calculate the *magnitude* of the sailing boat's velocity relative to the kayak.

(c) A sprinter covers 100 m in a time of 12 s, starting from rest. For the first two seconds, her acceleration is constant, and for the rest of the run she runs at constant speed. Calculate her top speed. Give your answer to two significant figures.

10.

Consider a block, of mass 15.0 kg, attached to a string, which holds the block stationary on an inclined plane ($\theta = 30$ degrees); see figure below.

(a) Redraw the diagram below indicating all of the forces acting on the block.

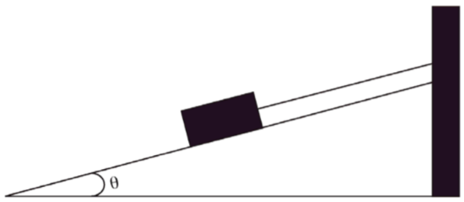
(b) Identify two action-reaction pairs in this system.

(c) Calculate the tension in the string.

(d) If the string is cut, ignoring friction, calculate the acceleration of the block down the slope.

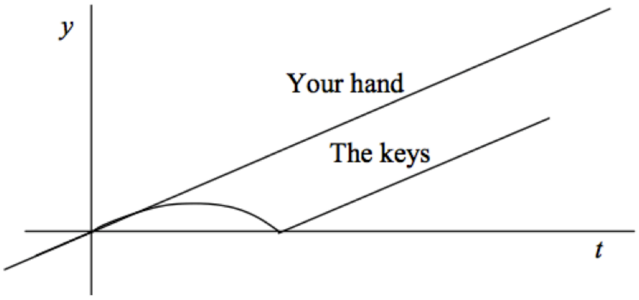
(e) If the surface of the inclined plane is **not** frictionless calculate the minimum value of the coefficient of static friction for which the block remains stationary, after the string is cut.

(f) If the coefficient of static friction is less than that calculated in previous part above and the coefficient of kinetic friction is 0.2, calculate the acceleration of the block down the slope.

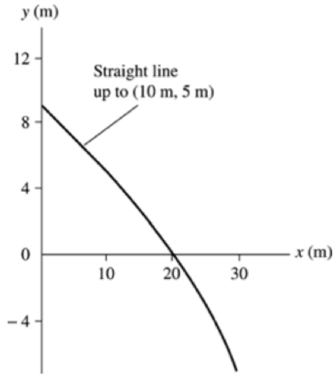


Short solutions

1.



2. C
3. $4.9\boldsymbol{i} + 2.8\boldsymbol{j}$ (in m)
4. 385 paces, heading 24.6° W of N
5. 9.21 m s^{-1}, 20° N of E
6. 19.6 m
7. a) *F=m(a+g)* b) 72.2 kg c) Up: 95.8 kg, Down: 48.6 kg d) 231 N, 0 m s^{-2}, No
8. a) 3 s b) -8 m s^{-1} c)



9. a)(i) 16.3 m/s (ii) $-16\boldsymbol{j}$ (iii) $6\boldsymbol{i} - 10.1\boldsymbol{j}$
   b) 7 m/s
   c) 9.1 m/s
10. (a) tension *T* up the slope, *mg* vertically downwards through the centre of mass, normal reaction *N* perpendicular to the slope, (static friction up the slope is zero as stem says "…a string, which holds the block stationary…)
    (b) tension of string on block (up slope), tension of block on string (down slope); gravity force of Earth on block (vertically down), gravity force of block on Earth (vertically up); normal reaction of surface of slope on block (perpendicular away from surface), normal reaction of block on surface (perpendicular into the surface)
    (c) $mg\sin\theta = T = 15 \times 9.8 \times \sin 30 = 73.5$ (74) N
    (d) $a = g\sin\theta = 4.9$ m s^{-2}
    (e) $\tan\theta = \mu_s = 0.58$
    (f) 3.2 m s^{-2}

Bibliography

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R. Knight, Physics for Scientists and Engineers - A Strategic Approach, Pearson (Addison-Wesley), 2/e (2008)
J. Walker, Fundamentals of Physics, John Wiley, 8/e (2008)

Working Space

Working Space

Physics 1 (PHYC10003)

Week 4: Forces and Rotational Motion

Discussion questions

1. Consider a person standing in a lift accelerating upwards. The upward normal force *N* exerted by the lift floor on the person is:

(a) larger than

(b) identical to

(c) smaller than

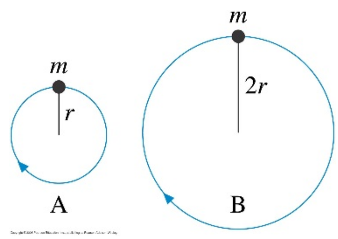
the gravitational force (*mg*) on the person.

Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall, (1997)

2. The figure shows two balls of equal mass moving in vertical circles. Is the tension in string A greater than, less than, or equal to the tension in string B if the balls travel over the top of the circle

(a) With equal speed and

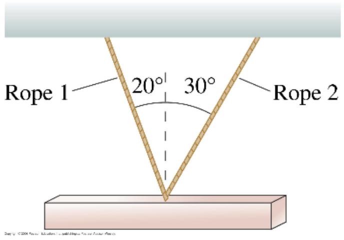
(b) With equal angular velocity (ω)?



Knight, Physics for Scientists and Engineers, 2/e (Conceptual Question 8.5)

Problem-solving questions

3. A 1000 kg steel beam is supported by two ropes. What is the tension in each?



Knight, *Physics for Scientists and Engineers*, *2/e* (Problem 6.29)

4. The velocity of a 3.00 kg particle is given by ($At\mathbf{i} + Bt^2\mathbf{j}$), where the constants A = 8.00 m/s^2, B = 3.00 m/s^3, (units for correct dimensional analysis) and *t* is in seconds. At the instant the net force on the particle has a magnitude of 35.0 N, what are the direction (relative to the positive direction of the *x* axis) of:

(a) The net force; and

(b) The particle's direction of travel?

Walker*, Fundamentals of Physics 8/e, Problem 5.32*

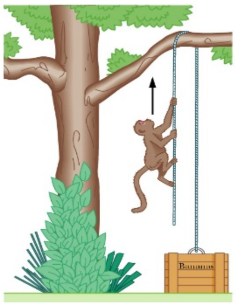
5. An object moving in a liquid experiences a *linear* drag force: $\vec{D} = -b\vec{v}$, where *b* is a positive constant called the *drag coefficient*. For a sphere of radius *R*, the drag constant can be computed as $b = 6\pi\eta R$, where η is the *viscosity* of the liquid.

(a) Find an algebraic expression for the terminal speed v_{term} of a spherical particle of radius *R* and mass *m* falling through a liquid of viscosity η.

(b) Water at 20°C has viscosity $\eta = 1.0 \times 10^{-3}$ N s m^{-2}. Sand grains have density 2400 kg m^{-3}. Suppose a 1.0-mm-diameter sand grain is dropped into a 50-m-deep lake whose water is at a constant 20°C. If the sand grain reaches terminal speed almost instantly (a good approximation), how long will it take the sand grain to settle to the bottom of the lake?

Adapted from Knight, Physics for Scientists and Engineers, 2/e (Problem 6.62)

6. A 10 kg monkey climbs up a massless rope that runs over a frictionless tree limb and back down to a 15 kg package on the ground (see figure).



(a) What is the magnitude of the least acceleration the monkey must have if it is to lift the package off the ground?

If, after the package has been lifted, the monkey stops its climb and holds onto the rope, what are the

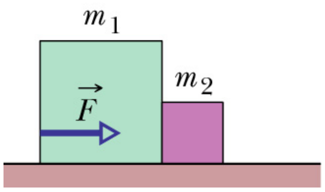
(b) magnitude and

(c) direction of the monkey's acceleration and

(d) the tension in the rope.

Jewett, *Fundamentals of Physics,* 8/e, Wiley (5.57)

7. Two blocks are in contact on a frictionless table. A horizontal force is applied to the larger block, as shown in the figure.



(a) If m_1 = 2.3 kg, m_2 = 1.2 kg, and F = 3.2 N, find the magnitude of the force between the two blocks.

(b) Show that if a force of the same magnitude F is applied to the smaller block but in the opposite direction, the magnitude of the force between the blocks is 2.1 N, which is not the same value calculated in (a).

(c) Explain the difference.

Jewett, *Fundamentals of Physics,* 8/e, Wiley (5.53)

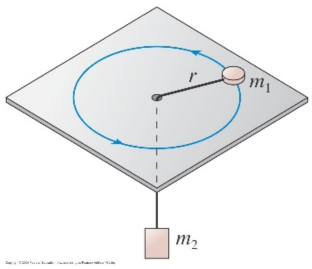
8. A highway curve of radius 500 m is designed for traffic moving at a speed of 90 km/hour. What is the correct banking angle of the road?

Knight, *Physics for Scientists and Engineers*, *2/e*

9. In an old-fashioned amusement park ride, passengers stand inside a 5.0-m-diameter hollow steel cylinder with their backs against the wall. The cylinder begins to rotate about a vertical axis. Then the floor on which the passengers are standing suddenly drops away. If all goes well, the passengers will 'stick' the wall and not slide. Clothing has a coefficient of static friction against steel in the range 0.60 to 1.0 and a kinetic coefficient in the range 0.40 to 0.70. A sign next to the entrance says 'No children under 30 kg allowed.' What is the minimum angular speed (in rpm) for which the ride is safe?

Knight, *Physics for Scientists and Engineers*, *2/e* (Problem 8.36)

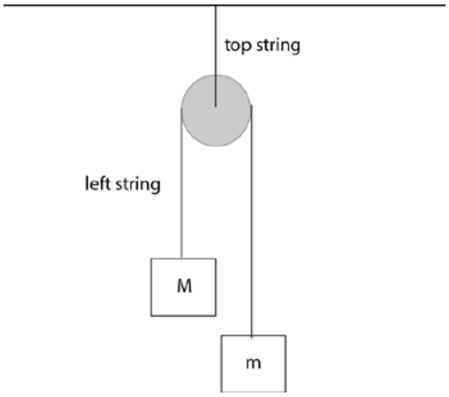
10. Mass m_1 on the frictionless table of the figure is connected by a string through a hole in the table to a hanging mass m_2. With what speed must m_1 rotate in a circle of radius r if m_2 is to remain hanging at rest?



Knight, *Physics for Scientists and Engineers*, *2/e* (Problem 8.46)

Mini-challenge questions

11. Two masses M and m are connected by a light string over a light frictionless pulley.



(a) What is the tension in the:

I. left string
II. right string
III. top string

in terms of *M, m* and *g.*

(b) Explain why the magnitude of the tension in the top string is not equal to the sum of the magnitudes of the tensions in the left and right strings. If you like, show that the difference is equal to $(M - m)^2 g/(M + m)$.

Past examination questions

12

4. A small rocket which has a **total mass of 0.20 Kg** consists of a motor and casing (the mass of which together is 0.04 Kg) and solid fuel. The motor provides a thrust of 12.0 N and an impulse of 15 N-sec. Ignoring the non-inertial character of an observer on earth and assuming the rocket is launched vertically,

(a) What is the size of its initial acceleration?

(b) For how long does the rocket engine burn (until all fuel is spent)?

(c) What is the speed of the gas emitted from the rocket? (Assume that all of the fuel is converted to gas and at a uniform rate).

When the rocket reaches its maximum altitude of 100 m, a parachute opens to permit the rocket to descend for recovery at terminal velocity. If the parachute has an effective area of 0.04 m^2 and in air density $\rho = 1.2$ Kg/m^3 has a drag coefficient C of 50,

(d) With what speed does it hit the earth?

(Drag force $= \frac{1}{2} C\rho A v^2$.)

Short solutions

1 (a) There must be a net upwards force for an upwards acceleration

2 (a) Tension in A > Tension in B (follows from $F_{NET} = mv^2/R$)

(b) Tension in A < Tension in B (follows from $F = m\omega^2 R$)

3 Tension in Rope 1 = 6397 N and in Rope 2 = 4376 N

4 (a) 46° to the positive *x*-axis (b) 28° to the positive *x*-axis

5 (a) $v_{TERMINAL} = (mg/6\pi\eta R)$ (b) 38 s.

6 (a) 4.9 m s^{-2} (b) 2.0 m s^{-2} (c) upwards (d) 120 N (All to 2 S.F.)

7 (a) 1.1 N (b) 2.1 N (c) larger block requires a larger force for same *a*

8 7.3°

9 24 rpm

10 $v = \sqrt{(m_2 rg/m_1)}$

11 (a) $T_{LEFT} = T_{RIGHT} = 2Mmg/(M + m)$

(b) Centre of mass of *M, m* system is accelerating downwards, so there must be a net force downwards – this is the difference between $(M + m)$ g and $2T = 4Mmg/(M + m)$. A little algebra shows this difference to be equal to $(M - m)^2 g/(M + m)$. When $M = m$ this goes to zero, as expected.

12 (a) 50.2 m s^{-2} (b) 1.25 s (c) 94 m s^{-1} (d) 0.57 m s^{-1}

Bibliography

E. Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall, (1997)

R. Knight, *Physics for Scientists and Engineers - A Strategic Approach*, Pearson (Addison-Wesley), 2/e (2008)

J. Walker, *Fundamentals of Physics*, John Wiley, 8/e (2008)

Working Space

Working Space

Physics 1 (PHYC10003)

Week 5: Momentum, Work and Energy

Discussion questions

1. A car accelerates from rest. In doing so it gains a certain amount of momentum and Earth gains
- (a) more momentum.
- (b) the same amount of momentum.
- (c) less momentum.
- (d) the answer depends on the interaction
- (e) between the two.

Mazur, *Peer Instruction: A User's Manual*

2. A car accelerates from rest. It gains a certain amount of kinetic energy and Earth
- (a) gains more kinetic energy.
- (b) gains the same amount of kinetic energy.
- (c) gains less kinetic energy.
- (d) loses kinetic energy as the car gains it.

Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall

3. A golf club continues forward after hitting the golf ball. Is momentum conserved in the collision? Explain, making sure you are careful to identify 'the system'.

Knight, *Physics for Scientists and Engineers,* 8/e (CQ9.11)

Calculation questions

4. A goose with a mass of 2.0 kg strikes a commercial airliner with a mass of 160,000 kg head-on. Before the collision, the goose was flying with a speed of 60 km/hr and the aeroplane's speed was 870 km/hour. Take the length of the goose to be 1.0 m long. You can assume the goose is a non-rigid body.
- (a) What is the change in momentum of the goose during this interaction?
- (b) Estimate the duration of the interaction?
- (c) What is the average force between the goose and the aeroplane during the interaction?

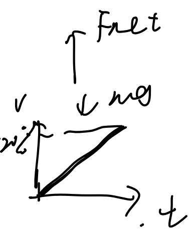
5. A soccer player kicks a soccer ball of mass 0.45 kg that is initially at rest. The player's foot is in contact with the ball for 3.0×10^{-3} s, and the force of the kick is given by:

$$F(t) = At - Bt^2,$$

where $A = 6.0\times10^6$ N/s, $B = 2.0\times10^9$ N/s^2 for $0 \le t \le 3.0 \times 10^{-3}$ s, where t is in seconds. Find the magnitude of:
- (a) The impulse on the ball due to the kick,
- (b) The average force on the ball from the player's foot during the period of contact,
- (c) The maximum force on the ball from the player's foot during the period of contact, and
- (d) The ball's velocity immediately after it loses contact with the player's foot.

Jewett, *Fundamentals of Physics,* 8/e, Wiley (9.35)

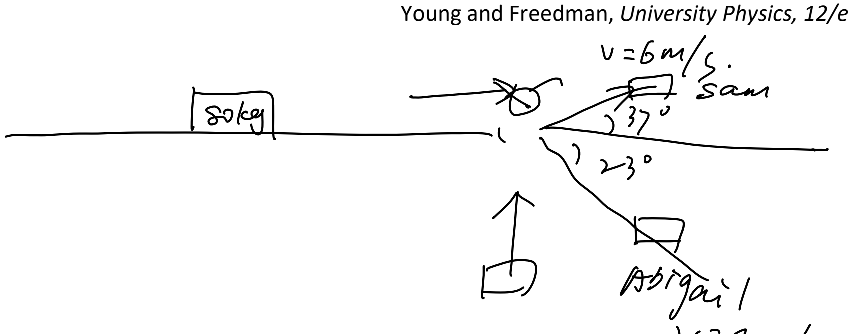
6. A small rocket to gather weather data is launched straight up. Several seconds into the flight, its velocity is 120 m/s and it is accelerating at 18 m/s^2. At this instant, the rocket's mass is 48 kg and it is losing mass at the rate of 0.50 kg/s as it burns fuel. What is the net force on the rocket?



Knight, *Physics for Scientists and Engineers* (9.33)

7. You and your friends are doing physics experiments on a frozen pond that serves as a frictionless, horizontal surface. Sam, with mass 80.0 kg, is given a push ~~and~~ slides eastward. Abigail, with mass 50.0 kg, is sent sliding northward. They collide, and after the collision Sam is moving at 37.0° north of east with a speed of 6.00 m/s and Abigail is moving at 23.0° south of east with a speed of 9.00 m/s.
- (a) What is the speed of each person before the collision?
- (b) By how much did the total kinetic energy of the two people decrease during the collision?

Young and Freedman, *University Physics, 12/e* (8.40)

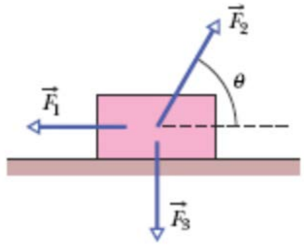


v=9m/s

8. The figure shows three forces applied to suitcase that moves leftward by 3.00 m over a frictionless floor. The force magnitudes are F_1 = 5.00 N, F_2 = 9.00 N, and F_3 = 3.00 N, and the indicated angle θ = 60.0°. During the displacement:

(a) What is the net work done on the case by the three forces?

(b) Does the kinetic energy of the case increase or decrease?



Jewett, *Fundamentals of Physics,* 8/e, Wiley (7.13)

9. A single force acts on a 3.0 kg particle-like object that has a position given by $x = at - bt^2 + ct^3$, where a = 3.0 m/s, b = 4.0m/s^2 and c = 1.0 m/s^3, with x in meters and t in seconds. Find the work done on the object by the force from t = 0 to t = 4.0 s.

Jewett, *Fundamentals of Physics,* 8/e, Wiley (7.37)

10. An 8.0 kg crate is pulled 5.0 m up a 30° incline by a rope angled 18° above the incline. The tension in the rope is 120 N, and the crate's coefficient of kinetic friction on the incline is 0.25.

(a) How much work is done by tension, by gravity and by the normal force?

(b) What is the increase in thermal energy of the crate and incline?

Knight, *Physics for Scientists and Engineers,* 8/e (11.51)

11. The loaded cab of an elevator has a mass of 3.0 × 10^3 kg and moves 210 m up the shaft in 23 s at constant speed. At what average rate does the force from the cable do work on the cab?

Jewett, *Fundamentals of Physics,* 8/e, Wiley (7.44)

12. The cable of the 1800 kg elevator Fig. 8-56 snaps when the cab is at rest at the first floor, where the cab bottom is a distance d = 3.7 m above a spring of spring constant k = 0.15 MN/m. A safety device clamps the cab against guide rails so that a constant frictional force of 4.4 kN opposes the cab's motion. (a) Find the speed of the cab just before it hits the spring. (b) Find the maximum distance x that the spring is compressed (the frictional force still acts during this compression). (c) Find the distance that the cab will bounce back up the shaft. (d) Using conservation of energy, find the approximate total distance that the cab will move before coming to rest. (Assume that the frictional force on the cab is negligible when the cab is stationary.)

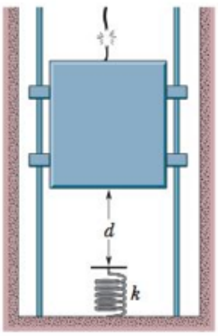


Figure 8-56 Problem 63.

J. Walker, *Fundamentals of Physics*, John Wiley, 10/e 2014

Past Exam questions

13.

(a) A sprinter with a mass of 60.0 kg leaves the blocks at the start of a race by pushing off with an average horizontal force of 700 N exerted over a 0.40 s interval of time. At what speed does the sprinter leave the blocks?

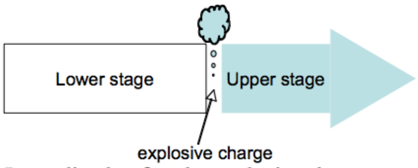
(b) The carbon isotope ^{14}C is used for carbon dating of archaeological artefacts. ^{14}C decays by a process known as beta decay in which the nucleus emits an electron (also known as a beta particle) and a subatomic particle called a neutrino. In one such decay, the electron and the neutrino are emitted at right angles to each other. The electron has a speed of 5.00 × 10^7 m/s and the neutrino has a momentum of 8.00 × 10^{-24} kg m/s.

What is the recoil speed of the resulting ^{14}N nucleus?

(Take the mass of the ^{14}C and ^{14}N nuclei to be 2.34 × 10^{-26} kg and the mass of the electron to be 9.11 × 10^{-31} kg. Ignore relativistic effects.)

14.

A **two-stage** rocket is travelling through space at a constant velocity of 1200 m/s, when a small explosive charge is used to separate the stages, as shown below.



Immediately after the explosion the upper stage of mass 1000 kg is found to be travelling at a velocity of 4500 m/s in the original direction.

a) Calculate the velocity of the lower section of mass 2000 kg.

b) How much additional energy is supplied by the explosion?

Short answers

1 (b) 2 (c)

3 System is club and ball; gravity forces much less than collision forces (hence can be ignored); momentum conservation only valid in very short time of actual collision.

4 (a) 517 N s; (b) 3.9 ms; (c) 1.3×10^5 N

5 (a) 9.0 N s; (b) 3.0×10^3 N; (c) 4.5×10^3 N; (d) 20 m s^{-1}

6 800 N 7(a) Sam: 9.97 m/s; Abigail: 2.26 m/s; (b) KE decreases by 639 J

8 (a) 15.0 J, –13.5 J, 0 J (b) KE increases by 1.5 J

9 Work done = 530 J

10 (a) 570 J, –196 J, 0 J (b) 38.5 J

11 2.7×10^5 W

12 (a) 7.4 m s^{-1} (b) 0.90 m (c) 2.8 m (d) 15 m

13 (a) 4.7 m s^{-1} (b) 1.98×10^3 m s^{-1}

14 (a) 450 m s^{-1} to the *left* (b) 8168 MJ

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J. Walker, *Fundamentals of Physics*, John Wiley, 8/e (2008) and 10/e 2014

H.D. Young and R.A. Freedman, *University Physics*, Pearson (Addison-Wesley), 12/e (2008)

Working Space

Working Space

Working Space

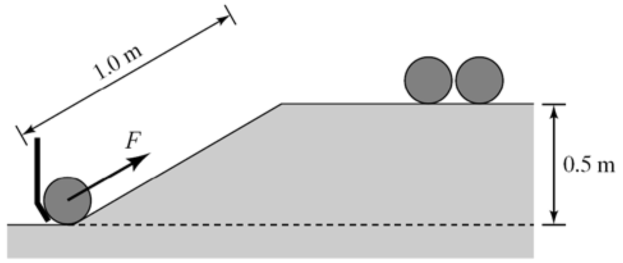
Physics 1 (PHYC10003)

Week 6: Energy Conservation and Rotational Motion

Discussion questions

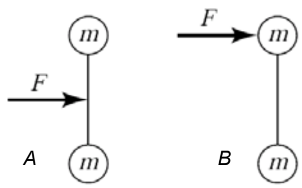
1. At the bowling alley, the ball-feeder mechanism must exert a force to push the bowling balls up a 1.0-m long ramp. The ramp leads the balls to a chute 0.5 m above the base of the ramp. *Approximately* how much force must be exerted on a 5.0-kg bowling ball?

(a) 200 N
(b) 50 N
(c) 25 N
(d) 5.0 N
(e) impossible to determine



Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall

2. A force F is applied to a dumbbell floating in a vacuum for a time interval Δt, first as in figure A and then as in figure B. In which case does the dumbbell acquire the greater centre-of-mass speed?



(a) A
(b) B
(c) no difference
(d) the answer depends on the rotational inertia of the dumbbell.

Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall

3. Consider the same situation as in Q2. In which case does the dumbbell acquire the greater energy?

(a) A
(b) B
(c) no difference
(d) the answer depends on the rotational inertia of the dumbbell.

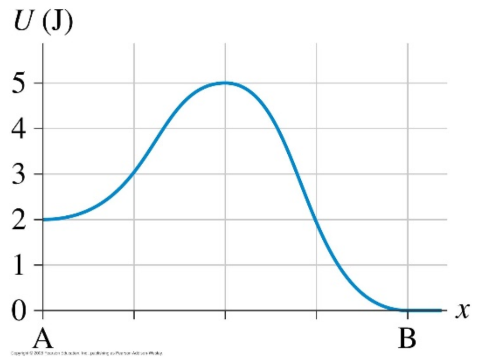
Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall

Calculation questions

4.

(a) In the figure below, what minimum speed does a 100 g particle need at point A to reach point B?

(b) What minimum speed does a 100 g particle need at point B to reach point A?



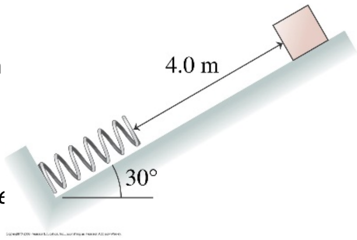
Knight, *Physics for Scientists and Engineers*, 8/e (10.32)

5

A 10 kg box slides 4.0 m down the frictionless ramp shown in the figure, then collides with a spring with spring constant 250 N/m.

(a) What is the maximum compression of the spring?

(b) At what compression of the spring does the box have its maximum speed?



Knight, *Physics for Scie*)

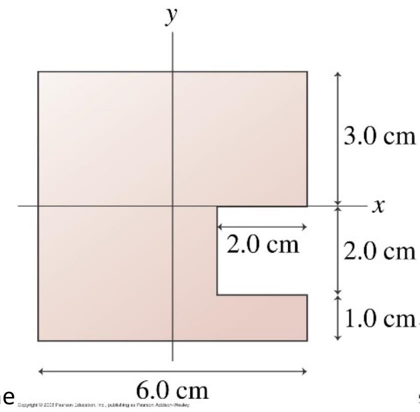
6

A thin 100 g disk with a diameter of 8.0 cm rotates about an axis through its centre with 0.15 J of kinetic energy. What is the speed of a point on the rim?

Knight, *Physics for Scientists and Engineers* (12.11)

7

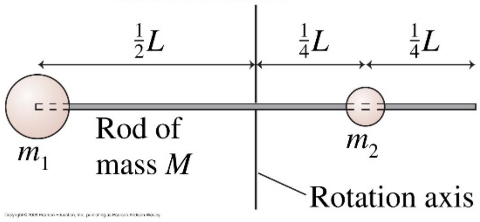
What are the *x*- and *y*-coordinates of the centre of mass for the uniform steel plate shown in the figure below?



cientists and Engineers (12.54)

8

Determine the moment of inertia about the below.



Knight, *Physics for Scientists and Engineers* (12.56)

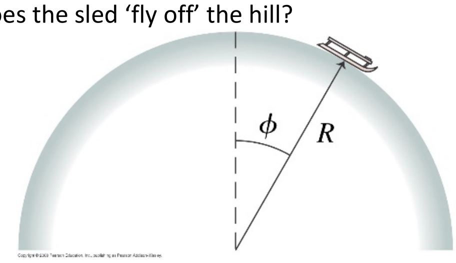
9

A sled starts from rest at the top of the frictionless, hemispherical, snow-covered hill shown in the figure.

(a) Find an expression for the sled's speed when it is at angle ϕ.

(b) Use Newton's laws to find the maximum speed the sled can have an angle ϕ without leaving the surface.

(c) At what angle ϕ_{max} does the sled 'fly off' the hill?

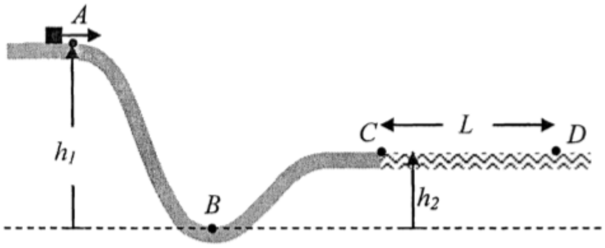


Knight, *Physics for Scientists and Engineers*, 8/e (10.76)

Examination questions

10

In the figure, a small block of mass 200 g passes point A with a speed of 7.0 m/s. It follows a frictionless path until it reaches the section between C and D of length $L = 12$ m, where the coefficient of kinetic friction is 0.70. The indicated heights are $h_1 = 6.0$ m and $h_2 = 2.0$ m.



What are the speeds of the block at:

(a) Point B?

(b) Point C?

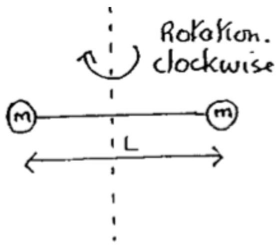
(c) Does the block reach point D?

(d) If your answer to part (iii) is yes, what is its speed at D and if your answer to part (iii) is no, how far through the rough section does it travel?

(e) How much energy is converted to thermal energy as the block travels through the rough section between C and D?

11

A body consisting of two small spheres, each of mass m, connected by a massless rigid rod, can rotate about an axis through the middle of the rod and perpendicular to it, as shown in the figure. The centres of the spheres are a distance L apart.



(i) Write an expression for the Rotational Inertia (Moment of Inertia) of the body about its axis of rotation.

The body is rotating in a clockwise direction, as viewed from above, with an angular velocity ω.

(ii) Sketch the figure, and show on it the vector representing ω.

In a particular case, m = 0.25 kg, L = 0.83 m and $\omega = 2.47$ rad s^{-1}.

(iii) (a) What is the magnitude of the central force on each ball?
(b) With what tangential speed are the balls moving?

In order to increase the rotational speed of the system, a constant tangential force of 9.6 N is applied to one of the balls for a period of 2.0 seconds.

(iv) (a) What is the magnitude of the torque this force provides?
(b) Sketch the figure above, and indicate on it the direction of the vector that represents this torque.

(v) What is the final angular velocity of the system?

Short solutions

1 C 2 C 3 B

4(a) 7.7 m/s (b) 10.0 m/s

5(a) 1.46 m (b) 19.6 cm

6 2.4 m/s

7 (–0.25 cm, 0.125 cm)

8 $L^2/4(M/3 + m_1 + m_2/4)$

9(a) $\sqrt{(2gR(1 - \cos\phi)}$ (b) $v_{max} = \sqrt{(gR\cos\phi)}$ (c) 48°

10(a) 13 m/s (b)11 m/s (c) No (d) 9.3 m (e)13 J

11(i) $mL^2/2$ (ii) vertically down the dashed line in the figure (iii)(a) 0.63 N (b) 1.0(2) m/s

11(iv)(a) 3.98(4) N m (b) vertically down the dashed line in the figure (v) 95 rad/s

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E. Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall, (1997)

R. Knight, *Physics for Scientists and Engineers - A Strategic Approach*, Pearson (Addison-Wesley), 2/e (2008)

J. Walker, *Fundamentals of Physics*, John Wiley, 8/e (2008)

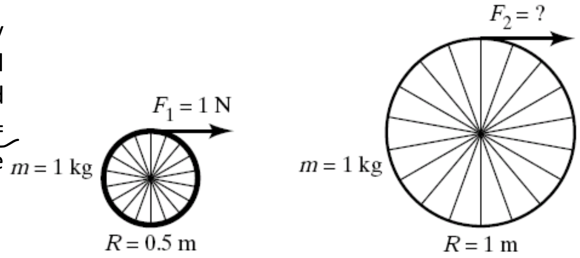
Working Space

Working Space

Physics 1 (PHYC10003)
Week 7: Energy and Rotational Motion

Discussion questions1. Two wheels have fixed hubs They each have a mass of 1 kg. They start to rotate from rest, and forces are applied as shown below. Assume the hubs and spokes are massless. The rotational inertia is given by $I = mR^2$. To impart the same angular accelerations, how large must F_2 be?

e



1kg

1×0.5^2

1kg

$1 \times 1^2 = 1 \times (2 \times 0.5)^2$

$= 4I.$

(a) 0.25 N
(b) 0.5 N
(c) 1 N
(d) 2 N
(e) 4 N

Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall

2. Two wheels initially at rest *roll* the same distance without slipping down identical inclined planes starting from rest. Wheel B has twice the radius but the same mass as wheel A. All the mass is concentrated in their rims, so that the rotational inertias are $I = mR^2$. Which has more translational kinetic energy when it gets to the bottom?

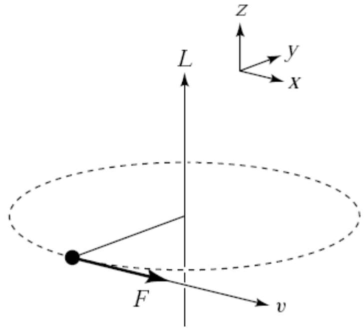
(a) Wheel A
(b) Wheel B
(c) The translational kinetic energies are the same.
(d) More information is needed.

Mazur, *Peer Instruction: A User's Manual*

3. A person spins a tennis ball on a string in a horizontal circle (so that the axis of rotation is vertical).At the point indicated below, the ball is given a sharp blow in the forward direction. This causes a change in angular momentum ΔL in the

(a) *x* direction
(b) *y* direction
(c) *z* direction

Mazur, *Peer Instruction: A User's Manual*



Problem solving questions

4. Evaluate the cross-products, $\vec{A} \times \vec{B}$ and $\vec{C} \times \vec{D}$

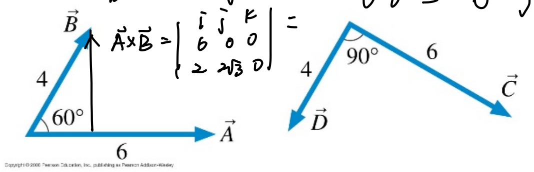
$\vec{A} = 6\hat{i}$

$\vec{B} = 2\hat{i} + 2\sqrt{3}\hat{j}$

$\vec{A} \times \vec{B} = \begin{vmatrix} i & j & k \\ 6 & 0 & 0 \\ 2 & 2\sqrt{3} & 0 \end{vmatrix} =$

$\begin{vmatrix} 0 & 0 \\ 2\sqrt{3} & 0 \end{vmatrix} i - \begin{vmatrix} 6 & 0 \\ 2 & 0 \end{vmatrix} j + \begin{vmatrix} 6 & 0 \\ 2 & 2\sqrt{3} \end{vmatrix} k$

$0\hat{i} - 0\hat{j} + 12\sqrt{3}k$



Knight, *Physics for Scientists and Engineers,* 8/e (12.39)

5. An object whose moment of inertia is 4.0 kg m^2 experiences the torque shown in the figure. What is the object's angular velocity at t = 3.0 s? Assume it starts from rest.

$\tau = I\alpha = I\frac{\omega}{t}$

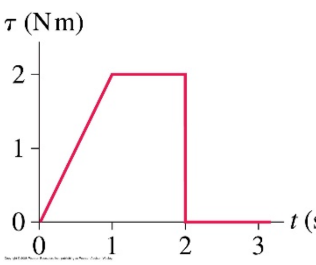
$d\tau = I\frac{d\omega}{dt}$

$\tau = I\alpha$

$\frac{\tau}{I} = \frac{d\omega}{dt}$

$\int \frac{\tau(t)dt}{I} = \int \frac{d\omega}{dt} dt$

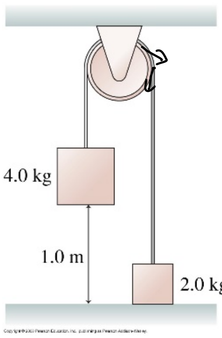
$\omega = \frac{1}{I}\int_0^3 \tau(t)\,dt$



Knight, *Physics for Scientists and Engineers,* 8/e (12.26)

$d = 12cm \quad r = 6cm$

6. The two blocks in the figure are connected by a massless rope that passes over a pulley. The pulley is 12 cm in diameter and has a mass of 2.0 kg. As the pulley turns, friction at the axle exerts a torque of magnitude 0.50 Nm. If the blocks are released from rest, how long does it take the 4.0 kg block to reach the floor?



$I = mr^2 = 2 \times (0.06)^2 \quad \cancel{0.0006} \quad \cancel{6\times10}$
$= 7.2 \times 10^{-4}$

$\tau = F \cdot r \qquad m = 2kg$

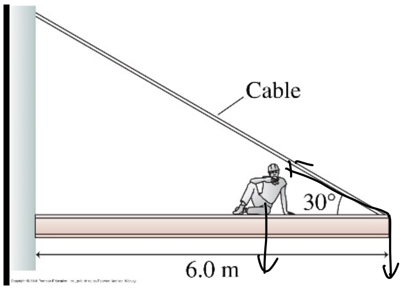
$\tau = I \cdot \alpha$

Knight, *Physics for Scientists and Engineers,* 8/e (12.70)

7. Force $\vec{F} = -10\hat{j}\ N$ is exerted on a particle at $\vec{r} = (5\hat{i} + 5\hat{j})\,\mathrm{m}$. What is the torque on the particle about the origin?

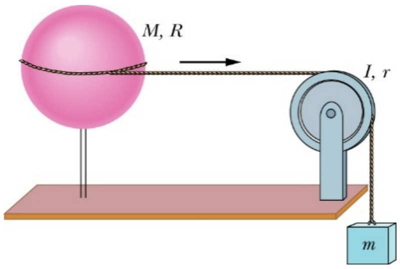
Knight, *Physics for Scientists and Engineers,* 8/e (12.44)

8. An 80 kg construction worker sits down 2.0 m from the end of a 1450 kg steel beam to eat his lunch. The cable supporting the beam is rated at 15,000 N. Should the worker be worried?



Knight, *Physics for Scientists and Engineers,* 8/e (12.63)

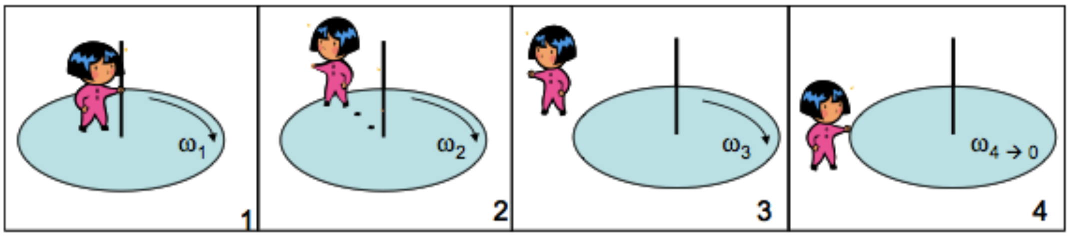
9. A uniform spherical shell of mass M = 4.5 kg and radius R = 8.5 cm can rotate about a vertical axis on frictionless bearings (see figure). A massless cord passes around the equator of the shell, over a pulley of rotational inertial $I = 3.0\times10^{-3}$ kg m^2 and radius r = 5.0 cm, and is attached to a small object of mass m = 0.60 kg. There is no friction on the pulley's axle; the cord does not slip on the pulley. What is the speed of the object when it has fallen 82 cm after being released from rest? Use energy considerations.



Jewett, *Fundamentals of Physics,* 8/e, Wiley (9.66)

Examination question

10. Jay is playing on a clockwise spinning platform of uniform thickness which is initially rotating at an angular velocity ω_1. Some time later, she decides that she wants to get off, and so moves to the edge of the platform which continues to rotate at an angular velocity ω_2. She then jumps off and some time later applies a force with her hand to the edge of the platform, bringing it to a complete relative stop. This is shown as a series of cartoons below.



(a) In what way will ω change as Jay moves from the middle to the edge of the platform in frame #2? Clearly outline the reasoning behind your answer.

The moment of inertia I of the platform, without Jay, is 100 kg m^2. Immediately after Jay jumps off, the platform continues to rotate at an angular velocity ω_3 = 1.5 rad/s (frame #3). Jay decides to stop the platform by applying a force tangential to the edge of the platform (as shown in frame #4). During this time, the angular velocity of the platform is given by

$$\omega_t = (\omega_3 - at^2)\ \text{rad/s}$$

where $a = 0.3\ \text{rad/s}^3$, ω_3 is as given above and t is in seconds.

(b) Consider the time period between when Jay first applies the force to the platform and when it comes to a complete stop.
   (i) How long does the platform take to stop?
   (ii) What is the angular acceleration of the platform at t = 1.0 s?
   (iii) Calculate the torque being applied by Jay to the platform at t = 1.0 s.

Short solutions

1 D (angular acceleration inversely proportional to *I and* torque*)*
2 C (conservation of energy equation is *mgh* = *mv*^{2} for both wheels)
3 C (right hand grip rule) 4(a) 21, out of page 4(b) 24, into page 5. 0.75 rads/s
6. 1.11 s 7. $-50\hat{\boldsymbol{k}}$ N m 8. Worker should be worried (tension is 15 300 N)
9 1.42 m s^{-1}
10 (a) angular speed will decrease, as *I* must increase and the total angular momentum must remain constant.
10 (b)(i) 2.2 s (ii) -0.6 rad/s^2 (iii) 60 Nm

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E. Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall, (1997)
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Working Space

Working Space

Working Space

Physics 1 (PHYC10003)

Week 8: Relativity

Discussion questions

1. When Einstein was a boy he wondered about the following question: A runner holds a mirror at arm's length in front of his face. Can he see himself in the mirror if he runs at (almost) the speed of light? Answer this question both according to the ether theory and according to Special Theory of Relativity.

Ohanian and Markert , Physics for Engineers and Scientists, 3/e

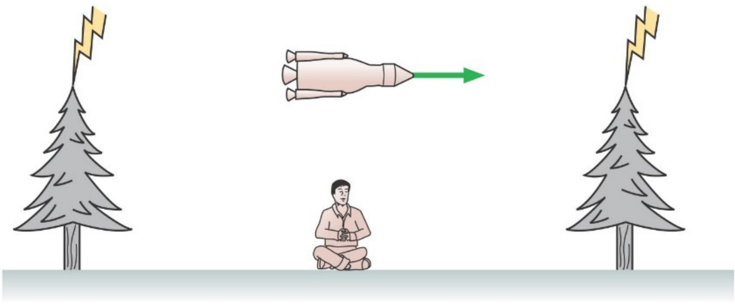
2. Firecracker A is 300 m from you. Firecracker B is 600 m from you in the same direction. You see both explode at the same time. Defining event 1 as "firecracker A explodes" and event 2 as "firecracker B explodes", does event 1 occur before, after or at the same time as event 2? Explain.

Knight, Physics for Scientists and Engineers 2/e

3. The figure shows a rocket travelling from left to right. At the instant it is halfway between two trees, lightning simultaneously (in the rockets reference frame) hits both trees.

   (a) Do the light flashes reach the rocket pilot simultaneously? If not, which reaches her first? Explain.

   (b) A student was sitting on the ground halfway between the trees as the rocket passed overhead. According to the student, were the lightning strikes simultaneous? If not, which tree was hit first? Explain.



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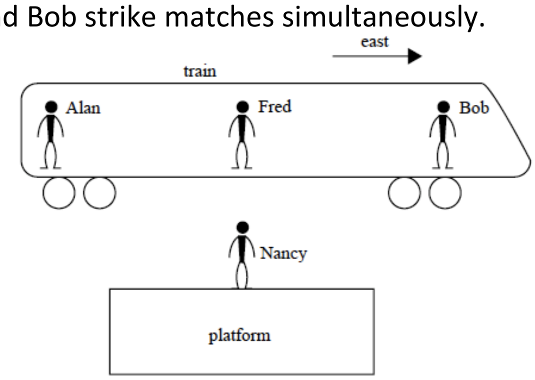
Knight, Physics for Scientists and Engineers 2/e

4. The diagram below shows Fred in a futuristic train travelling at a constant (relativistic) speed in an easterly direction in a straight line. Fred is halfway between two people, Alan and Bob, who are at opposite ends of the carriage. Nancy is standing on the platform. At the instant that Fred and Nancy are directly opposite each other, Fred sees both Allan and Bob strike matches simultaneously.



Describe how Nancy sees these two events.

VCAA 2008 examination (adapted)

Calculation questions

5. A newspaper delivery boy is riding his bicycle down the street at 5.0 m/s. He can throw a paper at a speed of 8.0 m/s. What is the paper's speed relative to the ground if he throws the paper (a) forward, (b) backward, and (c) to the side?

Knight, Physics for Scientists and Engineers 2/e (P37.5)

6. You are standing at x = 9.0 km. Lightning bolt 1 strikes at x = 0 km and lightning bolt 2 strikes at x = 12.0 km. Both flashes reach your eye at the same time. Your assistant is standing at x = 3.0 km. Does your assistant see the flashes at the same time? If not which does she see first and what is the time difference between the two?

Knight, Physics for Scientists and Engineers 2/e (P37.12)

7. You are flying a rocketship at 0.9c from star A toward star B. The distance between the stars is 1.0 ly. Both stars happen to explode simultaneously in your reference frame at the instant you are exactly halfway between them (which probably spoiled your trip!). Do you see the flashes simultaneously? If not, which do you see first and what is the time difference between them?

Knight, Physics for Scientists and Engineers 2/e (P37.15)

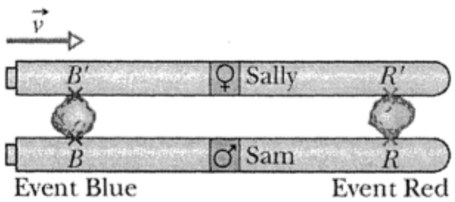
8. A 30 m long rocket train car is travelling from Los Angeles to New York at 0.5*c* when a light at the centre of the car flashes. When the light reaches the front of the car, it immediately lights a red lamp. Light reaching the back of the car immediately lights a green lamp.
   (a) Are lighting of the red and green lamps simultaneous events for a passenger seated in the car? If not, which occurs first?
   (b) Is the lighting of the two lamps simultaneous events for a cyclist waiting to cross the tracks? If not which occurs first?

Knight, Physics for Scientists and Engineers 2/e (P37.48), adapted

Past examination questions

9. Helen and George are twins living on Planet X. At age 20, Helen boards a spaceship and travels at 0.9*c* to Planet Y which is 3 light years distant (a light year is the distance that light travels in one year). George remains (at rest) on Planet X. Assume the planets are at rest in the same inertial reference frame.
   (a) With respect to the time taken for the trip, in which reference frame, George's or Helen's, is proper time measured? Briefly explain.
   (b) With respect to the distance travelled from Planet X to Planet Y, in which reference frame, George's or Helen's, is proper length measured? Briefly explain.
   (c) In George's reference frame calculate how long Helen took to reach Planet Y.

10. Sally and Sam are travelling on two spaceships. Both observers are standing at the midpoints of their spaceships. The two spaceships are travelling with a relative velocity difference of $\vec{v}$.
    The diagram below shows the instant of time when two large meteorites strike the two spaceships, one setting off a red flare, event Red, and the other a blue flare, event Blue. Each event leaves a permanent mark on each spaceship.



The light from event Red and event Blue reaches Sam at the same time. Sam later finds, from measurement of the marks on his spaceship, that he was standing exactly halfway between the locations of the events Red and Blue. Sam asserts that the two events were simultaneous while Sally observes a time difference between the two events.

(*The original question asked students to write a 'short essay' on of aspects of this)*

From which event does light reach Sally first? Give reasons why.

Short answers

1 Yes, according to Special Relativity 2 Event 1 occurs after event 2

3(a) Yes, simultaneous 3(b) No, left tree hit first

4 Nancy will 'see' the light from Alan arrive first

5(a) 13 m/s 5(b) 3 m/s 5(c) 9.4 m/s

6 assistant sees flash 2 a time of 40 μs after flash

7 light arrives simultaneously

8(a) simultaneous @ (–15 m, 0.050 μs) 8(b) green before red; time interval = 0.058 μs

9(a) Helen's 9(b) George's 9(c) 3.33 y

10 Light from event Red.

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Working Space

Working Space

Working Space

Physics 1 (PHYC10003)

Week 9: Relativity II

Discussion questions

1. Sam leaves Venus in a spaceship heading to Mars and passes Sally who is on Earth, with a relative speed of 0.5c.

(a) Each measures the Venus-Mars voyage time. Who measures a proper time: Sally, Sam or neither?

(b) On the way, Sam sends a pulse of light to Mars. Each measures the travel time of the pulse. Who measures a proper time?

Halliday, Resnick and Walker, *Fundamentals of Physics,* 7/e

2. Event A occurs at spacetime coordinates (300 m, 2 μs).

(a) Event B occurs at spacetime coordinates (1200 m, 6 μs). Could event A possibly be the cause of event B? Explain.

(b) Event C occurs at spacetime coordinates (2400 m, 8 μs). Could event A possibly be the cause of event C? Explain.

Knight, *Physics for Scientists and Engineers*

Problem-solving questions

3. A 100 m long train is heading for an 80 m long tunnel. If the train moves sufficiently fast, is it possible according to experimenters on the ground, for the entire train to be inside the tunnel at one instant of time? Explain.

Knight, Physics for Scientists and Engineers 2/e

4. Particle A has half the mass and twice the speed of particle B. Is the momentum p_A less than, greater than, or equal to p_B?

Knight, Physics for Scientists and Engineers 2/e

5. At what speed is the kinetic energy of a particle twice its Newtonian value?

Knight, *Physics for Scientists and Engineers,* 2/e

6. What is the speed of an electron whose total energy equals the rest mass of a proton?

Knight, *Physics for Scientists and Engineers,* 2/e

7. At what speed, as a fraction of *c*, does a moving clock tick at half the rate of an identical clock at rest?

$$\gamma = 2 = \frac{1}{\sqrt{1-\frac{u^2}{c^2}}}$$

Knight, Physics for Scientists and Engineers 2/e

8. The half-life of a muon at rest is 1.5 μs. Muons that have been accelerated to high speed are then held in a circular storage ring have a half-life in the laboratory reference frame of 7.5 μs.

(a) What is the speed of the muons in the storage ring?

(b) What is the total energy of a muon in the storage ring?

The mass of a muon is 207 times the mass of an electron. (m_e = 9.1 × 10-31 kg)

Knight, Physics for Scientists and Engineers 2/e

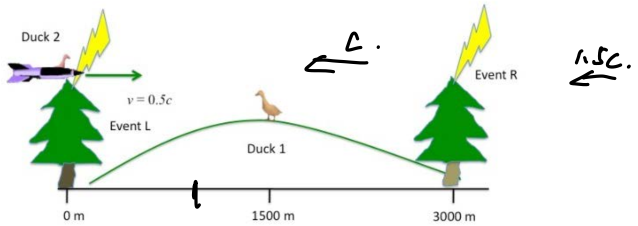
Mini-challenge questions

9. Duck 2 flies past in a rocket at v = 0.5*c* in the direction shown. In Duck 1's reference frame the two lightning bolts hit the trees simultaneously at t = 0. The left tree is struck just as Duck 2 passes by it. Duck 2 is at the origin of her reference frame and t'= 0 in Duck 2's frame just as she passes the left tree.

(a) In Duck 1's reference frame what are the space-time coordinates of Duck 2 when light from event L reaches Duck 2? (0, 0)

(b) In Duck 1's reference frame what are the spacetime coordinates of Duck 2 when light from event R reaches Duck 2? (1000,

(c) In Duck 2's reference frame, what are the spacetime coordinates for the events described in parts (a) and (b)? (c)(a) (0,0) (b). (0,



10. Two starships are each 1000 m long in their rest frame. Starship Orion, travelling at 0.8*c* relative to the earth, is overtaking starship Discovery, which is moving along at only 0.6*c*. According to the crew of the Discovery, how long does Orion take to completely pass? (How long is it from the instant the front of the Orion is at the back of the Discovery until the back of the Orion is at the front of the Discovery?)

Past Examination question

11. (a) Explain what is meant by the terms "relativity of simultaneity", "proper time" and "proper length" used in Special Relativity.

(b) An alien ship travels through the solar system at speed $v = 0.6c$ (as observed by scientists on Earth). The scientists track the ship as it travels from the Sun to the planet Venus. In their time frame, the sun and planets are approximately stationary, and the Sun-Venus distance is 150,000,000 km.

(i) Calculate the time it takes the ship to travel from the Sun to Venus as measured by an observer on Earth. Calculate the time it takes the ship to travel from the Sun to Venus as measured by an observer onboard the ship.

(ii) Calculate the Sun-Venus distance as measured by an alien observer on the ship.

(c) Draw a rough sketch graph of the linear momentum p of a particle as a function of speed v from the view point of Special Relativity. On the same set of axes, draw a rough graph of p against v from the view point of classical Newtonian mechanics.

Short Answers

1(a) Sam **1(b)** Neither of them
2(a) Yes: 225 m/μs (<*c*) **2(b)** No, 350 m/μs (<*c*)
3. Yes, contracted **4.** $p_A > p_B$ **5.** 0.786*c*
6. 0.99999985*c* **7.** 0.866*c*
8(a) 0.98*c* **8(b)** 8.5×10^{-11} J
9(a) $(x, t) = (0, 0)$ **9(b)** (x, t) = (1000 m, 6.7 μs)
9(c) event L = (0, 0); event R = (0, 5.8 μs) **10.** 17 microseconds
11(a) definition from lectures notes or text **11(b)(i)** 833 s and 667 s
11(b)(ii) 1.2×10^{11} m **11(c)** Classical momentum ($p = mv$) has a linear $p - v$ graph; relativistic momentum ($p = \gamma mv$) has an asymptotic graph (same shape as γ - v graph). See Fig 37- 13.

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Knight, *Physics for Scientists and Engineers*, Addison-Wesley2/e

Working Space

Working Space

Physics 1 (PHYC10003)

Week 10: Gravitation and Oscillations

Discussion questions

1. The gravitational force of a star on orbiting planet 1 is F_1. Planet 2, which is twice as massive as planet 1 and orbits at twice the distance from the star, experiences gravitational force F_2. What is the ratio F_1/F_2?

   Knight, *Physics for Scientists and Engineers,* 2/e

2. The mass of Jupiter is 300 times the mass of Earth. Jupiter orbits the sun with $T_{Jupiter}$ = 11.9 yr in an orbit with $r_{Jupiter\ orbit} = 5.2 r_{Earth\ orbit}$. Suppose Earth could be moved to the distance of Jupiter and placed in a circular orbit around the sun. Which of the following describes Earth's new period?
   i. 1 yr
   ii. Between 1yr and 11.9 yr.
   iii. 11.9 yr.
   iv. More than 11.9 yr.
   v. It would depend on Earth's speed.
   vi. It is impossible for a planet of Earth's mass to orbit at the distance of Jupiter.

   Knight, *Physics for Scientists and Engineers,* 2/e

3. The following oscillators are taken to the moon. Which would have a different period than that on Earth?
   i. A simple pendulum,
   ii. A physical pendulum (e.g. a metal bar with a hole drill through it at one end, hanging on a pin that allows the bar to swing freely.)
   iii. A mass hanging on the end of a spring.

4. A pendulum on Planet X, where g is unknown, oscillates with a period T = 2s. What is the period of this pendulum if:
   i. its mass is doubled? Note you do not know the values of m, L, or g so do not assume any specific values. Analyse based on ratios.
   ii. Its length is doubled?
   iii. Its oscillation amplitude is doubled?

   Knight, *Physics for Scientists and Engineers,* 2/e (C14.2)

Calculation questions

5. Calculate the magnitude of the gravitational force of attraction exerted on the moon by the Sun and the magnitude of the gravitational force of attraction exerted on the moon by the Earth. When the moon is directly between the Earth and the Sun what is the direction of the net force on the moon? Why doesn't the moon escape from its orbit around the Earth?

6. A surveillance satellite is in a circular orbit 500 km above the surface of the Earth. Calculate its orbital speed and period.

7. Suppose that on Earth you can jump straight up a distance of 50 cm. Can you escape from a 4.0 km diameter asteroid which has a mass of 1.0×10^{14} kg?

   Knight, *Physics for Scientists and Engineers,* 2/e (P13.39)

8. A 4000 kg lunar lander is in orbit 50 km above the surface of the moon. It needs to move out to a 300 km high orbit in order to link up with the mother ship. How much work must the thrusters do?

   (Knight, *Physics for Scientists and Engineers,* 2/e

9. An air-track glider attached to a spring oscillates with a period of 1.5 s. At t = 0 s the glider is 5.00 cm left of the equilibrium position and moving to the right at 36.3 cm.s^{-1}.
   i. What is the phase constant?
   ii. What is the phase at t = 0 s, 0.5 s, 1.0 s and 1.5 s?

   Knight, *Physics for Scientists and Engineers,* 2/e

10. A 200 g block hangs from a spring with k =10 N/m. At t = 0 s the block is 20 cm below the equilibrium position and moving upward with a speed of 100 cm.s^{-1}. Calculate the block's:
   i. frequency of oscillation
   ii. distance from equilibrium when the speed is 50 cm s^{-1}

iii. position at t = 1.0 s? Knight, *Physics for Scientists and Engineers*, 2/e

DATA

G = 6.67 x 10^{-11} N m^2 kg^{-2}.

Body	Mean radius of orbit (m)	Period (y)	Mass(kg)	Mean Radius (m)
Sun	-	-	1.99×10^{30}	6.96×10^{8}
Moon	3.84×10^{8}	27.3 days	7.36×10^{22}	1.74×10^{6}
Earth	1.50×10^{11}	1.00	5.98×10^{24}	6.37×10^{6}

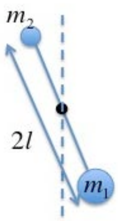
Mini-challenge questions

11. **T**wo Jupiter-sized planets are released from rest 1.0 × 10^{11} m apart. What are their speeds when they crash? (Use: $M_{Jupiter} = 1.9 \times 10^{27}\text{kg}, R_{Jupiter} = 1.4 \times 10^{8}\text{m}$)

Knight, *Physics for Scientists and Engineers,* 2/e

12. A physical pendulum consists of a massless rod of length 2*l* rotating about an axis through its centre. A mass m_1 is attached at the lower end of the rod and a smaller mass m_2 at the upper end. Find an expression for the angular frequency of this pendulum? (You may treat the masses as point masses.)

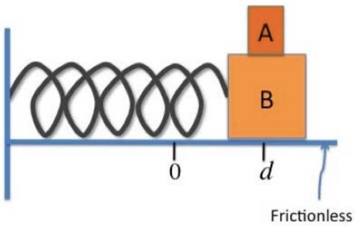
After Ohanian and Markert, *Physics for Engineers and Scientists,* 3/e



Examination questions

13. (b) If the Moon has a rotational period (rotation about its own axis) of 27.3 days, how high above the surface of the Moon would a satellite have to be placed for it to be in a geostationary orbit; that is, an orbit that stays over the same spot on the Moon's surface?
(c) Calculate the gravitational potential energy of the Earth-Moon system.

14. A small block A sits on a large block with a non-zero friction coefficient between them. Block B which rests on a frictionless surface is initially at x = 0, with the spring relaxed. It is pulled a distance d to the right and released. As the system undergoes SHM with amplitude d, block A is on the verge of slipping.



i. Is the acceleration of block A constant or varying? Explain.
ii. Is the magnitude of the frictional force between block A and block B varying? Explain.
iii. Is block A more likely to slip when block B is at x = 0 or at x = d? Explain.
iv. If the SHM began with an initial displacement greater than d, would slippage be more or less likely to occur? Explain.

Short solutions

1 2 **2** about 11.9 years **3** (i) and (ii)
4(i) no change **(ii)** period increases by ×√2 **(iii)** no change (provided amplitude small)
5 F (from Sun) = 4.34 × 10^{20} N; F (from Earth) = 2.0 × 10^{20} N; Sun does not give Moon enough KE to escape
6 7620 m s^{-1} and 5660 s
7 Escape speed from asteroid = 2.58 m s^{-1}; jump speed = 3.13 m s^{-1} ; escape possible
8 6.72 × 10^{8} J **9(a)** –120° **(b)** –120°, 0°, 120° and 240° (or in radians)
10(i) 1.125 Hz **(ii)** 23 cm **(iii)** 4.1 cm below equilibrium point
11 2.1 × 10^{4} m s^{-1}
12 $\omega = \sqrt{\frac{(m_1 - m_2)g}{(m_1 + m_2)l}}$ **13 (b)** 8.8 × 10^{7} m **(c)** 7.6 x 10^{28} J
14(i) varying **(ii)** varying **(iii)** $x = d$ **(iv)** more likely

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Working Space

Working Space

Physics 1 (PHYC10003)
Week 11: Traveling Waves

Discussion questions

1. The following four waves are sent along strings with the same linear densities. Rank the waves according to (i) their wave speed and (ii) the tension in the strings along which they travel greatest first: (*x* is in metres, *y* is in millimetres, *t* is in seconds):

   (a)

   (b)

   (c)

   (d)

2. Strings A and B have identical lengths and linear densities, but string B is under greater tension. If both strings are vibrating at their fundamental resonant frequencies, are they vibrating at the same frequency and if not, which has the greater frequency?

3. When an orchestra warms up, the players' warm breath increases the temperature of the air within the wind instrument, increasing the speed of sound. Do the resonant frequencies of the wind instrument increase, decrease or remain the same due to this change in temperature? Explain.

4. According to the equation we derived for the speed of a transverse wave on a string, if we increase the tension by a factor of 4 the wave speed increases by a factor of 2. However, in the case of a rubber string increasing the tension by a factor of 4 will result in the wave speed increasing by more than a factor of 2. Why might rubber strings be different?

   After Ohanian and Markert , *Physics for Engineers and Scientists,* 3/e (Q16.4)

5. In music, two notes that differ in pitch by one octave are a factor of 2 different in frequency. By what factor must the tension in a guitar string or violin string be increased to raise its pitch by one octave? Is there an easier way to achieve this change in pitch? Explain briefly.

6. In most wind instruments the pitch is changed by using valves or keys to alter the length of the air column. The bugle is a wind instrument that does not have valves or keys and yet a range of different notes can be played on this instrument. Briefly explain how this can be achieved and why notes of only certain pitches (frequencies) are possible.

Calculation questions

7. The equation of a transverse wave on a string is given by $y = 5\sin[30x - 900t]$ where *y* is in millimetres, *x* is in metres and *t* is in seconds. For this wave find the:

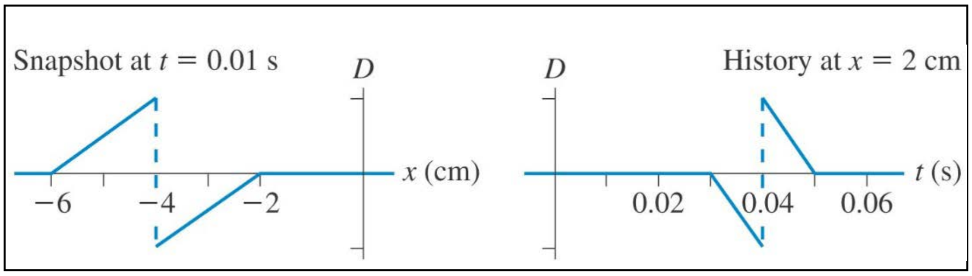
   (a) amplitude (b) angular frequency

   (c) wavelength (d) wave speed

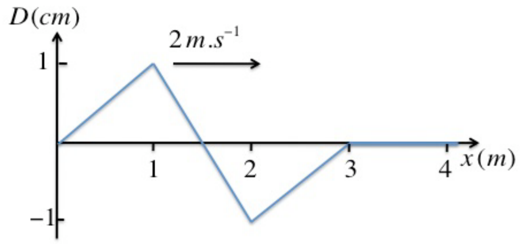
   (e) tension in the string if the mass per unit length of the string is 50 g m^{-1} .

8. The figure below shows a snapshot graph and a history graph for a wave pulse on a stretched string. They describe the same wave.

   (a) In which direction is the wave travelling? (b) What is the speed of this wave?



9. The accompanying figure shows a snapshot of a wave pulse at time t = 0. The wave pulse is travelling in the positive x-direction at 2 m.s^{-1}. Sketch a *history* graph (displacement versus time) for the position x = 4 m.



10. Pipe A has length *L* and one end open. Pipe B has length *2L* and two open ends. Which harmonics (for $n \leq 3$) of pipe B have a frequency that matches a resonant frequency of pipe A? Explain using diagrams.

11. Two separated loud speakers are emitting the same note and are in phase. A person stands 6 m from one speaker and 7 m from the other. What is the lowest frequency for destructive interference to occur at this point? (Speed of sound = 343 m s^{-1})

12. Two transverse waves traveling on the same string have displacements given by:

$$D_1 = 0.01\sin[3x - 600t]$$
$$D_2 = 0.01\sin[3x + 600t]$$

with amplitude and wavelength in metres, time in seconds.

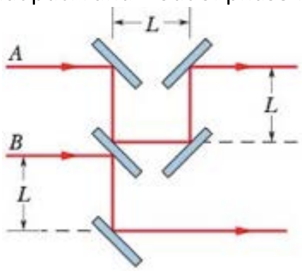
(a) Use the trigonometric identity given below to find an expression for the wave that results from the superposition of these two waves.

$$\sin\alpha + \sin\beta = 2\sin\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha-\beta)$$

(b) Explain what features of the equation for the superposition of these waves indicate that the superposition is not a traveling wave.

(c) Find the node spacing for the resultant wave.

13. In the diagram below, sound waves *A* & *B* have the same wavelength λ. They are in phase & travelling to the right, as shown. Wave *A* is reflected from four surfaces but ends up travelling in its original direction. Wave *B* ends in that direction after reflecting from two surfaces. The distance *L* in the diagram can be expressed as a multiple of λ by the equation $L = q\,\lambda$. Find the (a) smallest and (b) next smallest values of *q* that put *A* and *B* out of phase with each other after the reflections.



Past Examination question

14. (a) A transverse wave travelling along a stretched string is described by the function:

$$y = 0.020\sin(0.25x - 9.0t)$$

Where the displacements *x* and *y* are measured in metres and the time *t* is measured in seconds.

(i) Is the wave travelling in the positive x-direction or the negative x-direction?
(ii) Find a value for the amplitude of the wave.
(iii) Find a value for the frequency of the wave.
(iv) Find a value for the wavelength of the wave.
(v) Find a value for the wavespeed.
(vi) If the mass per unit length of the string is 20.0 g m^{-1}, calculate the tension in the string.

Short solutions

1 a d b c (follows from $v = \omega/k$); tensions will have the same rankings.

2 Not at the same frequency; B has the greater frequency

3 Wavelengths the same, fixed by length of instrument air columns; f increases

4 Speed in 'string' = $v = \sqrt{\frac{T}{\mu}}$; as T increases, μ also decreases.

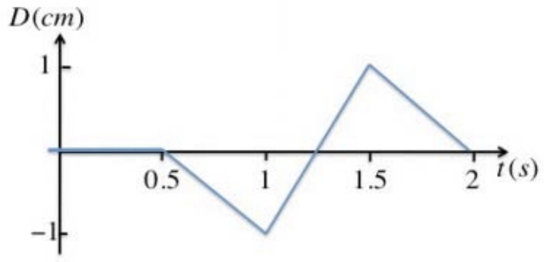
5 ×4 (from $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$); shorten string using your finger or a 'capo'

6 Use the harmonics. These are integral multiples of the fundamental (tubes open at both ends); odd-numbered multiples where tube open at on end only. The harmonics can be encouraged to 'sound' in a bugle by the lips 'buzzing' the desired harmonic at the mouthpiece.

7 5 mm, 900 rads/s, 20.9 cm (from $\lambda = 2\pi/k$), 30 m s^{-1} ($v = \omega/k$), T = 45 N

8 **(a)** Right **(b)** 2m/s

9



10 Fundamentals are the same ($\lambda = 4L$), also $n = 3$ ($\lambda = 4L/3$)

11 172 Hz

12 (a) D=0.02sin3$x \times$ cos 600t (b) argument ($kx - \omega t$) is missing (c) $\pi/3$

13 $q = 0.5$ and $q = 1.5$

14 positive, 0.020 m; 1.4 Hz, 25 m, 36 m s^{-1}, 25.9 N

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Working Space

Working Space

Working Space

Physics 1 (PHYC10003)

Week 12: Waves II and Physical Optics

Discussion questions

1. By how many dB does sound level intensity change when the sound intensity changes by:
(a) ×2 (b) ×4 (c) ×10 (d) ×10 000 (e) ×0.5 (f) $\times 10^{-5}$?

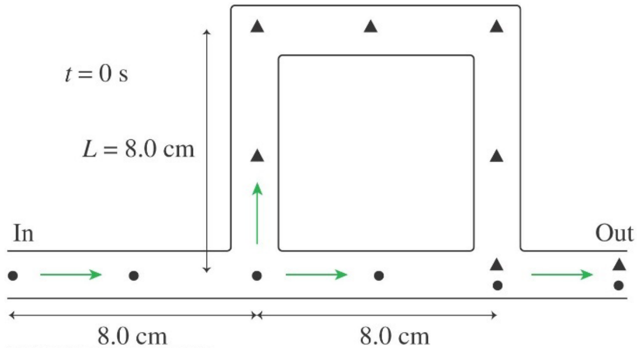
2. The sixth harmonic is set up in a pipe containing air.
Does the pipe have one or two open ends?
Is the midpoint of the pipe a pressure node, antinode, or some intermediate state?
If the air is replaced by carbon dioxide, what happens to the wavelength and frequency of the sixth harmonic?
DATA: speed of sound in air = 343 m/s; speed of sound in carbon dioxide = 267 m/s

Walker, *Fundamentals of Physics Extended*, 10/e

3. When two mechanical waves (for example, water waves) interfere destructively at one place, what happens to their energy?

Ohanian and Markert , *Physics for Engineers and Scientists,* 3/e

4. The figure shows a tube through which sound waves with λ = 4.0 cm travel from left to right. The wave divides at the first junction and recombines at the second. The dots and triangles show the positions of the wave crests at t = 0 s.
(a) How much extra distance does the upper wave travel?
(b) How many wavelengths is this extra distance?
(c) Do the recombined waves interfere constructively or destructively?



Knight, *Physics for Scientists and Engineers* 2/e

5. (a) Green light shines through a 100 mm diameter hole and strikes a screen. If the hole diameter is increased by 20% does the diameter of the circular spot of light on the screen increase, decrease or stay the same?

(b) Green light shines through a 100 μm diameter hole and strikes a screen. If the hole diameter is increased by 20% does the diameter of the circular spot of light on the screen increase, decrease or stay the same?

Knight, *Physics for Scientists and Engineers* 2/e (C22.8)

6. Narrow bright fringes are observed on a screen behind a diffraction grating. The entire experiment is then immersed (safely) in water. Do the fringes on the screen get closer together, farther apart, remain the same, or disappear?

Knight, *Physics for Scientists and Engineers* 2/e

7. In a single slit diffraction experiment with waves of wavelength λ there will be no dark fringes (intensity minima) if the slit width is small enough. What is the maximum slit width for which this occurs? Explain.

Young and Freedman, *University Physics*, 12/e

Calculation questions

8. A tuning fork of unknown frequency makes three beats per second when sounded together with a standard fork of frequency 384 Hz. The beat frequency *decreases* when a small piece of wax is put on a prong of the first fork. What was the frequency of this tuning fork before the wax was added?

9. If the intensity of a sound wave is changed from 10^{-12} W m^{-2} to10^{-8} W m^{-2} what is the change in sound intensity level?

10. Two submarines are near each other in motionless water. Submarine A is stationary. Submarine B is moving directly towards submarine A at 20 m/s. Submarine A sends out a sonar signal (a sound wave in water) at 1000 Hz. Take the speed of sound in water as 1520 m/s. Find:

(a) the sonar signal's frequency, as detected by submarine B.

(b) the frequency of the signal reflected by submarine B, as detected by submarine A.

11. A man in a fast-moving train hears a bell sounding at a level crossing as the train approaches. As the train recedes from the crossing, he hears the same bell continue to ring but with a frequency one octave lower (octave frequency ratio = 2:1). What is the speed of the train, assuming that the speed of sound in air is 330 m s^{-1}?

12. A double slit is illuminated simultaneously with orange light of wavelength 600 nm and light of an unknown wavelength. The m = 4 bright fringe of the unknown wavelength overlaps with the m = 3 bright fringe of the orange light. What is the unknown wavelength?

Knight, *Physics for Scientists and Engineers* 2/e (P22.3)

13. In a two-slit interference experiment, green light of wavelength 546 nm is used. On a screen 2.0 m away, what is the distance between the central maximum and the first minimum if the slit separation is 0.20 mm?

14. Two antennae transmit radio waves of the same frequency (10 MHz) and in phase. If the two antennae are 15 m apart what is the angular position of the first interference minimum? (Take zero along the perpendicular bisector of the line joining the antennae.)

15. The opening to a cave is a tall, 30 cm wide crack. A bat that is preparing to leave the cave emits a 30 kHz ultrasonic chirp. How wide (in metres) is the "sound beam" 100 m outside the cave opening? Use v_{sound} = 340 m/s.

Knight, *Physics for Scientists and Engineers* 2/e (P22.21)

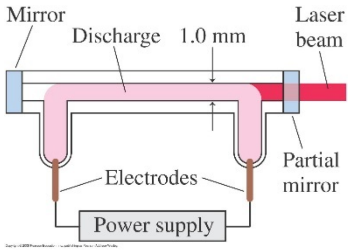
16. Light emitted by element X passes through a diffraction grating that has 1200 lines/mm. The diffraction pattern is observed on a screen 75.0 cm behind the grating. Bright fringes are seen on the screen at distances of 56.2, 65.9 and 93.5 cm from the central maximum. No other fringes are seen.

(a) What is the value of m for each of these diffracted wavelengths? Why is only one value possible?

(b) What are the wavelengths of light emitted by element X?

Knight, *Physics for Scientists and Engineers* 2/e (P22.40)

17. A helium-neon laser (wavelength = 633 nm) is built with a glass tube of inside diameter 1.0 mm, as shown in the figure. One mirror is partially transmitting to allow laser light out. An electrical discharge in the tube causes it to glow like a neon light. From an optical perspective, the laser beam is a light wave that diffracts through a 1.0 mm diameter circular opening.



(a) Can a laser beam be perfectly parallel, with no spreading? Why or why not?
(b) The angle θ_1 to the first minimum is called the divergence angle of a laser beam. What is the divergence angle of this laser beam?
(c) What is the diameter (in mm) of the laser beam after it travels 3.0 m?
(d) What is the diameter of the laser beam after it travels 1.0 km?

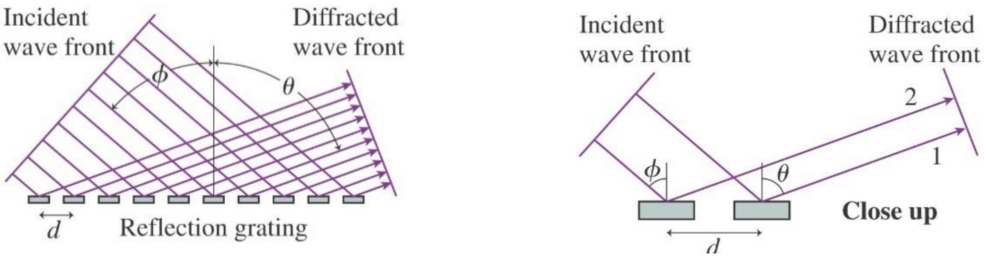
Knight, *Physics for Scientists and Engineers* 2/e

Mini-challenge question

18. The figure shows light of wavelength λ incident at angle ϕ on a reflection grating of spacing *d*. We want to find the angles θ_m at which constructive interference occurs.

(a) Find an expression for the path-length difference for paths 1 and 2 shown in the figure.
(b) Find an equation for the angles θ_m at which constructive interference occurs when the light is incident at angle ϕ (*m* will be a negative integer if path 2 is shorter than path 1).
(c) Show that the zeroth-order diffraction is simply a reflection.

Knight, *Physics for Scientists and Engineers* 2/e (P22.74)



Past exam question

19.

(b) In the centre of the shadow of a disk or sphere there is a small bright spot, called the Poisson spot, as shown in the figure below. Briefly explain how this bright spot arises.

(c) Two sources of light illuminate a double slit simultaneously. One has wavelength 580 nm and the second has an unknown wavelength. The $m = 5$ bright fringe of the unknown wavelength overlaps the $m = 4$ bright fringe of the light of 580 nm wavelength.

(i) Find the unknown wavelength.

(ii) For the 580 nm light, if the $m = 4$ bright fringes are 0.5 cm from the central maximum on a screen that is 2.0 m from the slits, what is the slit spacing?

Short solutions

1 (answers to one or two significant figures)
(a) +3 dB (b) +6 dB (c) +10 dB (d) +40 dB (e) -3dB (f) -50dB

2 (a) two open ends (b) pressure node
(c) wavelength the same, frequency lower (factor of 0.78)

3 In the constructive interference regions (E conserved only globally), or transferred into other energy like kinetic energy of the wave medium

4 (a) 16 cm (b) 4 (c) constructively

5 (a) increases (b) decreases

6 closer together

7 width = λ

8 387 Hz

9 +40 dB

10 **(a)** 1013 Hz **(b)** 1026 Hz

11 110 m/s

12 450 nm

13 2.7 mm

14 90°

15 7.6 m

16 all are m = 1; 500 nm, 550 nm, 650 nm /

17 (a) no (diffraction) (b) 0.044° (c) 4.6 mm (d) ~1.5 m

18 (a) $\Delta r = \Delta r_1 - \Delta r_2 = d(sin\theta - sin\phi)$ (b) $dsin\theta_m = m\lambda + dsin\phi$, m = ...-2, -1, 0, 1, 2,...
(c) At m = 0, $\theta = \phi$

19 (b) This is the *Poisson (or Fresnel) spot*; see text p1081/2 (c) 464 nm and 0.93 mm

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H.C. Ohanian & J.T. Markert, *Physics for Scientists and Engineers,* Norton and Co., N.Y.
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Young and Freedman, *University Physics*, 12/e

Working Space

Working Space

Physics 1 (PHYC10003)

Week 13: Ray Optics

Discussion questions

1. Suppose you have two pinhole cameras. The first has a small round hole in the front. The second is identical except that it has a square hole of the same area as the round hole in the first camera. Would the pictures taken by these two cameras, under the same conditions, be different in any obvious way? Explain.

   Knight, *Physics for Scientists and Engineers* 2/e

2. At sunset, the image of the Sun remains visible for some time after the actual position of the Sun has gone below the horizon. Explain.

   After Ohanian and Markert , *Physics for Engineers and Scientists,* 3/e

3. When you look at your reflection in the bowl of a spoon, it is sometimes upside down. Why? Is it always upside down? What happens if you turn the spoon over?

   Adapted from Knight, *Physics for Scientists and Engineers* 2/e

4. On a sunny afternoon, with the sun overhead, you can stand under a tree and look on the ground at the pattern of light that has passed through gaps between the leaves. You may see illuminated circles of varying brightness. Why are there circles when the gaps between the leaves have irregular shapes? What would these circles look like during a partial eclipse of the sun?

   Adapted from Knight, *College Physics*

5. A concave mirror brings the Sun's rays to a focus at a distance of 30 cm from the mirror. If the mirror were submerged in a swimming pool, would the Sun's rays (assume when the Sun is directly overhead) be focused nearer to, further from, or at the same distance from the mirror? What would happen if you replaced the mirror by a converging lens with the same focal length?

   Adapted from Knight, *College Physics*

6. Suppose that you want to install a mirror in your house that will show a full length image of someone 200 cm tall. What is the minimum length of such a mirror?

Calculation questions

7. The distance from your eyes to your toes is 165 cm. You are standing 200 cm in front of a tall mirror. How far is it from your eyes to the image of your toes?

   Knight, *Physics for Scientists and Engineers* 2/e

8. A laser beam in air is incident on a liquid at an angle of 37° with respect to the normal. The angle of the beam in the liquid is 26° with respect to the normal. What is the liquid's index of refraction?

   Knight, *Physics for Scientists and Engineers* 2/e

9. An object is 30 cm in front of a converging lens with a focal length of 10 cm. Use ray tracing (or algebraic methods) to find the location of the image. Is it upright or inverted?

   Knight, *Physics for Scientists and Engineers* 2/e

10. An air bubble inside an 8.0 cm diameter plastic ball is 2.0 cm from the surface. As you look at the ball with the bubble turned toward you, how far beneath the surface does the bubble appear to be?

    Knight, *Physics for Scientists and Engineers* 2/e

11. A converging lens has a focal length of 1 m. An object is 0.5 m from the lens. Use ray tracing to find the position of the image. Is the image real or virtual? What is the transverse magnification?

12. A 1.0 cm tall object is 20 cm in front of a concave mirror that has a 60 cm focal length. Calculate the position and height of the image. State whether the image is in front of or behind the mirror and whether the image is upright or inverted.

Knight, *Physics for Scientists and Engineers* 2/e

13. (a) Estimate the diameter of your eyeball.
    (b) Bring this page up to the closest distance at which the letters of the text are still sharp. This distance is called the near point of your eye (possibly corrected using glasses or contact lenses). Measure this distance.
    (c) Estimate the effective focal length of your eye. This includes the focussing due to the cornea, the lens and any corrective optics you wear. Ignore the effect of the fluid in your eye.

Knight, *Physics for Scientists and Engineers* 2/e

14. Show that images in thin concave (diverging) lenses and convex (diverging) mirrors are always upright and have a transverse magnification less than or equal to 1.

Mini-challenge question

15. A coin lies at the bottom of wishing well, filled with a liquid of refractive index = 1.45. The coin appears to be 1.0 m below the surface. What is the depth of the well (viewed from vertically above)?

16. A spherical mirror has a radius R. Show that, for small angles, the focal length $f = R/2$.

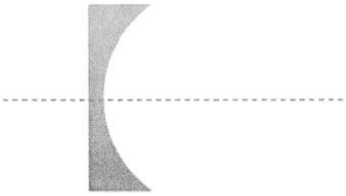
17. A luminous object and its real image from a converging lens of focal length f are separated by a fixed distance D.
    (a) Show that if $u \neq v$, where u is the distance of the object from the lens, and v is the distance of the image from the lens, there are only two possible positions for the location of the lens.
    (b) Show that the distance between the two possible values of u is given by $\sqrt{D(D - 4f)}$

Adapted from Halliday, Resnick and Walker, *Fundamentals of Physics* 6/e

Past exam question

18.

(a) If the spherical mirror shown in the figure below was cut in half horizontally and the top half of the mirror removed will the bottom half of the mirror still form an image, and if so, where? Explain briefly.



(b) Consider a point on an object near a lens.

(i) What is the minimum number of rays required to construct a diagram that locates its image point? Explain briefly with the aid of a diagram.

(ii) How many rays from this point actually strike the lens and refract to the image point?

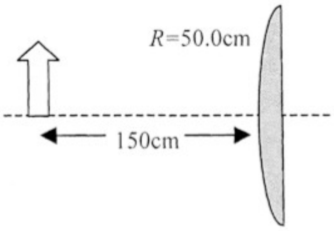
(d) An object is located 150 cm from a thin planoconvex glass ($n = 1.50$) lens of diameter 20.0 mm where the spherical surface has a radius of curvature of $R = 50.0$ cm, ,as shown in the figure below.

You can assume the thin lens approximation for this question.

(i) Calculate the focal length f of the lens.

(ii) Calculate the distance from the lens at which the image is formed.

(iii) Calculate the transverse magnification of this image.



Short solutions

1 shape of hole will not affect the image provided the hole is small (only lets 'one' ray through).

2 light from the Sun refracts as it passes through the atmosphere, forming an image of the Sun above the horizon.

3 if you view the spoon from outside its focal point (likely, as most spoons have a short *f*), there will be a real inverted image formed. If you view it from close up (inside *f*) you will see a magnified upright virtual image. When you turn it over, it becomes a convex (diverging) mirror, which *always* forms a virtual upright diminished image.

4 the circles are images of the Sun, formed by the 'pinhole cameras' of the gaps between the leaves. During a partial eclipse, the circles change to tiny 'eclipse' shapes.

5 same distance (still works as a mirror); a lens, however will form an image further from the lens (provided the *n* of the lens material is greater than the *n* of water).

6 100 cm (see http://dev.physicslab.org/Document.aspx?doctype=3&filename=GeometricOptics_PlaneMirrors.xml)

7 433 cm **8** 1.37 **9** Inverted, 15 cm on the other side of the lens **10** 1.54 cm

11 virtual, upright, magnified ×2, 1.0 m from lens (same side as object)

12 30 cm from mirror, opposite side from object, virtual, upright

13a assuming a value of ~ 4.0 cm (typical); **b** near point is about 25 cm (less if 'young'); **c** 3.4 cm.

14 use lens formula with positive values of *u* and negative values of *f*; make *v* the subject.

15 69 cm **18a** image still formed; same place **b** two; lots and lots **c** (i) 1.0 m (ii) 300 cm (iii) –2

-

Bibliography

H.C. Ohanian and J.T. Markert, *Physics for Scientists and Engineers,* Norton and Co., N.Y.
R. Knight, *Physics for Scientists and Engineers -- A Strategic Approach*, Pearson 2/e
Walker, Halliday & Resnick *Fundamentals of Physics*, John Wiley, N.Y., 10/e & 6/e Young and Freedman, *University Physics*, 12/e

Working Space

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Working Space

Appendix A
Uncertainties

Introduction – What Is Uncertainty?

DEFINITIONS

These will help you understand some words commonly used in everyday language that have a different meaning in the scientific lab.

Data - (or 'results') a series of measurements taken during an experiment. Each measurement should be stated with its uncertainty.

Uncertainty - (terms also used are **errors** and **confidence limits**) the amount of *accuracy* you can state your measurement due to the precision of the equipment you are using. The uncertainty is usually stated as a 'plus or minus' value e.g. ±0.1

Resolution - (or accuracy or precision) the smallest measurement you can make with a device determined by the scale used. For example, a ruler with mm gradings has better resolution than one with only cm gradings.

Error Analysis - working out the uncertainties of all data measurements and subsequent calculations to determine the accuracy of your final result.

Mistake - (or 'human error') is usually due to incorrect use of equipment, faulty equipment, incorrect analysis or assumptions. These are to be avoided and corrected rather than included in your final error analysis.

Systematic Errors - occur with every measurement due to a consistent mistake or error in the experimental setup, procedure or analysis. These are particularly hard to spot as they skew all the data, not just one measurement. Reaction time with a stop watch is an example.

Results - the final calculation of all your data determined by mathematical and/or graphical analysis using the physics theories. This MUST also include an uncertainty to demonstrate how accurate the result is and how well it compares with the theory.

The following pages will explain the processes for working out the uncertainties of your measurements and how to present your final results. Please read carefully, complete the practice problems before your first prac.

Error Analysis is our set of tools for dealing with experimental uncertainties. The aim is not to eliminate uncertainties – unfortunately, that's usually impossible. But by figuring out how best to estimate our uncertainties, we will produce practical and useful real-world results.

A Golden Rule

Ultimately, your analysis of uncertainties is based on your own estimates and judgment. The methods outlined below are guidelines, **not** absolute laws; every experimental situation will be unique. The key is always to think carefully about what you are doing, to ensure that your analysis is as reasonable and as sensible as possible.

Uncertainty in Measurements

The most basic uncertainties are those due to measurements. Whenever you measure a physical quantity, that measurement has an uncertainty. This is true even if we assume that the equipment is perfectly accurate and correct.

There are different sources of uncertainty detailed below. Sometimes only one sort of uncertainty will be relevant or significant; in other situations, there may be multiple sources of uncertainty to deal with. (If you are unsure which uncertainty is more relevant, you should probably choose the largest one.) Recognising which uncertainties are appropriate in which situations can be confusing at first. When in doubt, talk to your demonstrator.

If a **quantity** is labelled 'x', then its **uncertainty** is labelled 'Δx'.

So when we state a **measurement**, we write '$x \pm \Delta x$'. E.g. 3.4 ± 0.1 mm

NOTE: In the context of experimental results and uncertainties, Δ always means 'the uncertainty in', (not 'change in').

Δx is called the **absolute uncertainty** of x.

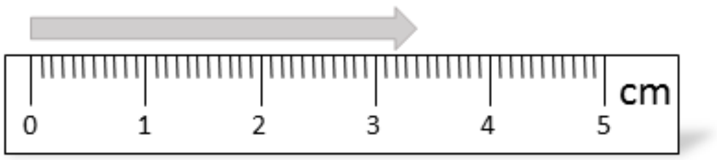
$\frac{\Delta x}{x}$ is the **proportional uncertainty** of x.

$\frac{\Delta x}{x} \times 100$ is the **percentage uncertainty** of x.

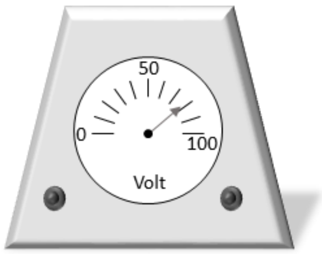
Determine the proportional AND percentage uncertainty of 3.4 ± 0.1 mm

Taking a Measurement: The 'Reading Error'

When reading a measurement from a device you will have a **reading error** due to the **resolution** of the measurement scale on the device. This may be the marks on a ruler, needle on a dial or display on a digital readout.



This 'reading error' uncertainty is generally estimated to be plus-or-minus half the smallest division of measurement. So, a ruler which is marked in millimetres can only be used to measure distances to the nearest millimetre. For example, using the ruler above we might measure arrow to be 34.0 mm long. We should state this result as 34.0 ± 0.5 mm. The uncertainty is 0.5 mm due to the reading error: if the result had been more than 34.5, then it would be read as 35, and if less than 33.5, then it would be read as 33 mm. Therefore, the appropriate range is 34.0 ± 0.5 mm.



State the two measurements to the left and their uncertainties. (Don't forget the units.)

Taking Several Measurements: Uncertainty from Averages

Sometimes we are measuring something which we know is stable and easily controlled (like the length of a piece of string). These sorts of measurements may only need to be made once, and so the reading error is the uncertainty.

However, much of the time the measurements of the quantity can vary, giving you a slightly different answer every time. The variability of this measurement forms the basis of the uncertainty in this case. By finding the **average** of many repeat measurements and the variation of these measurements we can determine the final result and its uncertainty.

Note that the more trials or repeat measurements you take the average will become more accurate and you will reduce the likelihood of mistakes. But the range of measurements are also likely to increase. If you are taking a large number of measurements (more than 12) you should use the **standard deviation** to determine the uncertainty.

HOW TO DETERMINE THE UNCERTAINTY OF AN AVERAGE (Up to 12 data points).

The final result is the **average of all measurements.**

The uncertainty is **half of the range.**

For example (reading error of the initial measurements is 0.1 mm):

Measurements:	153.2 ± 0.1; 153.6 ± 0.1; 152.8 ± 0.1; 153.0 ± 0.1 mm
Average:	(153.2 + 153.6 + 152.8 + 153.0) / 4 = 153.2 mm
Range:	153.6 – 152.8 = 0.8 mm
Uncertainty:	half range = 0.8 / 2 = 0.4 mm
Final Result:	153.2 ± 0.4 mm

*Half range uncertainty (±0.4) is larger than the Reading error (±0.1), therefore use the half range uncertainty in your final result. If the reading error was larger, you would use ±0.1. When in doubt, use the *largest* uncertainty.*

STANDARD DEVIATION

If there are lots of measurements, then the half-range error becomes less accurate. So we use the **standard deviation** to determine the spread of the data.

Standard deviation: $\sigma = \sum_{i=1}^{n} \frac{x_i - x_{av}}{n}$, where n is the number of data points and x_i is each data point.

If it is appropriate to use these techniques, they will be detailed in the laboratory exercise notes.

Find the half range uncertainty and the standard deviation for the set of data below;
23.5 ± 0.2, 25.2 ± 0.2, 24.8 ± 0.2, 23.9 ± 0.2, 26.0 ± 0.2, 22.7 ± 0.2

Minimising Errors

Uncertainty Analysis (see above) deals with the statistical uncertainties due to experimental measurement. However, basic statistical uncertainty analysis assumes that the actual measurements are still 'correct'. In real life, this is not always the case – equipment can be faulty, procedure can be incorrect, assumptions can be false, etc. It is important to understand the ways in which experimental errors can occur, and to learn to recognise and minimise them.

You will encounter mistakes and systematic errors during your experiments. It is important to look out for these, understand how they came about and show how you fixed them. Use the strategies below to help you do this.

How To Minimise Error

There are various general methods by which you can minimise the error and uncertainty associated with a measurement. The most important thing is simply to **think** about what you are doing. Don't just blindly follow directions! You should critically assess your experimental method as you go along. Does what you are doing make sense? If not, why not?

TRIAL RUNS

Whenever possible, you should do a brief trial run with your equipment before you take your 'actual' measurements. This will allow you to familiarise yourself with the equipment, and it provides an opportunity to discover potential sources of error sooner. If problems do occur, you will save time by altering your procedure before (instead of during) the actual experiment.

If you make a mistake (or you suspect that you might have), you should repeat your measurements to check your results. If you are unsure that you are using your equipment correctly, re-read the directions in the manual; if you are still unsure, talk to your demonstrator.

Don't try to cover up your mistakes! Discuss them in your logbook and detail what was changed to solve the problem. You will not lose marks for catching a mistake and fixing it, but you will lose marks if you try to cover it up or ignore it.

EQUIPMENT ASSESSMENT

You need to decide whether the equipment to be used is accurate enough for the task at hand. Can you (or should you) calibrate it? Should alternative equipment be used instead?

CAREFUL USE OF EQUIPMENT

For example:

- Meters with needle indicators should be tapped lightly, to check that the indicator is not sticking
- Check that the 'zero' settings on instruments are actually registering as 'zero'
- Arrange apparatus so that it cannot be easily knocked or bumped
- Connect electrical circuits and all electronic components securely

CONSISTENT PROCEDURE

Follow standard procedures carefully. When you change procedure or devise your own techniques, write out your new method in point form and follow it closely. If you are consistent and methodical in your approach, you will minimise the variability that comes from haphazard equipment use.

CHECKS AND CROSS-CHECKS

You shouldn't just record data: you need to think about what the results mean, and check that your answers make sense. Consider the following:

- Can you check your results while you are taking them, to see if they are consistent?
- Can you and your partner both take readings, and check each other's work as you go?
- Can you draw a graph as your results come in, to see if they are making sense?
- Can you already guess, roughly, what the results should be? Are they doing what you expect?

ANALYSIS

Think about how you are analysing your data to ensure you are using the correct mathematics and physics.

- Only round off numbers at the end of a calculation.
- Make sure your assumptions are correct or appropriate for the experimental conditions.
- Make sure the theory you use is applicable for the experimental conditions.

PRESENTING THE FINAL RESULT

When presenting the final result of your experiment, you should consider the uncertainty of the final result too. In later years you will determine the uncertainty of your final result mathematically and take into account all measurements.

In first year, we would like you to estimate the uncertainty of your results due to the **largest** measurement uncertainty. You can do this by determining the largest %uncertainty of your measurements and using the same percentage for your results.

If you took measurements of 25.3 ± 0.5 mm (or 2% uncertainty) and 38 ± 2 V (or 5% uncertainty) the second measurement is likely to impact on your overall results the most.

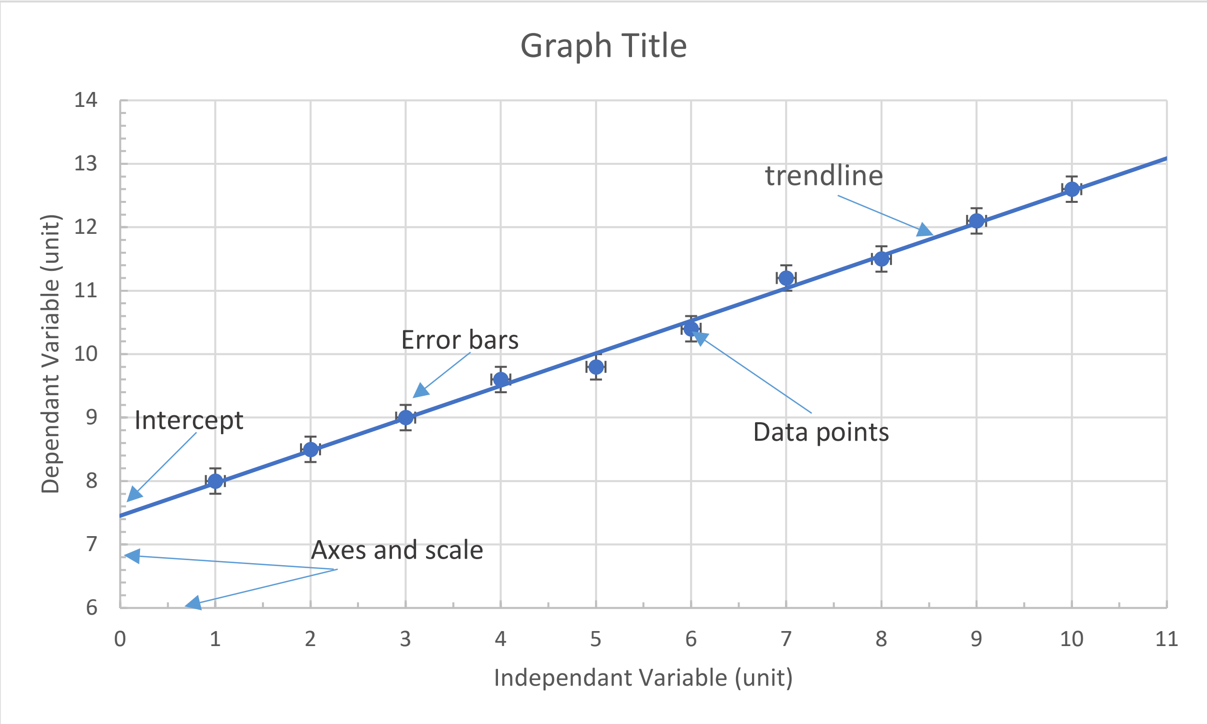
Your final result was 1502 V/m with a 5% uncertainty or 1502 ± 75 V/m.

NOW you can discuss the validity of your result by comparing to the expected value.

Appendix B
Graphs and How to Use Them

Graphs are a great way to represent and analyse data. Trends and relationships between variables become clear when the data are graphed in a meaningful way. It is important to learn both how to create useful graphs and how to extract information from them.

Plotting Graphs — Key Points and Elements



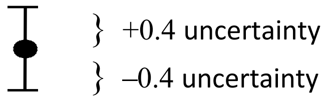
- **Labels** – always label both *axes* and the *graph* itself. Be sure to include UNITS eg: Length (m), Time (x 10^2) (s).
- **Axes** – each graph will have a vertical and horizontal axis
    - **independent** variable - this is the quantity that you control, and that you have chosen the initial values of – e.g. the force that you apply to an object. *Horizontal axis*
    - **dependent** variable - this is the quantity which varies due to the independent variable – e.g. the acceleration that results from the force you apply. Usually, the dependent variable is the thing that we are investigating. *Vertical Axis*
    - **scale -** use a scale that displays your data in the best way. The range should spread the data evenly across the graph which may mean that you will need to exclude the zero point of an axis.
- **Data** - Plot data points clearly, **include error bars** (see below) to display the uncertainty values of each point.
- **Trendline** – a line of best fit through the data points (see below)
    - **Intercept** – point on axis (horizontal and/or vertical) where trendline crosses.

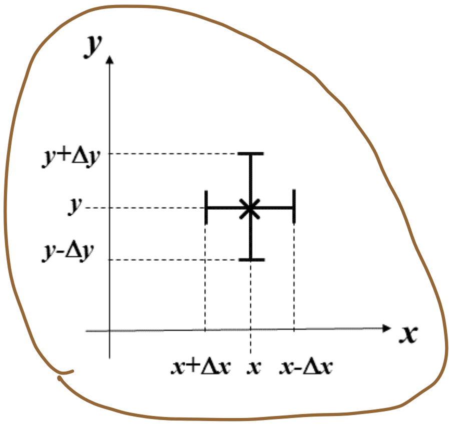
Error Bars — Graphing Uncertainties

You must always show the uncertainty values of your results on graphs. Uncertainties are displayed on graphs using **error bars**, which show the 'plus-or-minus' values on either side of a data point.

For example: a distance measurement 'x' equal to 153.2 ± 0.4 mm can be displayed below:

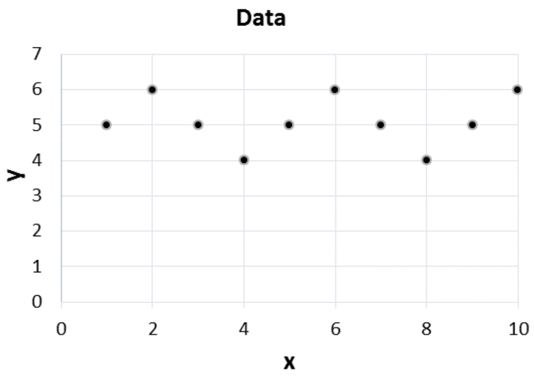
$$x + \Delta x = 153.2 + 0.4 = \quad 153.6$$
$$x = \quad 153.2$$
$$x - \Delta x = 153.2 - 0.4 = \quad 152.8$$



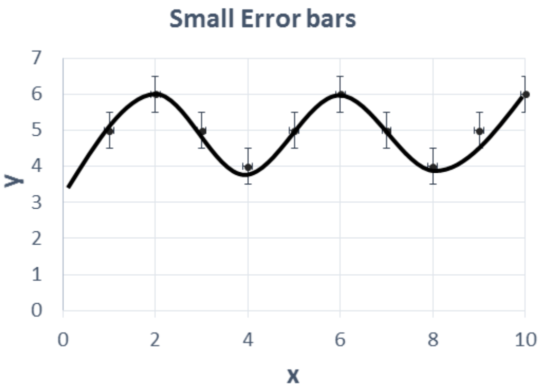


Data points will often have errors due to both the independent and dependant variables, so we should include both **horizontal** and **vertical** error bars. In this way, the error bars will mark out a region of uncertainty in which we expect the 'actual' data point (x,y) to be.

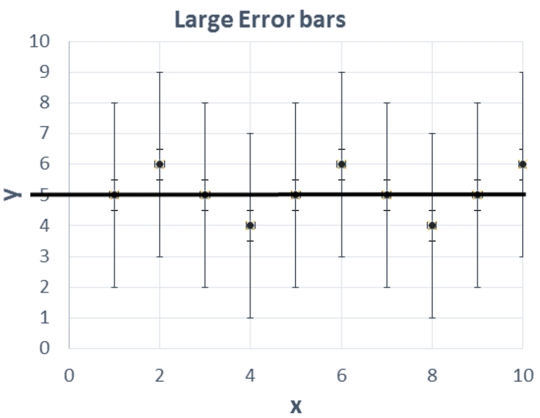
We need error bars to be able to see the true relationships between data. For instance, without error bars we might obtain a graph like this:



It appears as if these points could be joined together to fit a sine wave. However, this may not actually be the case. If the uncertainties for x and y are both small (e.g. ~5%), then the error bars look something like this:



As you can see, a sinusoidal curve fits within these error bars quite well, and so it is reasonable to conclude that this relation is probably a sine wave. However, if the uncertainties are larger (e.g. ~50%), then the error bars look something like this:



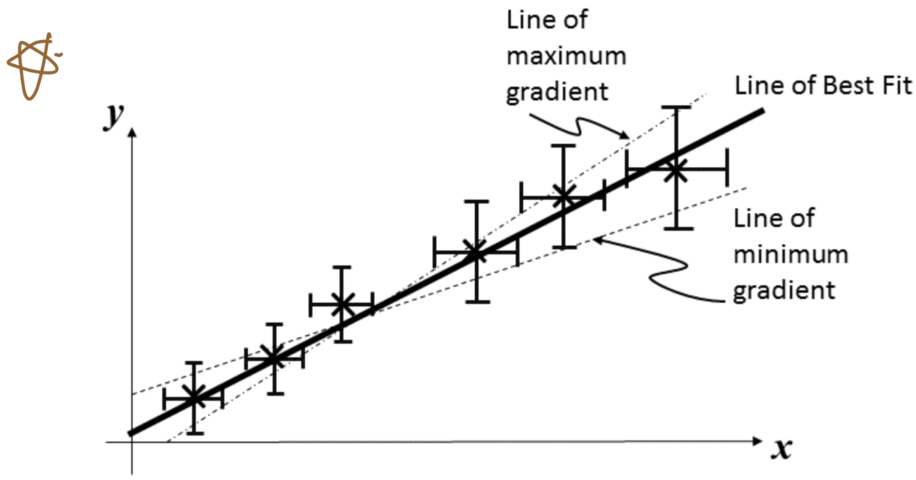
In this case, a straight line would fit the data just as well as a curve. It may be a sine wave relation, but the uncertainties are too large for us to be sure.

Straight Lines

In experimental work, we often want to look for a **linear relationship** between two physical quantities. If a graph of $\boldsymbol{x}$ versus $\boldsymbol{y}$ produces a straight line, then we may conclude that the relationship between $\boldsymbol{x}$ and $\boldsymbol{y}$ is **linear**. This means that the quantities are related by a linear equation (i.e. an equation of the form $\boldsymbol{y} = m\boldsymbol{x} + c$).

Unfortunately, data points will rarely form a perfectly straight line on a graph. In these cases, we need to find the **line of best fit**.

The following graph represents a typical example:



- Draw a line of best fit with a ruler that passes inside all (or most) of the error bars.
- Determine the gradient and y-intercept of your line and present as $\boldsymbol{y}=m\boldsymbol{x}+c$
- Draw two more lines that represent the minimum and maximum gradients (m_{min} and m_{max}) the data can have, again passing through most if not all the error bars. Find their gradients.
- The uncertainty of the gradient can be determined by the difference of the min and max gradients. i.e. $\text{gradient} = m \pm \Delta\left(\frac{m_{max}-m_{min}}{2}\right)$

Examine your data carefully: there may be one or two points which are obviously very different to the others. If you believe that these differences are mistakes or due to some experimental error, then you may decide to ignore them when constructing your line of best fit. (Also be sure to investigate how and why this happened and include a comment!)

Converting Curves to Straight Lines

A graph will often look more like a *curve* than a straight line. Unfortunately, it is difficult to sketch a reliable curve from scattered data points, and it is even more difficult to extract an obvious mathematical relation from a curve. However, if we already have a theoretical relation for our data, we can sometimes use this to convert our curve graph into a straight-line graph. A straight-line graph can be used to extract a linear relationship between the data (see **Straight Lines**, above).

By converting to a linear graph, we make it much easier to analyse the theoretical relationship between the data. It also makes it easier to extract the information corresponding to the gradient 'm' and the axis intercept 'c'.

Linear relationships are also simpler to extrapolate beyond the measured data. It is easy to see how a straight line will continue across the graph; extrapolating a curve is more difficult.

Converting to a Straight Line — Example

The period $\boldsymbol{T}$ of circular motion of an object of mass $\boldsymbol{M}$ depends on the centripetal force $\boldsymbol{F}$ causing the circular motion, and the radius $\boldsymbol{r}$ of the motion, given by the following equation:

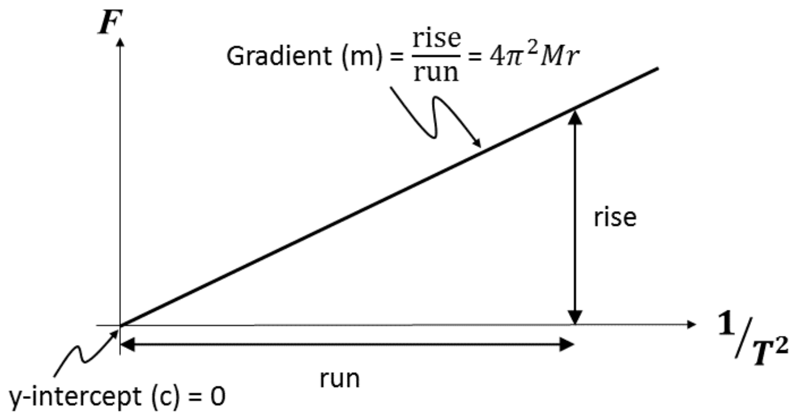
$$F = \frac{4\pi^2 Mr}{T^2}$$

When $\boldsymbol{F}$ versus $\boldsymbol{T}$ is graphed, we will expect to see a curve corresponding to the above equation.

We can turn this curve into a straight line by rewriting the above equation into a **linear form**.

$$\begin{aligned} F &= \frac{4\pi^2 Mr}{T^2} \\ F &= \left(4\pi^2 Mr\right)\left(\frac{1}{T^2}\right) + 0 \\ y &= \quad (m) \qquad (x) \quad + c \end{aligned}$$

The equation is now in a linear form (i.e. $\boldsymbol{y} = m\boldsymbol{x} + c$). By graphing $\boldsymbol{F}$ versus $(1/\boldsymbol{T}^2)$ instead of $\boldsymbol{F}$ versus $\boldsymbol{T}$, we should create a linear graph instead of a curve graph. Instead of looking for a curve to check that the data matches the equation, we can instead look for a straight line.



$\boldsymbol{F}$ corresponds to $\boldsymbol{y}$	:	vertical axis
$\frac{1}{T^2}$ corresponds to $\boldsymbol{x}$	:	horizontal axis
$4\pi^2 Mr$ corresponds to m	:	gradient
$\boldsymbol{F}$ axis intercept corresponds to c	:	in this case, zero

Using Excel for Equations and Graphs

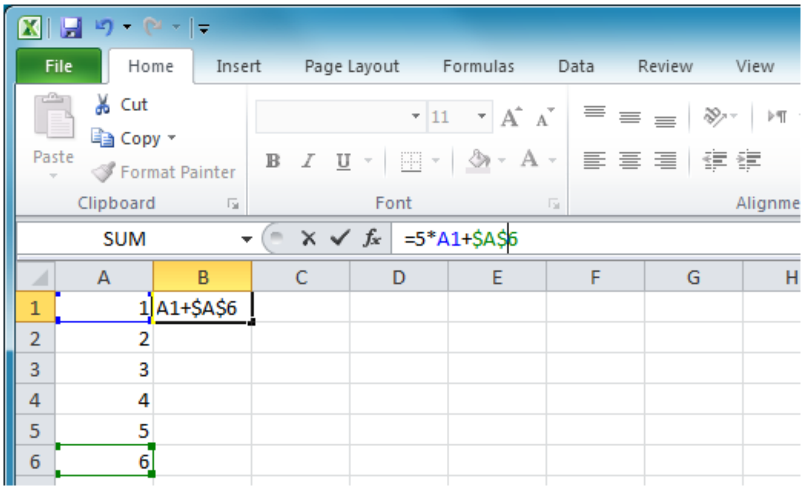
Often you will be creating your graph with Excel which you can print out and paste into your log book.

Data

Enter your data into a spreadsheet in Excel. Include a column for errors if you have them for both your variables. Use clear labels and units for your table. You may also have to use equations in your spreadsheet.

Equations

Sometimes you may need to use an equation to manipulate your data before you graph it or produce the final answer.

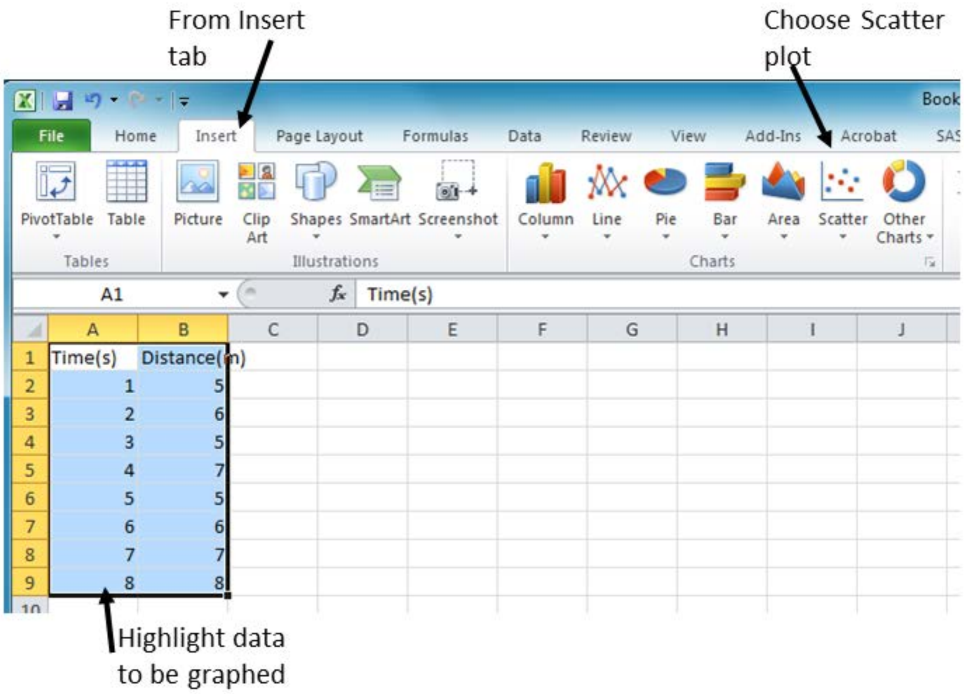


- Click in the cell you want to put the new data in. At the Equation Line type '=' followed by the equation you wish to use. If you are using data from another cell in your equation – click that cell instead of writing in the number.
- Using '$' forces that column or row to stay the same. So **A6** will always have the value of **6**, whereas **A1** will change to **A2** if you drag the equation down. You do this by clicking and dragging the little black square on the bottom right corner.
- Here are some of the more common commands you may use to create an equation;

operation	**command**	**example**
x^2	^2	=A1^2
xb	*	=A1*B1
$\frac{x}{b}$	/	=A1/A2
$\sum x$	SUM(number1,number2…)	=SUM(A1:A10)
Standard deviation, σ	STDEV(number1,number2…)	=STDEV(A1:A10)

Graph

To create a graph, select your numerical data to be graphed and choose the **Insert** tab, and pick **Scatter** from the **Charts** section. You will then need to select your graph and select the **Chart tools, Layout** tab. In this section you will see how to change your axis titles, graph labels, axis scales, include error bars and trendlines.



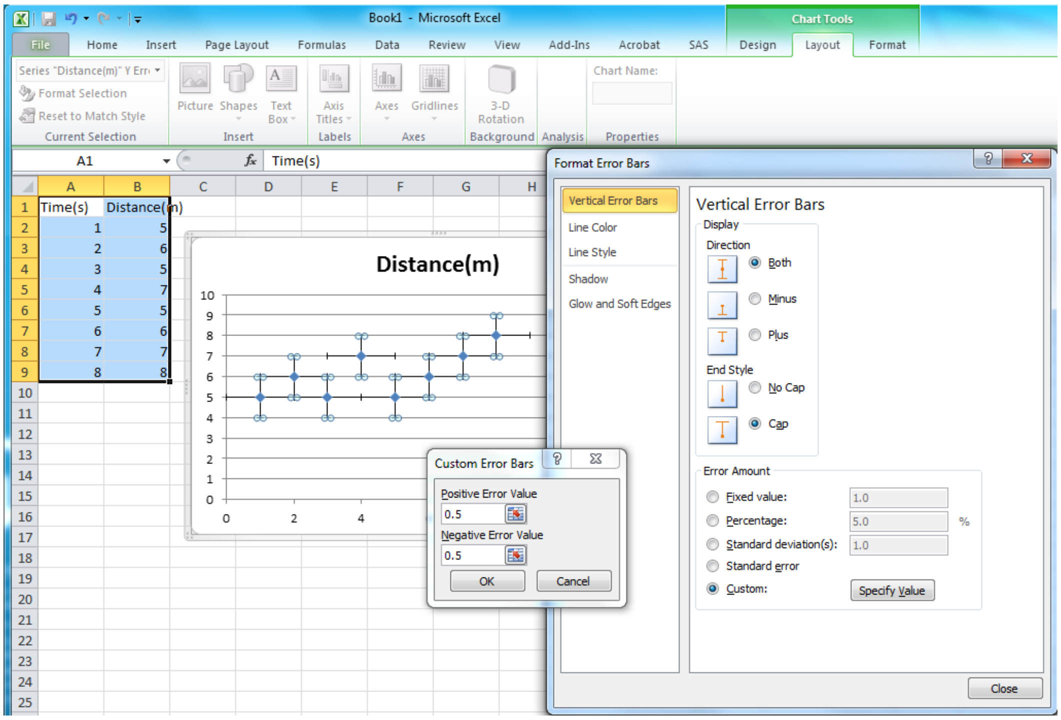
- **Scales -** Choose scales that make your graph simple and clear. Choose axis ranges that spread points evenly across the graph, rather than cramping them all into a corner. (This may mean that you need to exclude the zero point of an axis.)

- **Help -** If you are unsure of how to do something with your graph, explore the tab sections thoroughly and use Excel's **Help** function. Excel **can** do everything that you need – you only need to learn how (and where). If in doubt, ask a fellow student or your demonstrator.

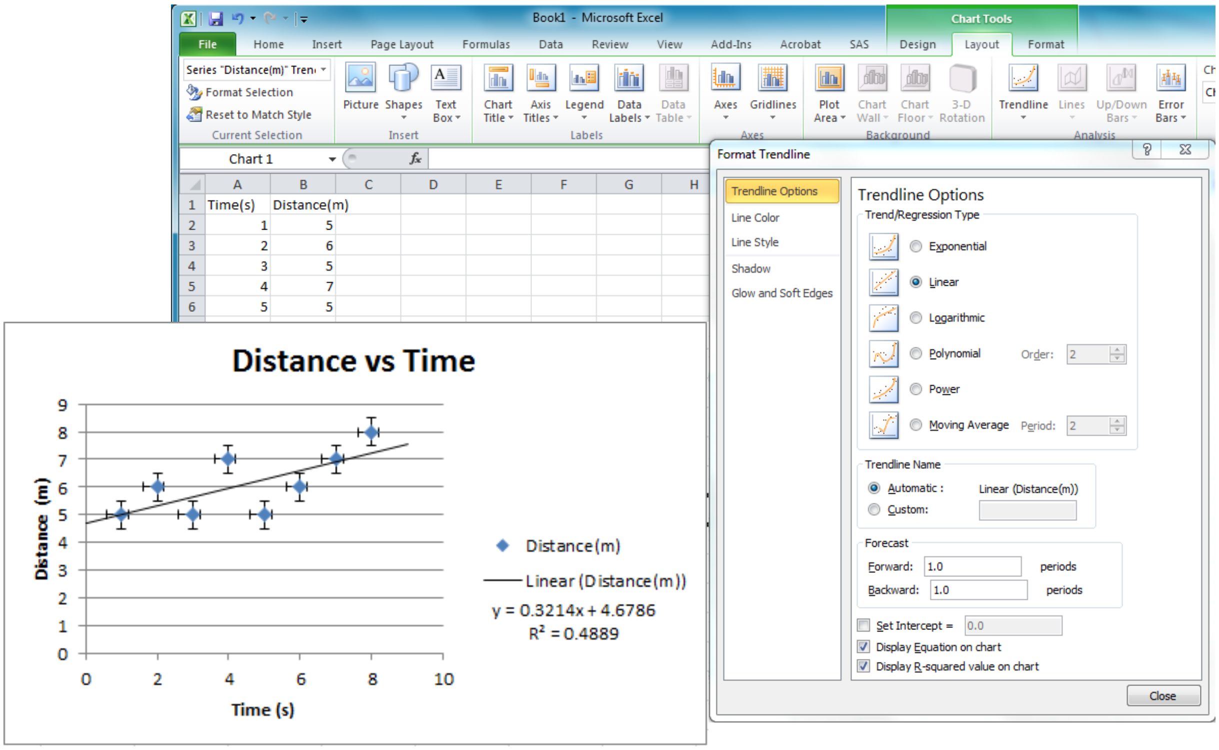
- **Changes -** When your graph is complete, remember that you can still alter it. You should right-click on elements of the graph to explore the options available.

Error bars in Excel -

- double-click the graph's data points,
- select the **Chart Tools, Layout** tab
- choose **Error bars**.
- select **more options,**
- use the fixed value to place your y error value or you can use **Custom Error bars**.
  - At this point Excel will also insert some default x error bars, if you have an error for x as well, select the horizontal error bar and insert correct value, or delete if you do not want them (sometimes they are so small you cannot see them to select – in which case do not worry about them).



Excel Trendlines



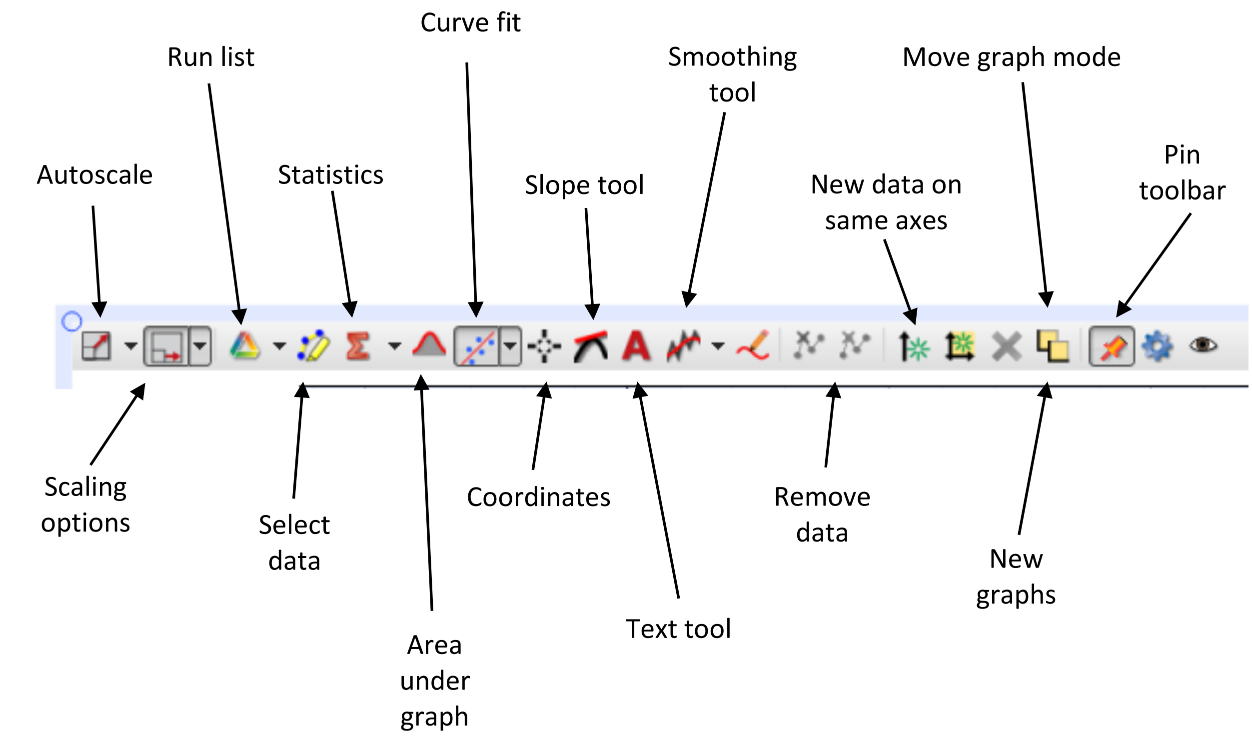
Excel can be made to construct lines of best fit for its graphs: select the data points on the graph, and right-click to choose **Add Trendline** from the pop-up menu. However, be careful: Excel's trendline methods won't work for all sets of data. Be sure to double-check that its lines look reasonable and sensible. Excel creates the Trendline via the Least Squares Fit method. We won't discuss this here, but you may like to investigate this method yourself.

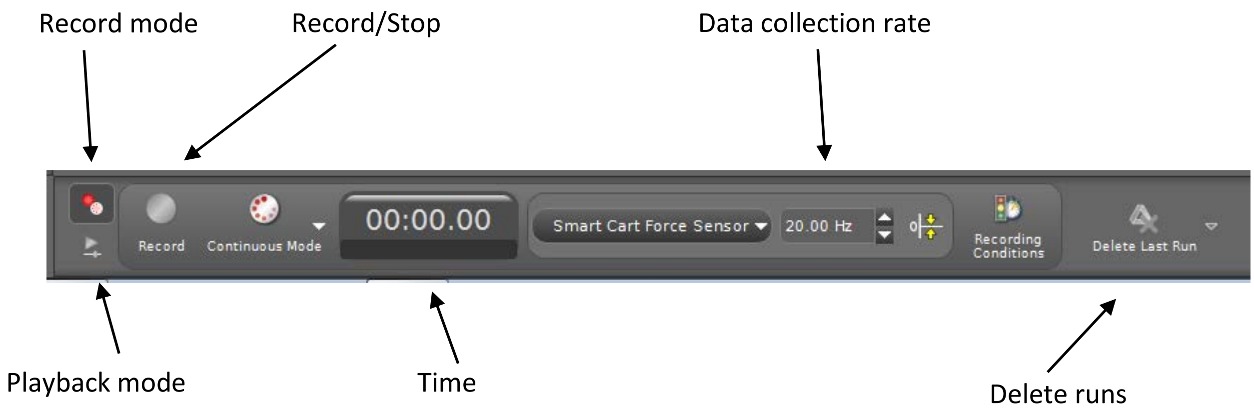
You can make changes to the chart title, axes, legend, etc. by right clicking on the area or using the **Chart Tools, Layout** menu options. (see above figure)

Appendix C
PASCO Capstone

Capstone Menus

The PASCO data logging carts connect via Bluetooth to the computer and you can generate the motion data of your cart in real time. Below are the main menus you will use and what the most used buttons do.



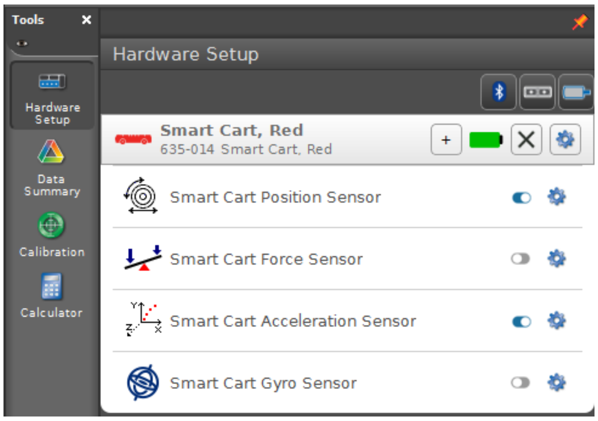


Helpful Hints:

Click on Run List arrow to allow multiple sets of data to be displayed on one graph

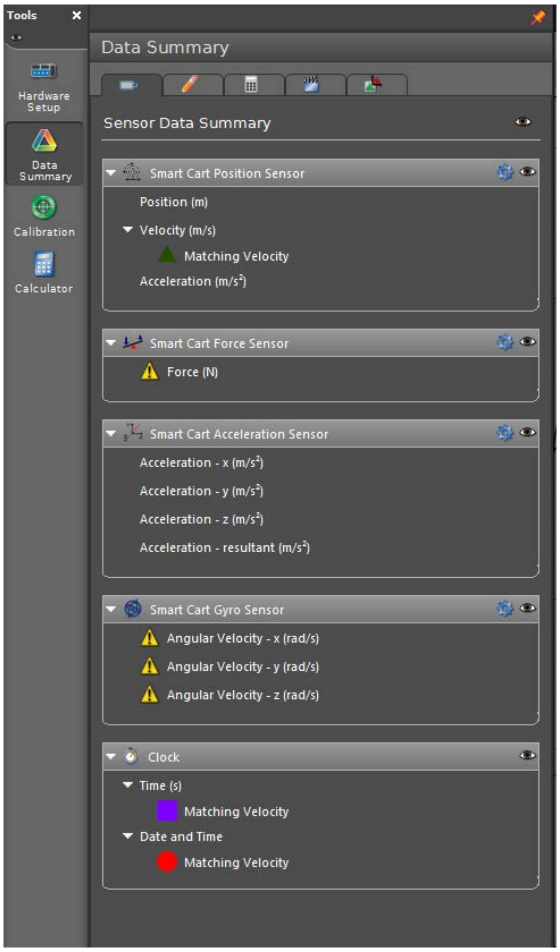
Ctrl-Z will undo previous actions.

When starting up in Capstone, you will need to select your cart via the Hardware Setup screen. *Check the number on your cart*. Don't select someone else's cart as you will receive their motion data!



The Calculator allows you to take your position/time, velocity/time or acceleration/time data and use it to integrate, differentiate, add, multiply, etc. To use the data you have collected, click on the rainbow triangle and select the data type and run.

The Calculated value can then be graphed by selecting 'Calc1' on the vertical axis.



Select Data to be logged and displayed from the Data Summary tab or by selecting the axis label on the graph.

Formulae and Data

Newtonian constant of gravitation	G	6.673×10^{-11} m^3 kg^{-1} s^{-2}
Gravitational acceleration at Earth's surface	g	9.80 m s^{-2}
Radius of Earth	R_E	6.37×10^6 m
Speed of light in vacuum	c	3.00×10^8 m s^{-1}
Speed of sound in air (20 °C, 1atm)	v_{sound}	343 m/s
Avogadro constant	N_A	6.022×10^{23} kg mol^{-1}
Elementary charge	e	1.6022×10^{-19} C
Electron mass	m_e	9.11×10^{-31} kg
Planck constant	h	6.6261×10^{-34} J s
Atomic mass equivalent	$m_u c^2$	931.5 MeV

Some Mathematical Formulae:

$\sin(-\theta) = -\sin(\theta)$	$\cos(-\theta) = \cos(\theta)$
$\frac{d}{d\theta}(\sin\theta) = \cos\theta$	$\frac{d}{d\theta}(\cos\theta) = -\sin\theta$
$\sin\theta \approx \theta$ for small θ $\cos\theta \approx 1$ for small θ	$\sin\alpha + \sin\beta = 2\sin\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha-\beta)$
$C_{\text{circle}} = 2\pi r \qquad A_{\text{circle}} = \pi r^2$	$A_{\text{sphere}} = 4\pi r^2 \qquad V_{\text{sphere}} = \frac{4}{3}\pi r^3$

Equations:

$\vec{v} = \frac{d\vec{r}}{\text{dt}}, \vec{a} = \frac{d\vec{v}}{\text{dt}}, \vec{a} = \frac{\vec{F}_{\text{total}}}{m}$	$\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$	$x_f = x_i + \int_{t_i}^{t_f} v_x(t)\text{dt}$
$v_{x_f} = v_{x_i} + \int_{t_1}^{t_2} a_x \, \text{dt}$	$\vec{r}_f = \vec{r}_i + \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$	$v_{\text{xf}}^2 = v_{\text{xi}}^2 + 2a_x\Delta x$
$\vec{r} = \vec{r}' + \vec{V}t, \qquad \vec{r}' = \vec{r} - \vec{V}t$	$\vec{v} = \vec{v}' + \vec{V}, \qquad \vec{v}' = \vec{v} - \vec{V},$	$x = r\theta \quad (\theta$ in radians)
$\omega = \frac{d\theta}{\text{dt}}, \qquad \alpha = \frac{d\omega}{\text{dt}}$	$v_t = \omega r$	$a = \sqrt{a_r^2 + a_t^2}$
$a_r = \frac{v^2}{r}$	$a_t = \frac{\text{dv}_t}{\text{dt}}$	$\theta_f = \theta_i + \omega_i\Delta t + \frac{1}{2}\alpha(\Delta t)^2$ $\omega_f = \omega_i + \alpha(\Delta t)$ $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$
$p = m\vec{v}$	$\vec{F} = \frac{d\vec{p}}{\text{dt}}$	$J_x = F_{x,\text{avg}}\Delta t = \Delta p_x$
$K = \frac{1}{2}mv^2$	$U_g = mgy$	$U_s = \frac{1}{2}k(\Delta x)^2$
$W = \int_{\vec{r}_i}^{\vec{r}_f} \vec{F} \cdot d\vec{x}$	$F_x = -\frac{\Delta U}{\Delta x}$	$P = \frac{\text{dW}}{\text{dt}} = \vec{F} \cdot \vec{v}$

$x_{\mathrm{cm}} = \frac{1}{M}\sum_i m_i\, x_i$	$y_{\mathrm{cm}} = \frac{1}{M}\sum_i m_i\, y_i$	$I = \sum_i m_i\, r_i^2, I = I_{\mathrm{cm}} + \mathrm{Md}^2$
$\vec{\tau} = \vec{r} \times \vec{F}$	$\vec{L} = \vec{r} \times \vec{p}, \qquad \vec{L} = I\vec{\omega}$	$\frac{d\vec{L}}{\mathrm{dt}} = \vec{\tau}_{\mathrm{net}}$
$\vec{\tau}_{\mathrm{net}} = I\vec{\alpha}$	$K_{\mathrm{rot}} = \frac{1}{2} I\omega^2$	$T^2 = \left(\frac{4\pi^2}{\mathrm{GM}}\right) r^3$
$F_G = \frac{\mathrm{Gm}_1 m_2}{r^2}$	U_r=-$\frac{\mathrm{Gm}_1 m_2}{r}$	F_{spring}=-$k\Delta x$
$f = \frac{1}{T}, \qquad \omega = 2\pi f$	$x(t) = A\cos(\omega t)$	$\omega = \sqrt{\frac{k}{m}}$
$\omega = \sqrt{\frac{g}{l}}$	$\omega = \sqrt{\frac{\mathrm{Mgl}}{I}}$	$\beta = 10\log_{10}\left(\frac{I}{I_0}\right),$ $I_0 = 10^{-12}\, W/m^2$
$D(x,t) = A\sin(kx \pm \omega t + f_0)$	$f_D = f_S \frac{v \pm v_D}{v \mp v_S}$	$v = \sqrt{\frac{T_s}{\mu}}, \qquad v = \sqrt{\frac{B}{\rho}}$
$d\sin\theta = m\lambda$	$\Delta\theta = \frac{1.22}{D}\lambda$	$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$
$n = \frac{c}{v}, \quad n_i\sin\theta_i = n_f\sin\theta_f$	$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$	m=-$\frac{s'}{s}$
$f_\# = \frac{f}{D}$	$P = \frac{1}{f}$	$\mathrm{NA} = n\sin\theta$
$\beta = \frac{v}{c}, \ \gamma = \frac{1}{\sqrt{1-\beta^2}}$	$\Delta t = \frac{\Delta\tau}{\sqrt{1-\beta^2}}$	$L = l\sqrt{1-\beta^2}$
$s^2 = c^2(\Delta t)^2 - (\Delta x)^2$	$x' = \gamma(x - \mathrm{vt})$ $t' = \gamma(t - \mathrm{vx}/c^2)$	$x = \gamma(x' + vt')$ $t = \gamma(t' + v\,x'/c^2)$
$u' = \frac{u - v}{1 - \mathrm{uv}/c^2}$ $u = \frac{u' + v}{1 + u'\,v/c^2}$	$p = \gamma_p \mathrm{mu}$ $E^2 = E_0^2 + (\mathrm{pc})^2$ $E_0 = \mathrm{mc}^2$	$E = \gamma_p \mathrm{mc}^2 = E_0 + K$

Schedule

Laboratory Exercises each week take place during a 2.5 hour laboratory session. They cannot be carried over between weeks. If you miss a class, you can only make it up during the same week.

There are no lab classes in the first week of semester. The table below outlines the schedule for semester one:

Week beginning	Groups B1 & B2	Groups B3 & B4
4 March	No lab class	No lab class
11 March	Experiment 1: Pendulum	Experiment 1: Pendulum
18 March	Experiment 2: Gravity	Experiment 2: Gravity
25 March	No lab class	No lab class
1 April	Experiment 3: Friction	No lab class
8 April	Experiment 4: Moment of Inertia	Experiment 3: Friction
15 April	No lab class	No lab class
22 April	Easter Break	Easter Break
29 April	No lab class	Experiment 4: Moment of Inertia
6 May	Experiment 5: Angular Momentum	Experiment 5: Angular Momentum
13 May	Experiment 6: Polarisation	Experiment 6: Polarisation
20 May	Exercise 7: Wavelength of light	Exercise 7: Wavelength of light
27 May	Experiment 8: Vibrations	Experiment 8: Vibrations