

Physics Laboratory Manual

PHYC 10180
Physics for Ag. Science
2018-2019



Name.....

Partner's Name

Demonstrator

Group

Laboratory Time

Contents

Introduction	3
Laboratory Schedule	4
Grading Process and Lab Rules	5
UCD plagiarism statement	6
Experiments: Springs	7
Investigating the Behaviour of Gases	17
Investigation of Acceleration	27
Investigation of Heat Capacity	37
Investigation of Fluid Flow	45
Investigation of Archimedes' Principle	51
Investigation of Rotational Motion	57
Appendix 1: Graphing	67
Appendix 2: Grading scheme	69

Introduction

Physics is an experimental science. The theory that is presented in lectures has its origins in, and is validated by, experiment.

Laboratories are staged through the semester in parallel to the lectures. They serve a number of purposes:

- ***an opportunity, as a scientist, to test theories by conducting meaningful scientific experiments;***
- ***a means to enrich and deepen understanding of physical concepts presented in lectures;***
- ***an opportunity to develop experimental techniques, in particular skills of data analysis, the understanding of experimental uncertainty, and the development of graphical visualisation of data.***

Based on these skills, you are expected to present experimental results in a logical fashion (graphically and in calculations), to use units correctly and consistently, and to plot graphs with appropriate axis labels and scales. You will have to draw clear conclusions (as briefly as possible) from the experimental investigations, on what are the major findings of each experiment and whatever or not they are consistent with your predictions. You should also demonstrate an appreciation of the concept of experimental uncertainty and estimate its impact on the final result.

Some of the experiments in the manual may appear similar to those at school, but the emphasis and expectations are likely to be different. Do not treat this manual as a 'cooking recipe' where you follow a prescription. Instead, understand what it is you are doing, why you are asked to plot certain quantities, and how experimental uncertainties affect your results. It is more important ***to understand and show your understanding*** in the write-ups than it is to rush through each experiment ticking the boxes.

This manual includes blanks for entering most of your observations. Additional space is included at the end of each experiment for other relevant information. All data, observations and conclusions should be entered in this manual. Graphs may be produced by hand or electronically (details of a simple computer package are provided) and should be secured to this manual.

There will be six 2-hour practical laboratories in this module evaluated by continual assessment. Note that each laboratory is worth 5% so each laboratory session makes a significant contribution to your final mark for the module. Consequently, attendance and application during the laboratories are of the utmost importance. At the end of each laboratory session, your demonstrator will collect your work and mark it.

Laboratory Schedule

Please consult the lab notice board contact the lab manager, Thomas O'Reilly (Science East Room 1.41) to see which of the experiments you will be performing each week. This information is also summarized below.

Timetable: Wednesday 2-4: Groups 1,3,5, and 7
 Wednesday 4-6: Groups 2,4,8,10 and 11
 Friday 3-5: Groups 6 and 9.

Semester Week	Week Start Date 2018	Room		
		Science East 143	Science East 144	Science East 145
1	10 th Sep	Springs: 1,2	Springs: 3,4	Springs: 5,6
2	17 th Sep	Springs: 7,8	Springs: 9,10	Springs: 11
3	24 th Sep	Gas: 1,2	Newton 2: 3,4	Heat Capacity: 5,6
4	1 st Oct	Gas: 7,8	Newton 2: 9,10	Heat Capacity: 11
5	8 th Oct	Gas: 5,6	Newton 2: 1,2	Heat Capacity: 3,4
6	15 th Oct	Gas: 11	Newton 2: 7,8	Heat Capacity: 9,10
7	22 nd Oct	Gas: 3,4	Newton 2: 5,6	Heat Capacity: 1,2
8	29 th Oct	Gas: 9,10	Newton 2: 11	Heat Capacity: 7,8
9	5 th Nov	Rotation: 1,2	Archimedes: 3,4	Fluids: 5,6
10	12 th Nov	Rotation: 7,8	Archimedes: 9,10	Fluids: 11
11	19 th Nov	Rotation: 5,6	Archimedes: 1,2	Fluids: 3,4
12	26 th Nov	Rotation: 11	Archimedes: 7,8	Fluids: 9,10

Grading Process

Grading is an important form of feedback for students, who benefit from this feedback for continuous improvement. Grading is staged through the semester in synchronisation with the labs. This is the grading process:

1. See appendix 2 for the labs grading scheme.
2. A lab script is graded by the lab demonstrator and returned to the student in the subsequent scheduled lab slot. Students resolve concerns regarding their grade with this demonstrator either during or immediately after this lab slot.
3. The grade is visible online within a week of the script being returned. Grades are preliminary but can be expected to count towards a module grade once visible online.

If the above doesn't happen, it is the student responsibility to resolve this with the demonstrator as early as possible.

Lab Rules

1. No eating or drinking.
2. Bags and belongings are placed on the shelves provided in the labs.
3. Students are only permitted to start a lab where they have this school of physics manual in print. The school of physics lab manual for your module is available in print from the school of physics admin office and is also available online from the school of physics pages.
4. It is the student's responsibility to attend an originally assigned lab slot. Zero grade is assigned by default for no attendance at this lab.

In the case of unavoidable absence, it is the student's responsibility to complete the lab in an alternative slot as soon as possible. If this is done, the default student grade of zero is updated online with the awarded grade after an additional two weeks. However, such an alternative lab slot can't be guaranteed as lab numbers are strictly limited. The lab manager, Thomas O'Reilly (Room Science East 1.41), may be of help in discussing potential alternative lab times. Where best efforts have been made to attend an alternative lab slot but this hasn't been possible, students should then discuss with their module coordinator.

5. Students work in pairs in the lab, however reports are prepared individually and must comply with UCD plagiarism policy (see next page).

UCD Plagiarism Statement

(taken from http://www.ucd.ie/registry/academicsecretariat/docs/plagiarism_po.pdf)

The creation of knowledge and wider understanding in all academic disciplines depends on building from existing sources of knowledge. The University upholds the principle of academic integrity, whereby appropriate acknowledgement is given to the contributions of others in any work, through appropriate internal citations and references. Students should be aware that good referencing is integral to the study of any subject and part of good academic practice.

The University understands plagiarism to be the inclusion of another person's writings or ideas or works, in any formally presented work (including essays, theses, projects, laboratory reports, examinations, oral, poster or slide presentations) which form part of the assessment requirements for a module or programme of study, without due acknowledgement either wholly or in part of the original source of the material through appropriate citation. Plagiarism is a form of academic dishonesty, where ideas are presented falsely, either implicitly or explicitly, as being the original thought of the author's. The presentation of work, which contains the ideas, or work of others without appropriate attribution and citation, (other than information that can be generally accepted to be common knowledge which is generally known and does not require to be formally cited in a written piece of work) is an act of plagiarism. It can include the following:

1. Presenting work authored by a third party, including other students, friends, family, or work purchased through internet services;
2. Presenting work copied extensively with only minor textual changes from the internet, books, journals or any other source;
3. Improper paraphrasing, where a passage or idea is summarised without due acknowledgement of the original source;
4. Failing to include citation of all original sources;
5. Representing collaborative work as one's own;

Plagiarism is a serious academic offence. While plagiarism may be easy to commit unintentionally, it is defined by the act not the intention. All students are responsible for being familiar with the University's policy statement on plagiarism and are encouraged, if in doubt, to seek guidance from an academic member of staff. The University advocates a developmental approach to plagiarism and encourages students to adopt good academic practice by maintaining academic integrity in the presentation of all academic work.

UCD Physics Laboratory: Investigation of Springs

Student Name: _____
Lab Partner Name: _____
Lab Date/Time: _____

Student Number: _____
Demonstrator Name: _____

Goal

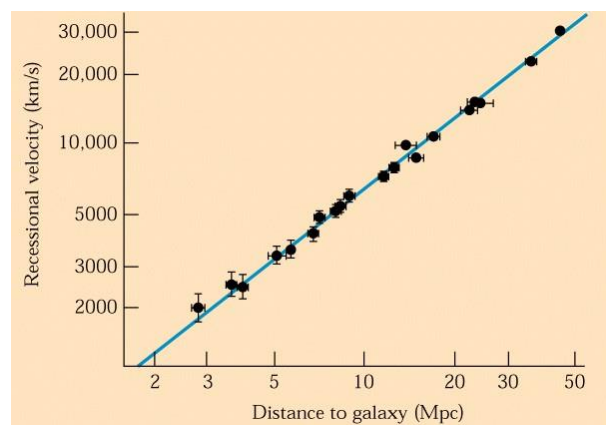
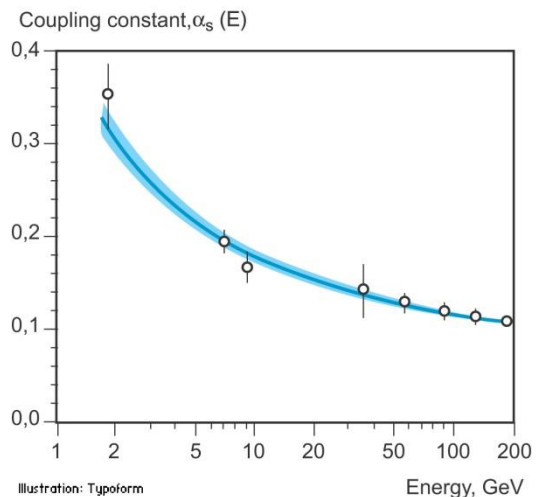
You will physically interpret experimental measurements with a straight line fit to data that you measure. Specifically, you will investigate how springs stretch when different objects are attached to them and you will learn about the graphing of scientific data. You will compare the stiffness of two springs. You do not need prior knowledge of this topic to participate in this laboratory session.

Warm-up exercises: Plotting scientific data

In many scientific disciplines and particularly in physics, you will come across plots similar to those shown here.

Note some common features:

- horizontal and vertical axes;
- axes have labels and units;
- axes have a scale;
- points with vertical and/or horizontal lines through them;
- a curve or line superimposed.



Why do we make such plots?

What features of the graphs do you think are important and why?

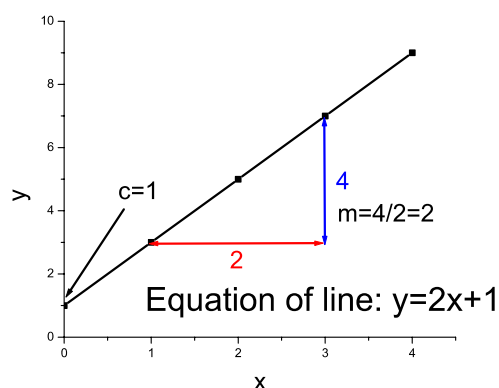
The equation of a straight line can be written as:

$$y = m x + c$$

The variable 'y' is how far up the point is, whilst the variable 'x' is how far along the x-axis the point is.

The variable m is the slope or gradient of the line. It tells you how steep a line is and is calculated by dividing the change in y by the change in x for the same part of the line.

c is the intercept of the line and is the point where the line crosses the y -axis, at $x = 0$.



In this experiment, you will demonstrate the way a spring extends. The more a spring is pulled, the more it extends. For reference, the relationship between a pulling force and the extension of a spring is given by 'Hooke's Law', however you don't need knowledge of this law to do this experiment. Instead, you will discover the behaviour of a spring through your own measurements.

Experimental set-up

In this experiment, we apply a controlled force to a spring by means of hanging weights from it. You will use 2 different springs, a retort stand, a ruler, a mass hanger and a number of 10-g masses.

Set up the experiment to be used as shown in the photographs. Let's call one of your two springs 'spring 1' and the other 'spring 2'.



Calculate the initial (unstretched) length of spring 1: _____

Calculate the initial (unstretched) length of spring 2: _____

Think about how you can most easily determine the length of each spring as you add weights and it extends. You might want to keep the top of the spring at a fixed position and just determine the revised position of the bottom of the spring to more quickly work out the length of the spring each time.

Add the mass hanger to each of the springs in turn. We know that springs should extend when pulled, but do the lengths of the springs change on adding this hanger? Explain.

Add masses to the hanger one at a time, for each of spring 1 and spring 2. What are the minimum number of masses required for each spring to begin to extend?

Now you will collect all your data. Then you will interpret the data graphically.

Procedure and Data

It is a typical scientific process to take data whilst increasing a (controlled) parameter and then also while decreasing it. This is what you are asked to do here, where the controlled parameter is the mass on the spring.

Add the 10-g disks to the mass hanger one at a time whilst measuring the revised length of the spring. Once all your masses have been added, continue taking measurements by taking measurements where taking one mass off at a time. Fill in the following tables.

Measurements for spring 1:

Object Added	Total mass added to the spring hanger (g)	Spring length whilst adding masses, in cm (<i>plot as crosses</i>)	Spring length for taking away masses, in cm (<i>plot as dots</i>)
Disk 1	10		
Disk 2	20		

Measurements for spring 2:

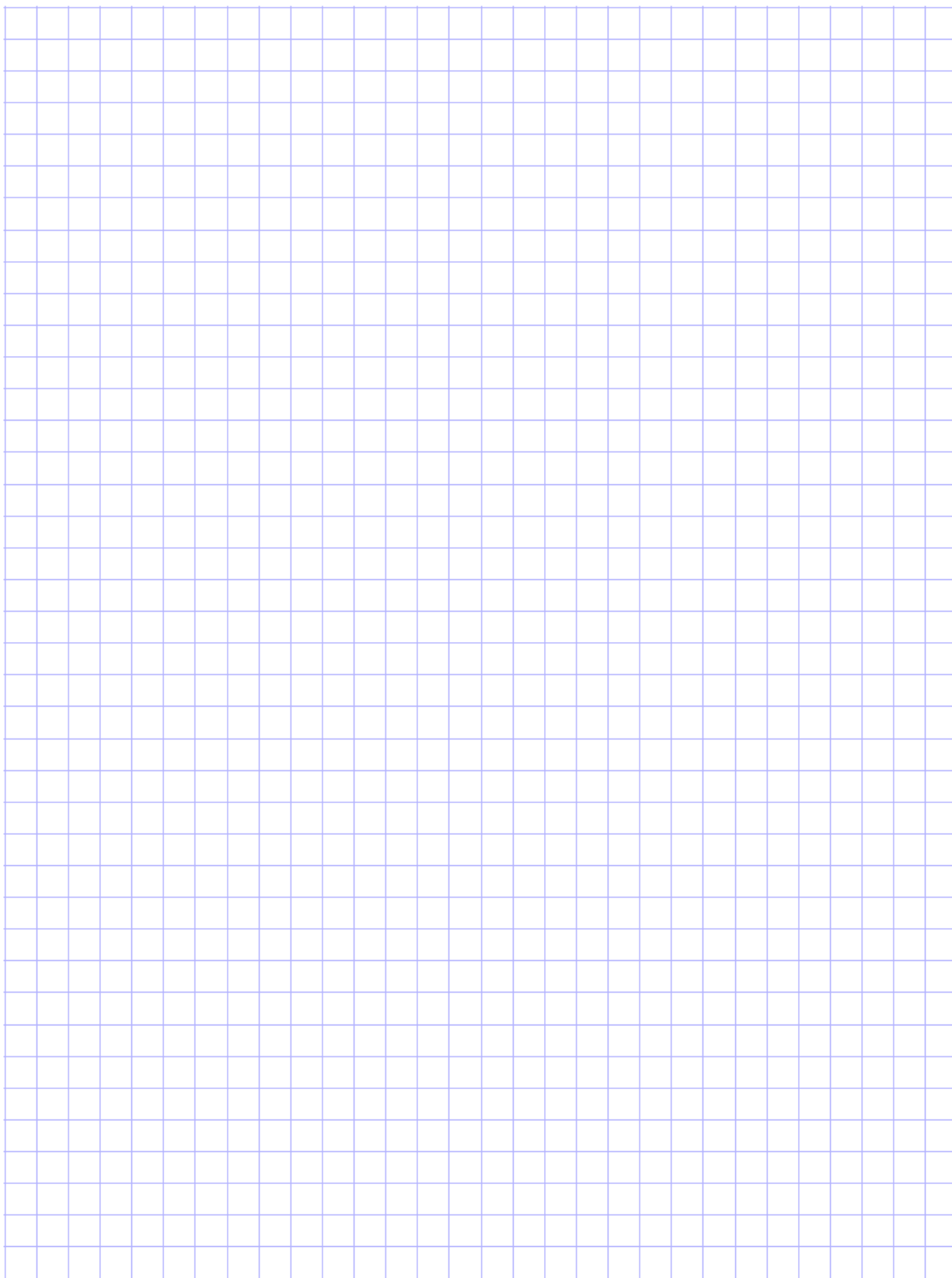
Object Added	Total mass added to the spring hanger (g)	Spring length whilst adding masses in cm (<i>plot as crosses</i>)	Spring length whilst taking away masses, in cm (<i>plot as dots</i>)
Disk 1	10		
Disk 2	20		

Results

Add the data you have gathered for both springs to your graph on the following page. You should plot the length of the spring in centimetres on the vertical *y*-axis and the total mass added to the hanger in grams on the horizontal axis. Plot your first column points as *crosses* and your second column of points as *dots* (*small solid circles*). You might also differentiate these with different colour pens if you are able.

Suggested is for you to start the *y*-axis at -10 cm and have the *x*-axis run from -40 g to 100 g. Choose a scale that is simple to read and that spreads the data across the page. Label your axes and give them units, something you should always do even if not asked. Include other features of the graph that you consider important.

Plot your graph by hand on this page and make your best estimate for a straight line fit to your data. *Note, your tutor will account for fitting done by hand.*



Note: we want to examine how a spring extends as a function of the mass hanging from it. For this, it's only useful to fit a line to data from where the spring starts to extend. Let's assume that your data follows a straight line for each spring, once it starts to extend.

Taking note of the above, fit a straight line as best as you can to your data for each of the two springs (2 lines in total). *Do this by eye. Your tutor will account for your fitting by hand.*

At what mass-value does your straight fitted lines intercept (cross) the x-axis:

Intercept with x-axis for the spring 1 fitted line: _____ g

Intercept with x-axis for the spring 2 fitted line: _____ g

Considering measurement errors, how well do these values compare to the previous measurement that you made at the end of the 'Experimental set-up' section for the mass required to begin to stretch each of the springs?

Is it possible that these intercept values measured from your graphs are more accurately determined than those in the 'Experimental set-up' section? If so, explain why and state any assumptions necessary for this.

In everyday language we may use the word 'slope' to describe a property of a hill. For example, we may say that a hill has a steep or gentle slope. Generally, the slope tells you how much a value on the y-axis changes for a change on the x-axis.

As discussed in the 'warm-up', a straight line can be described by $y = mx + c$, where m is the steepness (slope) of the line i.e., the change in y divided by the change in x for the line, and c is the y -value where the line intercepts (crosses) the y -axis i.e., where $x = 0$. Note that c is not the same intercept that we calculated above, which was for where the line crosses the x -axis.

Calculate the slopes of the two lines that you have drawn (fitted by eye) for each of springs 1 and 2. Also provide correct units for your slopes in terms of grams and centimetres.

Use the slopes of these two lines to compare the stiffness of the springs and explain.

Physically interpret the meaning of your c -values i.e., the values of y where your fitted lines intercept the y -axis.

Look at the example graphs given in the earlier 'warm-up exercises' section. Horizontal and vertical lines through the data points represent experimental uncertainty derived either from taking measurements many times (say 10 times or more) and seeing a variation in values, or from determining a precision from known accuracies of instruments. In this experiment, uncertainty in the masses is insignificant, but there may be uncertainty in the length measurements.

Compare your data taken where adding weights (first column of your data tables) to that taken where taking away weights (second column of your data tables). Estimate (don't calculate) to what accuracy these two columns of data agree for spring 1, and likewise for spring 2. Do this by inspecting your tables and/or your graphs.

Is this observed uncertainty in length larger or smaller than that determined from the accuracy of your ruler? Discuss.

Conclusion

The behaviour of springs is said to be 'linear'. Explain this more clearly with reference to your responses and graphs in this lab.

Implications

An ear receives small forces from sound waves that result in small mechanical deviations of the eardrum and ossicles. How do these deviations approximate to being 'linear' with the applied force even though the coupling mechanisms are so complex?

The mechanics of the ear stiffens in aging and hearing declines as a result. If the eardrum and ossicles stiffen by a factor of three, by how much would the maximum deviation of the ossicles change as a result? Explain your reasoning referring to what you have learned in this laboratory.

The deviation of a car suspension can be considered 'linear' with an applied force. Assume this for comparing the suspensions of the following two cars. Car 1 is twice as heavy as car 2 and it compresses its suspension by one third as much as Car 2. Comment on the relative stiffness of the suspensions referring to what you have learned in this laboratory.

UCD Physics Laboratory: Investigating the Behaviour of Gases

Student Name: _____
Lab Partner Name: _____
Lab Date/Time: _____

Student Number: _____
Demonstrator Name: _____

Goal

You will experimentally investigate the validity of a physical law. After this session, you will have more understanding of the process of experimental verification, and how the law you are testing is relevant to everyday experiences.

Specifically, you will test the Ideal Gas Law relating three variables of Volume, Pressure and Temperature using containers of air. To do this, you will keep one quantity fixed so that you can investigate how two other variables are related. In the first part you will keep the temperature constant and vary the volume to see how the pressure changes. In the second part you will keep the volume constant and vary the temperature to see how the pressure changes.

Warmup exercises

In this laboratory session, we investigate the relationship between the three properties of gases that we can most readily sense: volume, temperature and pressure. We call these macroscopic properties. But we understand that these properties derive from the movement of individual atoms/molecules (microscopic behaviour) that make up a gas, which move randomly, colliding with each other and the sides of the container.

- Pressure, P . The motion of billions of billions of gas particles in a container, causes them to collide with each other and with the sides of their container. In doing so they push on the sides of the container and we measure this as a pressure. For pressure, we use the S.I., unit of a force divided by an area, N/m^2 which is also called the Pascal, Pa.
- Volume, V . A gas is a collection of atoms and/or molecules that expands to fill any container of any shape. For volume, we use the S.I., unit of m^3 .
- Temperature, T . When a container of gas is heated, energy is transferred to the gas from a source of heat. Both the temperature and the internal energy (U) of the gas increase, and we find that $T \propto U$. This internal energy is in the form of a kinetic (motion) energy for the molecules. The molecules move faster as the temperature of a gas increases. Likewise, when a gas is cooled, the molecules slow down.

Using the above information, circle the correct answers below:

If you heat a gas, do the molecules move faster or slower?	faster / slower
If moving faster, do the molecules collide with the container walls more, or less, frequently?	more / less
If the molecules collide more frequently with the container walls, does the pressure increase or decrease?	increase / decrease
If you increase the container volume, are molecular collisions more or less frequent?	more / less
If the molecules collide less frequently, does the pressure increase or decrease?	increase / decrease

Clearly, all three gas properties are interconnected, but how? If we keep one property fixed, we can investigate the relationship between the other two. For example:

- If we keep the gas temperature fixed, we can see how changes in volume affect pressure.
- If we keep the gas volume fixed, we can see how changes in temperature affect pressure.

These two relationships were first investigated by Irish scientist, Robert Boyle (1662), and French chemist, Gay-Lussac (1701). From the above information, can you figure out what remaining relationship was investigated by French scientist, J Charles (1780)?

A relationship between measurable quantities that is demonstrated experimentally and repeated in different ways over many years, can be said to be a physical law. Three scientists proved three relationships between the gas properties, leading to:

- Boyle's Law relating P and V .
- Gay-Lussac's Law relating P and T
- Charles' Law relating V and T

Since these three relationships are interconnected, we can combine them and we call the combined relationship the Ideal Gas Law, which is given by:

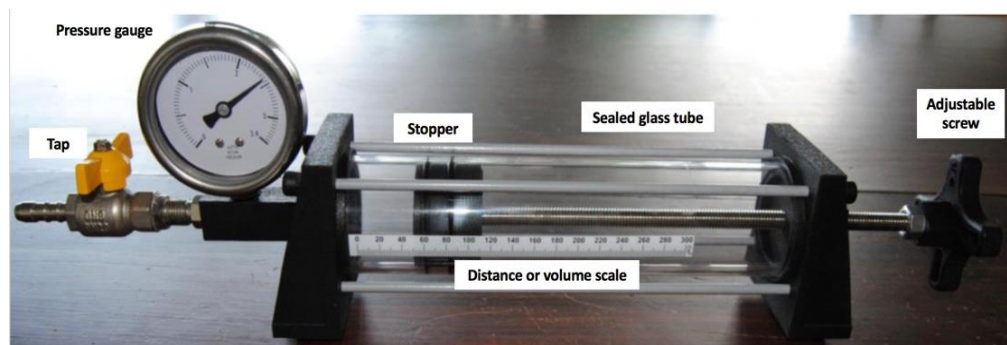
$$PV = nRT$$

where the constant of proportionality is the product of two constants, nR , where n is the number of moles of gas atoms/molecules there are and R is the ideal gas constant. Let's now test these ideas with two experiments.

Experiment 1: How the *pressure* of a gas changes when its *volume* is changed

Apparatus

- A pressure gauge, with a scale in units of pressure i.e. pascals (Pa).
- A sealed glass tube of gas (air), marked with a scale of distance (mm) or volume (ml).



Procedure

- Open the tap (by turning it to a position parallel to the tube). Note the pressure reading. This is your baseline pressure; the pressure of the air all around us.
- Twist the adjustable screw to move the stopper to about a fifth of the way along the tube (as shown in the picture). This is simply a practical starting point for the number of readings to be conducted within the timeframe for the experiment.
- Close the tap to define a fixed amount/mass of gas. Record the baseline pressure.
- Twist the adjustable screw so that the stopper reduces the volume that the gas can occupy within the tube. As you do, notice what happens to the pressure reading. Take readings of pressure as you reduce the volume. (If the tube is marked with units of ml you can write down the volume directly in these units. If the tube is not in these units, you can calculate the volume of the gas by assuming the radius of the tube is 1 cm.)
- Estimate the accuracy of your measurements of volume and pressure.
- Open the tap, to release pressure, and unscrew the stopper to return it to its original position.
- **Note: the equipment is only designed to work up to the maximum pressure on the scale. Keep below this pressure.**

Data

Volume (ml)	Pressure (Pa)

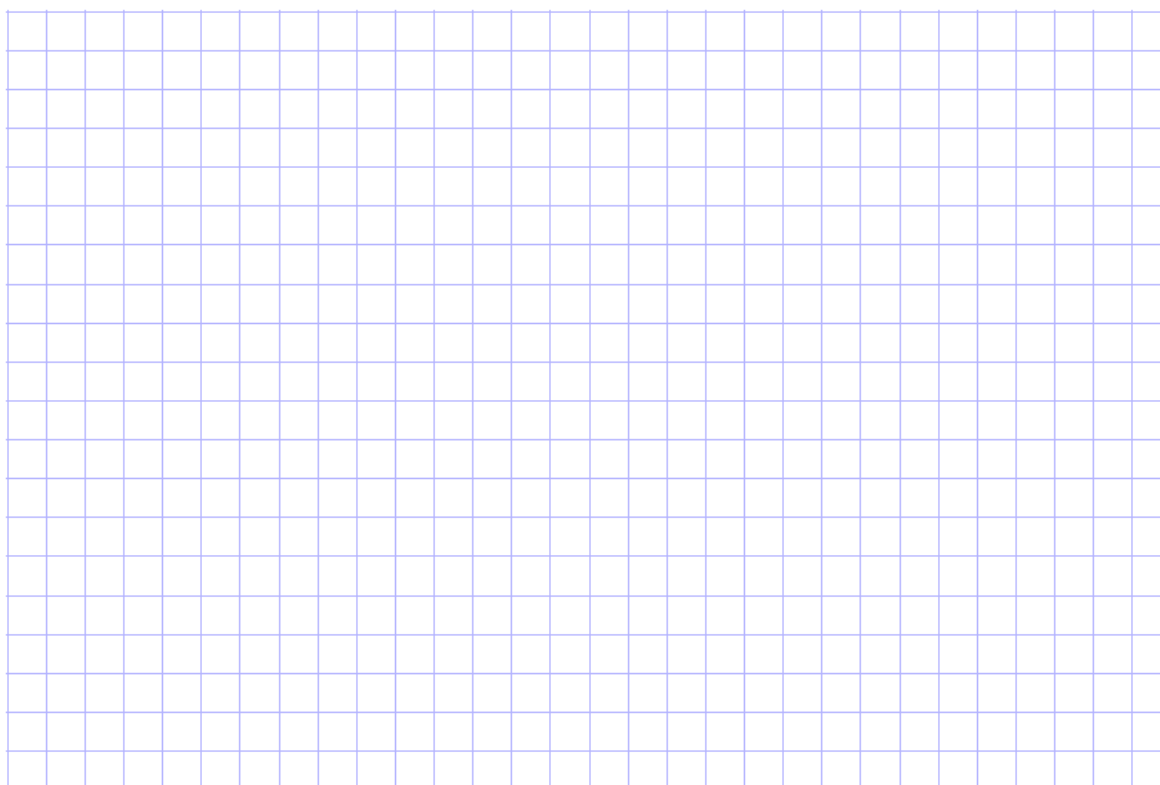
Estimate of error in Volume measurements (ml)	Estimated Error in Pressure measurements (Pa)

Do the following plots by hand on this page, or, use JagFit (see back of manual) and attach your two printed graphs to this page. Important: take care to label axes correctly and include units. *Note, your tutor will account for fitting where done by hand.*

Plot P along the y-axis, as a function of V along the x-axis:



Now plot P along the y-axis, as a function of $1/V$ along the x-axis:



From your graphs, describe how the gas properties are related. Is there a linear relationship between any two variables i.e., does a straight line fit to your points?

A straight-line graph is given by the equation $y = m x + c$, where m is the slope and c is the value of y where the line intercepts the y -axis i.e., where $x = 0$. Determine the slope and the intercept value, c , for your straight-line graph and give these values here, including units.

Do you expect the intercept to be at the origin where $P = 0$ and $V = 0$? Explain.

Conclusion

We investigated the relationship between pressure and volume, where temperature is held constant. This is Boyle's Law. From this experiment, briefly state this relationship in your own words and state if this is consistent with the Ideal Gas Law, for which $PV \propto T$.

Implications

When we inhale, we lower the diaphragm muscle to increase the volume of our lungs. When we exhale, we raise the diaphragm to decrease the volume. Relate this to differences in pressure between the inside and outside of the lungs with the aid of Boyle's Law (the Ideal Gas Law).

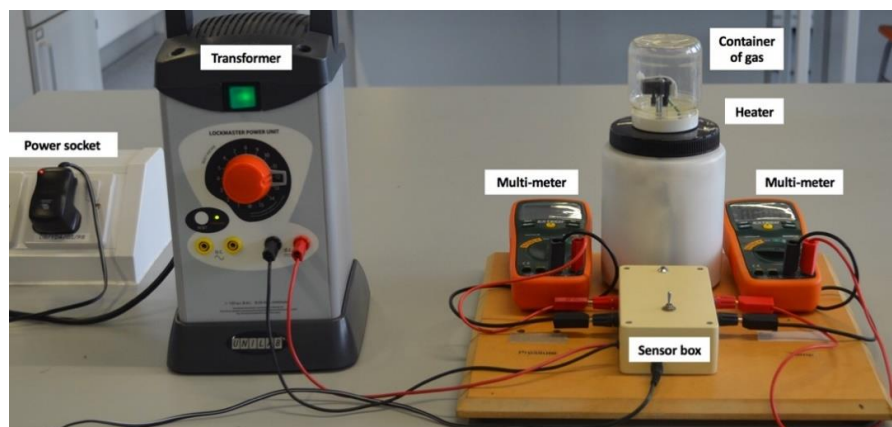


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Explain another everyday example that relates pressure and volume (for a temperature that's approximately fixed), using the Ideal Gas Law.

Experiment 2: How the *pressure* of a gas change when its *temperature* is changed

Apparatus



- A sealed container of gas (air), connected to a heater.
- A white box containing connections to temperature and pressure sensors.
- Two multi-meters, one to read pressure and one to read temperature.

Procedure

- Ensure all connections are in place (see picture).
- Turn the dial on the “pressure” multi-meter to V (volts), and press the “range” button until it is set to the millivolt (mV) range. You can record mV as a proxy for the units of pressure, Pascals (Pa). Set the “temperature” multi-meter to degrees Celsius (°C).
- Turn on the sensors, by checking that the white box is plugged in and then flipping the switch so that its light comes on. Record the temperature and pressure, as per the multi-meters.
- Turn on the heater. For this, first check that the large transformer is plugged in and then press the on-switch. At this point the gas is being heated and you will notice the temperature readings will slowly increase.
- Take temperature and pressure readings at intervals of about 5 °C until the temperature reaches about 80 °C. Then immediately switch off the heater by pressing the green button.
- Estimate the accuracy of your measurements of temperature and pressure.
- Turn off all equipment, by returning switches to original positions and disconnecting power.

Data

Temperature (°C)	Pressure (Pa)

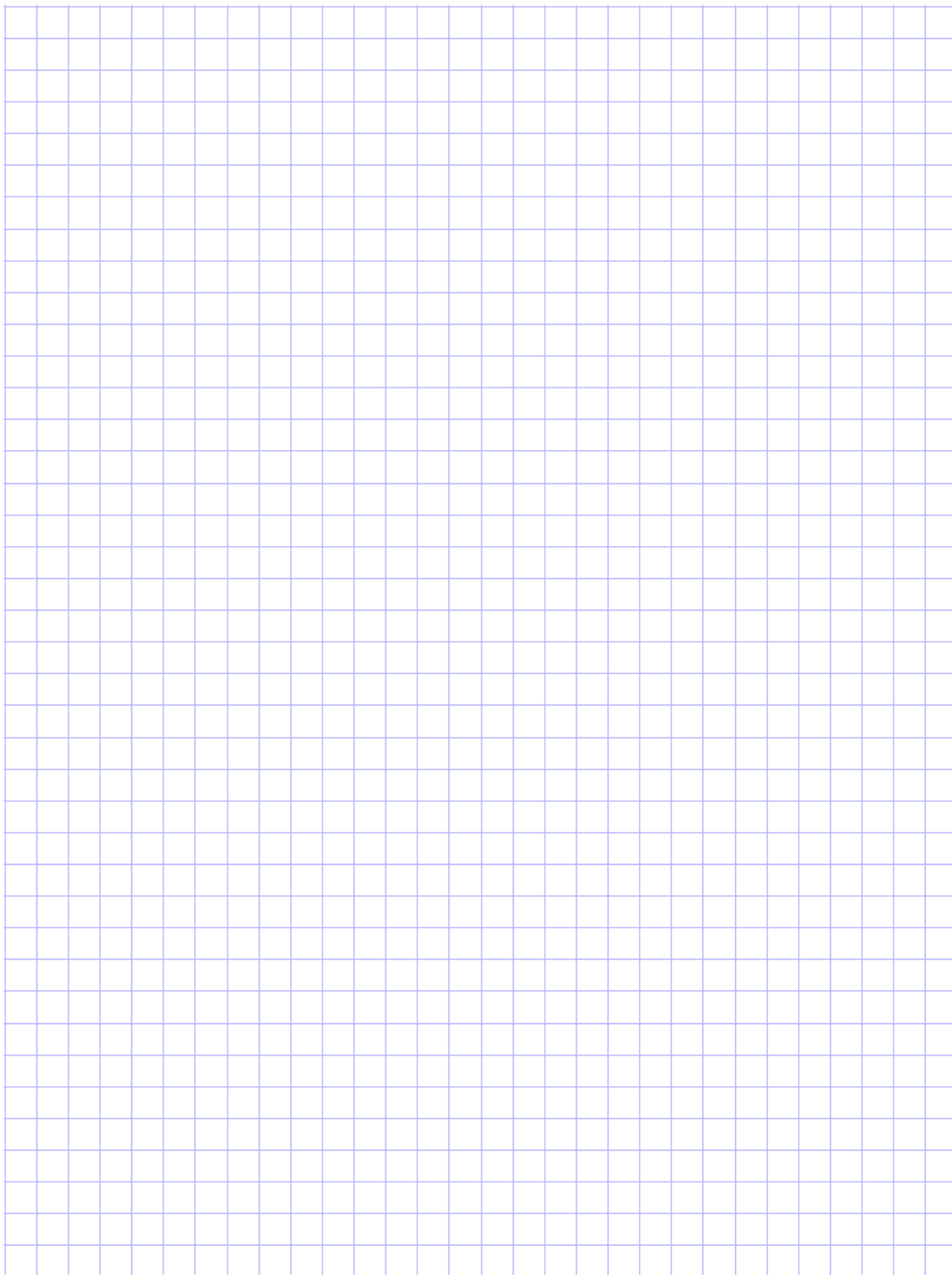
Estimated error in Temperature measurements (°C)	Estimated Error in Pressure measurements (Pa)

Results

Plot pressure, P , (y-axis) as a function of temperature, T in $^{\circ}\text{C}$ (x-axis).

Do this by hand on this page, or, use JagFit (see back of manual) and attach your printed graph to this page. Important: take care to label axes correctly and include units.

Note, your tutor will account for fitting where done by hand.



From your graph, describe how the gas properties of pressure and temperature are related. Is there a linear relationship between any two variables i.e., does a straight line fit to your points?

The curve of a straight-line graph is given by the equation $y = m x + c$, where m is the slope and c is the value of y where the line intercepts the y -axis i.e., where $x = 0$. Determine the slope and the intercept value, c , for your straight-line graph and give these values here, including units.

From your values of m and c , determine the value of temperature in $^{\circ}\text{C}$ for which P would extrapolate to being zero.

Describe what the molecules of the gas would be doing in everyday language at this temperature, T_0 , for which $P = 0$?

Conclusion

We investigated the relationship between pressure and temperature, where volume is held constant. This is Gay-Lussac's Law. From this experiment, briefly state this relationship in your own words.

Explain how your measurements are consistent with the Ideal Gas Law, for which $PV \propto T$.

Implications

Car tyres increase in pressure by $3 \times 10^4 \text{ N/m}^2$ after driving for 20 mins. Explain this with the aid of the Ideal Gas Law

A jam jar can be easier to open after warming it up in a bowl of hot water. Explain this with the aid of the Ideal Gas Law.

Explain another everyday example that relates pressure and temperature (for a volume that's approximately fixed), using the Ideal Gas Law.

UCD Physics Laboratory: Investigation of Acceleration

Student Name: _____

Student Number: _____

Lab Partner Name: _____

Demonstrator Name: _____

Lab Date/Time: _____

Goal

You will experimentally investigate the validity of a physical law. After this session, you will have more understanding of the process of experimental verification, and how the law you are testing is relevant to everyday experiences. You do not need prior knowledge of this topic to participate in this laboratory session.

Specifically, you investigate test Newton's 2nd Law, a law relating three variables of force, mass and acceleration, using a cart on a track. It is useful to keep one quantity fixed so that you can investigate how two other variables are related. To do this, you will keep a force fixed along the direction of motion, and relate an acceleration to a mass.

Warmup exercises

Newton's second law is given by the vector relationship, $\vec{F} = m\vec{a}$, for which a force causes an acceleration and the constant of proportionality is mass, m . However, for motion confined to a straight line (one dimensional motion), we can simplify this law to the scalar relationship, $F = m a$, where F is the value of the net force acting on an object along its allowed direction of motion, and a is the value of acceleration in this direction of motion. We consider only motion in a straight line in this laboratory and so we are able to use this scalar form of the law.

If you throw a heavy ball with a force F and then throw a light ball with the same force, which ball gathers more speed? _____
heavy/light

Acting under constant acceleration, a cart starts from rest and has a speed of 2 m/s after 5 s. What is the acceleration of the cart? _____

Forces cause acceleration. For example if you kick a ball of mass m with a force ' F ', its acceleration is ' a '; if you then kick the same ball with a force twice as big, ' $2F$ ', then it accelerates at ' $2a$ '. In other words, the acceleration, a , is larger when the force, F , is larger:

$$a \propto F$$

The acceleration is larger when the mass, m , of the object is smaller:

$$a \propto \frac{1}{m}$$

We can combine these two relationships into one:

$$a \propto \frac{F}{m}$$

Isaac Newton (1687) provided experimental evidence of this relationship, and so it became a 'Law'. It is now called Newton's 2nd Law, and is more commonly written as:

$$F = m a$$

The unit of force is kg·m/s² which is called the Newton (symbol N), in honour of Isaac Newton.

If an apple falls from a tree, it speeds up until it hits the ground. So there must be a force which causes this acceleration. The acceleration due to the Earth's gravitational force field has been measured experimentally to be 9.8 m/s². We denote this as '*g*' since its value is always the same, instead of generic acceleration '*a*' (which can have many values). So the gravitational force is the product, *mg*.

To test Newton's 2nd Law, you will keep one quantity fixed so that you can investigate how two other variables are related. Specifically, you will keep the force fixed and relate a horizontal acceleration to a mass which is varied.

Apparatus

- One cart, of mass 0.5 kg
- A low-friction track, with a pulley wheel on one end
- A string, with a ring weight tied to one end and a hook to the other, threaded over the pulley wheel with the hook attached to the cart.
- Two photogates connected to a blue data-logger
- Three metal bars, of mass 0.5 kg each, which can be added to the cart to increase its mass

Where using a pulley, the string has an equal tension throughout. This simplifies our thinking, because we can consider the stage as being accelerated horizontally due to a constant horizontal force of magnitude, *F*, and we also consider *F* to be the magnitude of force exerted vertically between the string and the ring-weight. We return to this with an equation later.

Experiment: Acceleration from a constant force along a horizontal plane

Experimental set-up

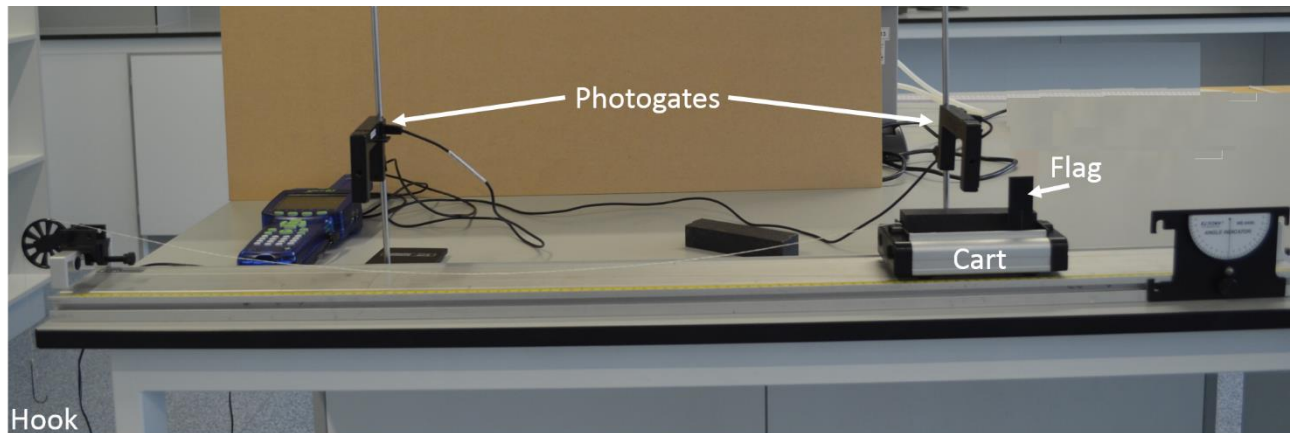


Fig 1

i) Setting up the cart on the track:

- Position the track on the laboratory bench in such a way that the pulley wheel hangs over one end of the bench.
- Ensure the track is level. This is done via an adjustable leg at one end.
- Place the cart on the track at the opposite end to the pulley wheel.
- You will find a string, with a ring tied to one end and a hook tied to the other. Attach the hook to the cart and thread the string over the pulley wheel so that the ring hangs down. The weight of the ring will accelerate the cart along the track.
- Insert the rectangular metal "flag" into the hole at head of the cart, with the largest surface facing you. Make sure the flag is secure and does not move. (This can be achieved by lifting it slightly out of the hole). The role of the flag is to interrupt the light beam of the photogates (see below).

ii) Setting up the two photogates:

- The photogates comprise an infrared light source on one side, and a detector on the other, fig 2. Infrared light is invisible to the human eye but is represented by the red line in the figure. When the beam is interrupted it sends a signal to the blue data-logger.
- Place the photogates at positions 30 cm and 80 cm on the track. In this way, the distance between the gates is 50 cm.
- In order to calculate acceleration, we must measure the change in velocity in a given time interval.
- The velocity is determined by how long the cart's metal flag takes to move past a given photogate. The photogate is connected to a blue data-logger, which reports how long the beam is interrupted for (i.e. time). It then uses the width of the flag (i.e. distance) to estimate the velocity of the cart. For this reason, we must input the width of the flag (or flag length) when we set up the data-logger (below). The cart *velocity* is calculated from how long it takes its flag to pass through the photogate beam. To output these results, the blue data-logger must be set up correctly (see below).

- The cart *acceleration* is determined by computing the change in velocity between the two photogates.

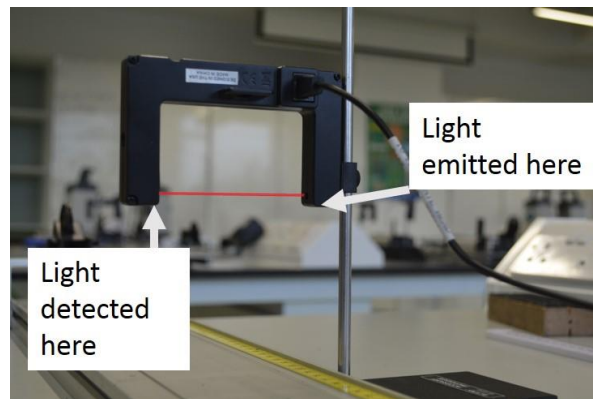


Fig 2

iii) Setting up the blue data-logger:

- Turn on the power supply at the socket. Turn on the blue data-logger. A screen will appear, select “photogate timing” and enter the flag length (0.0250 m) and photogate spacing (0.5000 m) by pressing to edit and again to confirm.
- Ensure that only ‘Velocity In Gate’ and ‘Time Between Gates’ are set to visible.
- Then press the home key.
- Press F1 or navigate to the graph section. Once on the graph screen, press F4 to open the graph menu. Navigate to ‘Two Measurements’ and press select.
- Press the select key and navigate to the ‘Y’ (i.e. y-axis), which should be visible on the right-hand side of the graph. Press select and choose ‘Time Between Gates’. This will now appear on the right of the graph. The left axis should already be displaying “Velocity in Gates”.
- You can now record data by pressing .
- On the graph screen, velocity will be displayed as a line and the time taken to travel between gates will be displayed as both a single point on the graph and as a numerical value along the right-hand side Y axis of the graph.
- To read the data from your completed run accurately, press F3 and select ‘Smart Tool’. Use the navigation buttons to see the precise values for the points on the graph.
- To save your experimental data, use the arrow keys to highlight your data file in the RAM memory and press “F4 files”. Select the “copy file” option and then choose the external USB as the destination for the file, and press “F1 OK”. Transfer the USB data stick to the lab computer and create a graph.

Procedure

- On the data-logger, press to begin recording data, and again after the cart has completed a run.
- Record the total mass being accelerated (i.e. the mass of the cart, the metal block on the cart, the ring-weight). Release the cart and record its velocity and time as it passes each photogate.
- Add a metal bar to the cart to increase its mass and repeat the above steps.
- Repeat until you have added three metal bars. Be sure that the metal bars are not stacked too high i.e. that they do not trigger the photogate.

Data:

Mass of ring, m_{ring} (kg)	Mass of cart, m_{cart} (kg)	Velocity 1, v_1 (m/s)	Velocity 2, v_2 (m/s)	Time 1, t_1 (s)	Time 2, t_2 (s)	Acceleration, a (m/s ²)

- Calculate the acceleration (i.e. the change in velocity during a given time interval):

$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

- On the blue data-logger, use the arrow keys to highlight your data file in the RAM memory and press "F4 files". Select the "copy file" option and then choose the external USB as the destination for the file, and press "F1 OK". Before transferring the USB data stick to the lab computer to create a graph, we must decide what to put on the x and y axes (see below).

Results

If Newton's 2nd Law is indeed, $F = m a$, it will plot as a straight line i.e., it will take the form:

$$y = k x + c$$

where k is the gradient (slope), and c is what we will call the intercept (the value of y where x is zero). Here we refer to k instead of the traditional m for the gradient of a straight line, because we have already used m to mean mass.

In this investigation, we kept the force constant and increased the mass in order to investigate how acceleration changes. Therefore, we put mass on the x-axis and acceleration on the y-axis. How can we rearrange Newton's 2nd Law into the mathematical format of a straight line graph, where the x-axis is the mass and the y-axis is the acceleration?

We could rearrange $F = m a$ into the format $y = k x + c$ as follows:

$$\frac{1}{a} = \frac{1}{F} m$$

where a is acceleration, F is force, m is mass and $c = 0$

We know m is mass, but which mass? (Circle the correct answer below)

- i) $m = m_{cart}$
- ii) $m = m_{ring}$
- iii) $m = m_{cart} + m_{ring}$
- iv) $m = m_{cart} - m_{ring}$

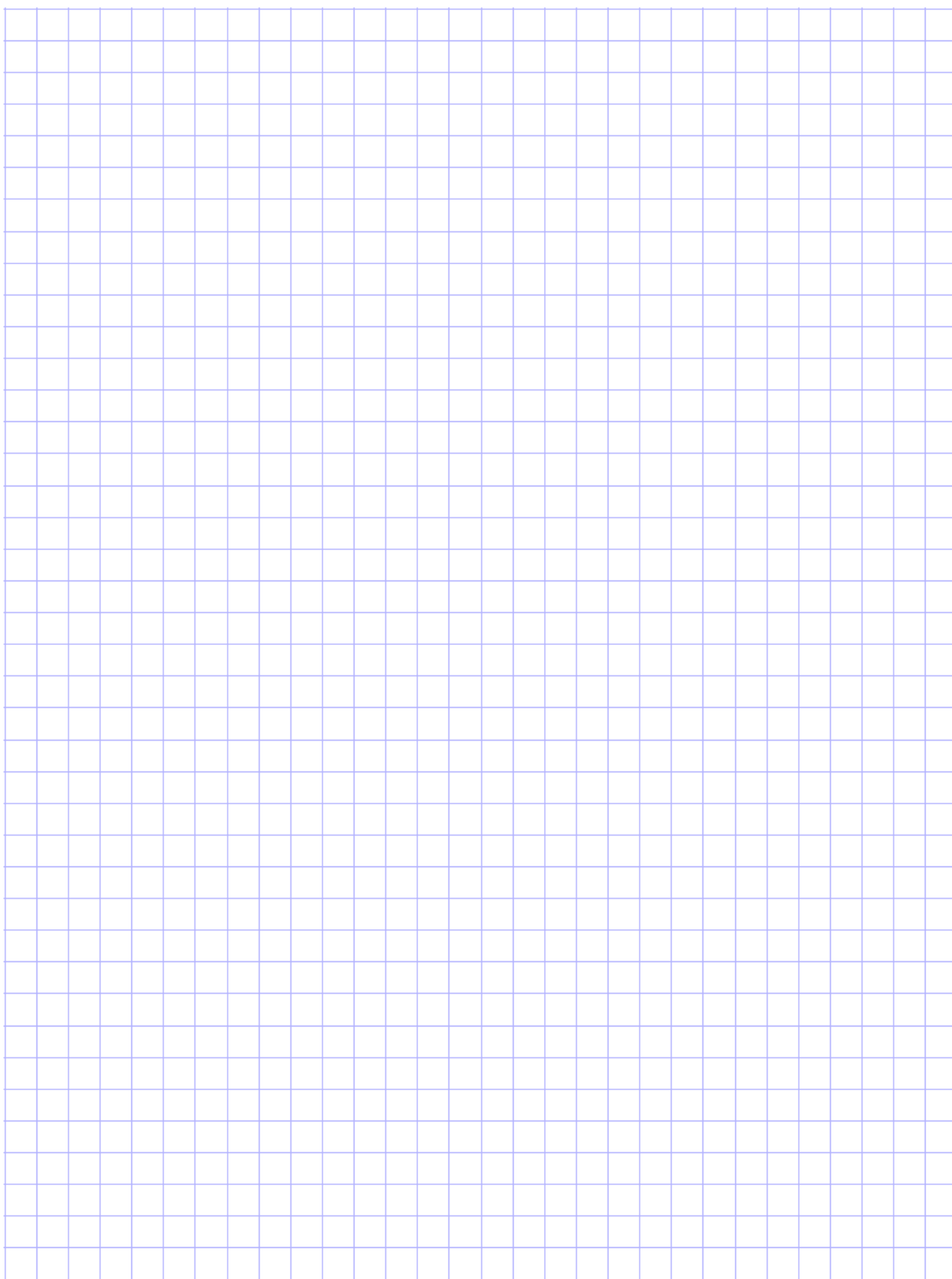
The cart and ring are connected together and so they have the same magnitude of acceleration, a , and the net mass moving is $m_{cart} + m_{ring}$. Thus, we can more usefully rearrange our equation as follows:

$$\begin{aligned}\frac{1}{a} &= \frac{1}{F} (m_{cart} + m_{ring}) \\ &= \frac{1}{F} m_{cart} + \frac{1}{F} m_{ring}\end{aligned}$$

Now, for this case where $\frac{1}{a}$ is the y-axis and m_{cart} is the x-axis, which term is the slope of this graph? And which term is the intercept i.e., the value of y where x is zero?

Plot your experimental data, with $\frac{1}{a}$ as the y-axis and m_{cart} as the x-axis. If the graph is a straight line, then you have verified Newton's 2nd Law.

Plot your graph by hand on this page and make your best estimate for a straight line fit to your data. *Note, your tutor will account for your fitting by hand.*
Important: take care to label axes correctly and include units.



You can now find a value for F in two separate ways and compare them for accuracy, as follows:

From your graph determine the slope, and hence calculate F .

From your graph determine the intercept, and hence calculate F .

Compare your value of F determined in the two different ways above, determine the best value of F and estimate the uncertainty on your resulting value for F .

From the value you found for F , calculate the acceleration due to gravity, g . How does it compare to the generally accepted value of g ?

Hint: because we use a pulley, the force, F also acts vertically on the ring. The vertical motion of the ring can therefore be considered under solely this tension force F and the force due to gravity, $m_{ring}g$.

Conclusion

We sought to experimentally verify Newton's 2nd Law, $F = m a$.
State Newton's 2nd Law in your own words:

Implications

If you simultaneously drop a bowling ball and a billiard ball, they will hit the ground at the same time. This means that they were both accelerated at the same rate. What is this rate?

Does the bowling ball experience a larger, smaller or the same force as the billiard ball?
Use Newton's 2nd Law to justify your answer.

A car of mass, m , is pulled into motion in a straight line by a lorry exerting a force, F on a rope. Assuming no friction, determine the acceleration of the car where the rope is aligned along the same direction as the car's motion.

UCD Physics Laboratory: Investigation of Heat Capacity

Student Name: _____

Student Number: _____

Lab Partner Name: _____

Demonstrator Name: _____

Lab Date/Time: _____

Goal

You will experimentally investigate the validity of a physical law. After this session, you will have more understanding of the process of experimental verification, and how the law you are testing is relevant to everyday experiences. You do not need prior knowledge of this topic to participate in this laboratory session.

Specifically, you will determine the heat capacity of two metals from measurements you make of their temperature on being heated.

Warm-up exercises

Heat can be thought of as energy that flows from one object to another due to their temperature difference. We will use the variable, Q for an amount of heat and this is in units are Joules, J. When we heat an object, we increase the object's internal energy and as a result let's say we increase its temperature, T by an amount, ΔT .

Heat Capacity for an object is defined as $Q/\Delta T$. So where different objects, of different forms and materials, experience different increases in temperature after receiving the same amount of heat, we can say that they have different Heat Capacities.

Which do you think takes more energy, to heat a bath of water from 20 °C to 30 °C, or to heat a cup of coffee from 20 °C to 30 °C? Bath / Coffee

For the same value of ΔT , two identical objects where combined will require double the amount of heat as just one of the objects. This is required for the law of Conservation of Energy to be obeyed. It follows that it takes more heat to increase the temperature of a more massive object, and we find that the heat capacity for an object depends on its mass. To best define a property for a material, we use the idea of Specific Heat Capacity, which is the Heat Capacity per kilogram of the material. As such, Specific Heat Capacity, c is defined as:

$$c = \frac{Q}{m \Delta T}$$

where the heat supplied is Q in units of Joules, the mass is m in units of kg, the temperature change is ΔT in units of degrees Celsius, °C, or equivalently in Kelvin, K, given this is a temperature difference.

We can see from this equation that the Specific Heat Capacity is the energy transferred to raise the temperature of a 1 kg object by 1 °C. Maybe a better name for it would have

been 'Specific Energy Transfer', but the name 'Specific Heat Capacity' was arrived at before we had understanding of conservation of energy in thermodynamics.

Write here the units for specific heat capacity, worked out from its definition in the previous equation:

In this laboratory session, we will add an amount of heat (Q) to a metal sample of known mass (m) and measure the resulting temperature change (ΔT). From this, we will calculate the specific heat capacity (c). We will do this for an aluminium block and for a copper block.

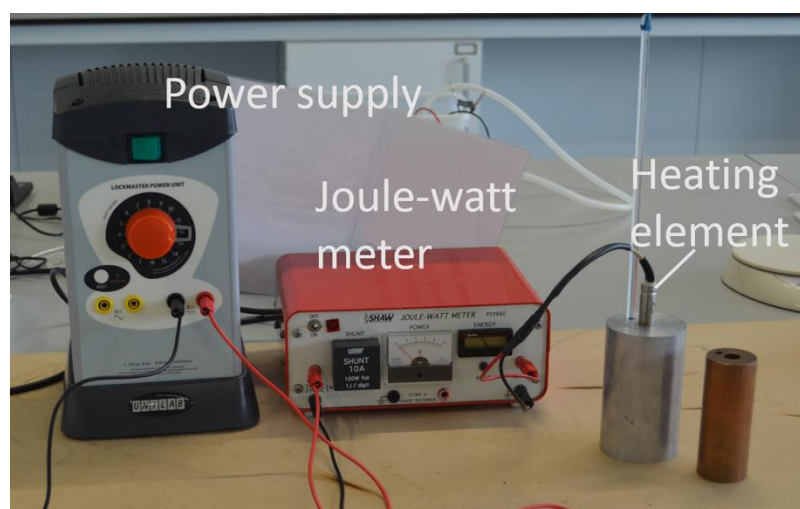
Safety

- Do not place the metal blocks or the heating element directly onto the lab bench. Use an insulating mat.
- Take care when handling the metal blocks and the heating element, as they can be hot.
- Switch off all of the apparatus when you have completed the experiment.

Apparatus

- Power supply
- Joule-Watt meter (meter which measures energy)
- Heating element (metal rod/element which inserts into the centre of the metal blocks)
- Aluminium block, mass 1 kg
- Copper block, mass 1 kg
- Thermometer
- Stop-watch

Experiment: Measuring the heat capacity of two metals, aluminium and copper



Experimental Set-up

We will use electricity to generate heat. As current flows through the heating element, its temperature increases.

- Place the heating element into the central hole of the metal block (start with the aluminium block).

We then need to connect the heating element to the power supply. However, to measure the amount of heat energy generated (Joules), we must include a Joule meter in our circuit also.

- Connect the positive (red) and negative (black) sockets of the Joule-Watt meter to the positive and negative sockets of power supply.
- Connect the two wires of the heating element to the Joule-Watt meter (where it says 'load'), according to the positive and negative polarity.
- Set the power supply to 12 volts DC.
- Insert the thermometer into the other hole in the metal block, to allow measurement of temperature ($^{\circ}\text{C}$).

Procedure

- Record the initial temperature of the block, T_1 , at time $t_1 = 0$.
- Press reset on the Joule-Watt meter and reset the timer.
- Switch on the power supply and start the stop-watch.
- Insert the heating element as far as possible into the block and measure the fraction of the length of the heating element which is inserted. Let's call this fraction, f . Record these fractions here:

	Fraction of element inserted, f
Aluminium	
Copper	

- Record the energy supplied to the heating element according to the Joule-Watt meter.
- Scale the Joule-Watt meter reading, E , according to the fraction of the heating element inserted in the block, f , to get the heat energy transferred to the block, Q i.e., $Q = f E$.
- Record the temperature at one-minute intervals, until the temperature has risen by 20 degrees or after 20 minutes, whichever comes first. This is time, t_1 .
- Switch off the power supply and wait for the temperature to begin to lower. Then begin recording measurements of the temperature as a function of time as the block cools, starting from what we will call time, t_2 .

Data

Record your data on the following page

Aluminium, Al		
Time, t (minutes)	Heat transferred, $Q = f E$ (J)	Temp, T (°C)
Heating		
0 (t_0)		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20 (t_1)		
Cooling (no heating)		
Time, t (minutes)	X	Temp, T (°C)
0 (t_2)		
1		
2		
3		
4		
5		
6		
8		
10		
12		
14		
16		

Copper, Cu		
Time, t (minutes)	Heat transferred, $Q = f E$ (J)	Temp, T (°C)
Heating		
0 (t_0)		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20 (t_1)		
Cooling (no heating)		
Time, t (minutes)	X	Temp, T (°C)
0 (t_2)		
1		
2		
3		
4		
5		
6		
8		
10		
12		
14		
16		

Results

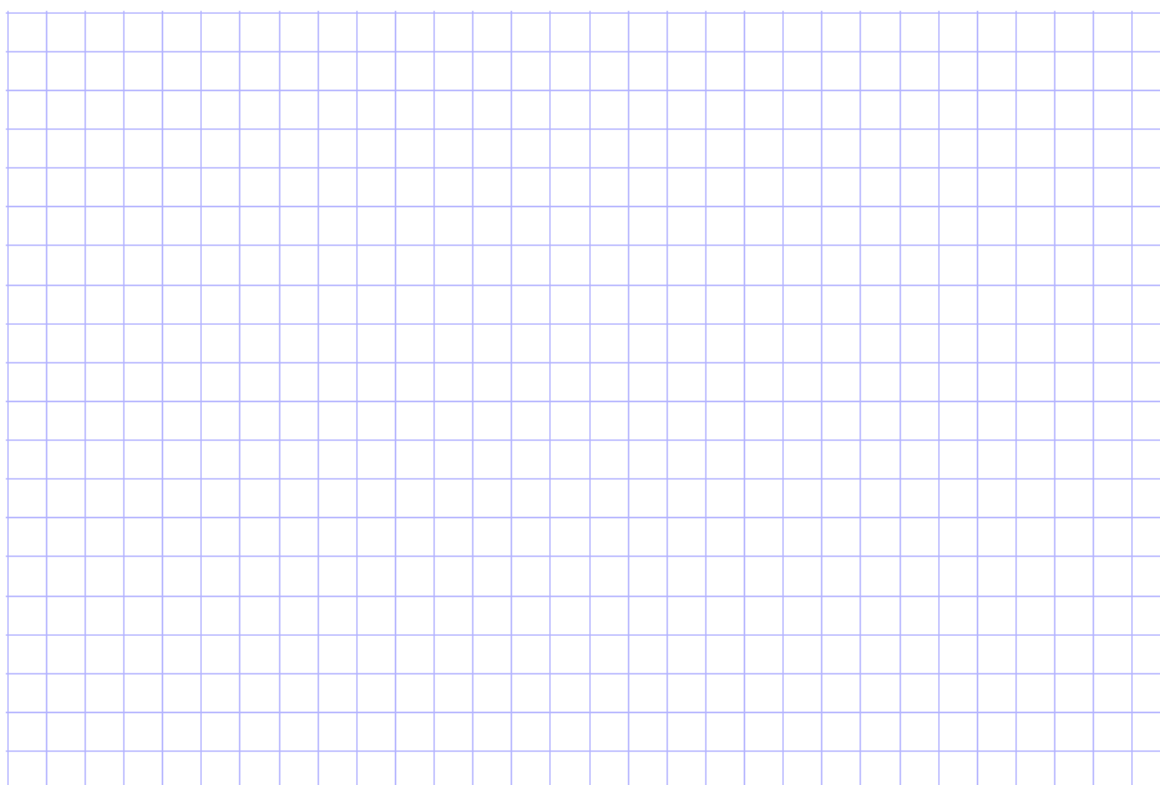
Make plots by hand on the following page, or, use JagFit (see back of manual) and attach your two printed graphs to this page. Label axes correctly and include units.

Note, your tutor will account for fitting done by hand.

a) Plot the temperature difference, $\Delta T = T(t) - T(t_0)$ along the y-axis, as a function of the heat supplied to the block, Q along the x-axis. This is your data from time t_0 to t_1 . Do this for both the Al and the Cu blocks:



b) Now plot temperature, $T(t)$ along the y-axis, as a function of time, t along the x-axis, when the blocks are cooling. This is your data starting from time t_2 . Do this for both the Al and the Cu blocks:



Describe the relationship between the parameters, ΔT and Q in your plot 'a'.

Determine the slopes for your best straight-line fits to your Al and Cu points on your first graph (graph a). Give these values here, including units:

Al:

Cu:

A general straight-line graph is given by the equation $y = n x + k$, where n is the slope and k is the value of y where the line intercepts the y -axis i.e., where $x = 0$. It's typical to refer to ' m ' and ' c ' for the gradient and intercept, but you'll remember we are already using these variables for defining Specific Heat Capacity as $c = \frac{Q}{m \Delta T}$. Maybe more usefully here, we can rearrange this equation for heat capacity to give: $\Delta T = \left(\frac{1}{mc}\right) Q$.

What might you expect the gradients from your first plot to be equivalent to in terms of m and c ? Explain.

From these gradients, calculate the specific heat capacity of the two metals and compare them to the generally accepted values as measured by others.

Metal	Specific Heat Capacity, as measured by you (J kg ⁻¹ °C ⁻¹)	Specific Heat Capacity, generally accepted values (J kg ⁻¹ °C ⁻¹)
Aluminium		960
Copper		385

Your results likely differ from these generally accepted values. But we haven't yet considered heat transfers out of the block via air-conduction or radiative emission (the giving off of infrared light). These can be significant heat loss mechanisms. Let's turn to think about this now.

By inspecting plot 'b' (for when both blocks were cooling), arrive at estimates for the heat lost from the block during the times you were heating each of the blocks. Give these estimates and your reasoning here. Also annotate your plot 'b' to help clearly convey your reasoning.

From this, make an estimate for the fraction (percentage) of heat lost relative to that imparted to each block, during the time the heating element was switched on.

Critical thinking. Does your above consideration of heat loss, quantitatively explain the discrepancy between your measured values and the generally accepted values for the heat capacities?

Can you suggest an additional mechanism that might contribute to a discrepancy?

Conclusions

In this experiment, we explored the relationship between heat and temperature and we measured the specific heat capacity, c , for two metals.

The words, 'heat' and 'temperature' are often confused in everyday life. We might hear it said that the 'fridge door was opened and the cold got out', or 'the water in the kettle contains a lot of heat'. Clearly state what heat, Q , really is:

Implications

1. An electric heater supplies 18 kJ of heat energy to a metal block of mass 0.5 kg. The temperature of the block rises from 20 °C to 100 °C during the heating process. Assuming that very little heat is lost from the block during heating, determine (and explain here) the specific heat capacity of the metal. Can you make a case here for what element this metal is (which forms the Earth's core) by its specific heat capacity?

Ans. $450 \text{ J kg}^{-1} \text{ }^{\circ}\text{C}^{-1}$

2. Estimate how much heat energy is required to boil just enough water to make two full cups of tea? Let's say a full cup is 250 ml.

Ans. about 170kJ

UCD Physics Laboratory: Investigation of Fluid Flow

Student Name: _____

Student Number: _____

Lab Partner Name: _____

Demonstrator Name: _____

Lab Date/Time: _____

Theory

When a fluid moves through a channel of varying width, as in a Venturi apparatus, the volumetric flow rate (volume/time) remains constant but the velocity and pressure of the fluid vary. In the Venturi apparatus there are two different channel widths.

The flow rate, Q , of the fluid through the tube is related to the speed of the fluid (v) and the cross-sectional area of the pipe (A). This relationship is known as the **continuity equation**, and can be expressed as

$$Q = A_0 v_0 = A v \quad (\text{Eq.1})$$

where A_0 and v_0 refer to the wide part of the tube and A and v to the narrow part. As the fluid flows from the narrow part of the pipe to the constriction, the speed increases from v_0 to v and the pressure decreases from P_0 to P .



Figure 1: Fluid flow through a pipe of varying diameter

If the pressure change is due only to the velocity change, a simplified version of Bernoulli's equation can be used:

$$P = P_0 - \frac{\rho}{2} \{v^2 - v_0^2\} \quad (\text{Eq. 2})$$

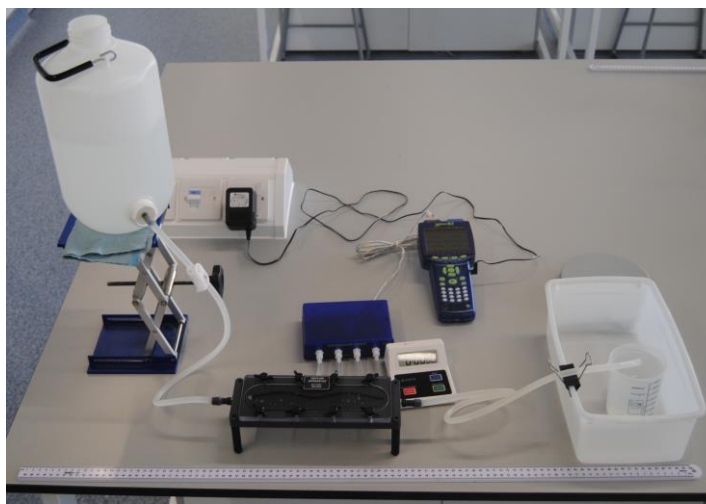
Here ρ is the density of water: 1000 kg/m³.

The flow rate also depends on the pressure, P_0 , behind the fluid flowing into the apparatus. In this experiment the pump provides the pressure that makes the fluid flow through the apparatus. The higher the power to the pump the greater the pressure and the faster the fluid flows.

In this experiment you will use the Venturi apparatus to investigate fluid flow and verify that equation 2 holds. You will also investigate how the voltage supplied to the pump affects the pressure and flow rate.

Apparatus

The apparatus consists of a reservoir, which is a plastic box, of water connected to a Venturi apparatus through which the water can flow into a collecting beaker, itself placed in a box. The electrical pump in the box causes the water flow in the apparatus.



Procedure

Using the spare apparatus in the laboratory, measure the depth of the channel and the widths of the wide and narrow sections. Calculate the large (A_0) and small (A) cross-sections by multiplying the depth by the width for the two sections of the apparatus.

Depth _____ Width(large) _____ Width (narrow) _____
Area (A_0) _____ Area (A) _____

Before putting any water in the apparatus, connect the Venturi apparatus to the Quad pressure sensor and GLX data logger.

1. Connect the tubes from the Venturi apparatus to the Quad Pressure Sensor. Ensure that they are connected in the right order. The one closest to the flow IN to the apparatus is connected to number 1 etc.
2. Connect the GLX to the AC adapter and power it up.
3. Connect the Quad Pressure sensor to the GLX. A graph screen will appear if this is done correctly.
4. Navigate to the home screen (Press "home" key) and then navigate to 'Digits' and press select. Data from two of the four sensors should be visible.
5. To make the data from all four sensor visible press the F2 key. All sensor input should now be visible.
6. Make sure that the eight fixing taps on the Venturi apparatus are all just finger tight. Fill the reservoir so that the pump is fully submerged in the plastic box. **Ensure that the outlet of the apparatus is in the beaker which is in the box.** Turn on the power supply to the pump and set the voltage to 10V. Remove any air bubbles by gently tilting the outlet end of the Venturi apparatus upwards.
7. Calibrate the sensors, using the atmospheric pressure reading:
 - (i) Press "home" and "F4" to open the sensors screen.
 - (ii) Press "F4" again to open the sensors menu.
 - (iii) From the menu, select "calibrate" to open the calibrate sensors window.
 - (iv) In the first box of the window, select "quad pressure sensor".
 - (v) In the third box of the window, select "calibrate all similar measurements".
 - (vi) In the "calibration type" box, select "1 point offset".
 - (vii) Press "F3", "read pt 1".
 - (viii) Press "F1", "OK".

Measure the time that it takes for 400 ml ($0.4\text{ l} = 4 \times 10^{-4} \text{ m}^3$) of water to flow through the Venturi apparatus. Be sure to read the water level by looking at the bottom of the meniscus.

When the flow is steady note the pressures on the four sensors. Enter your data in the table. Repeat the measurements twice more. **Be sure to return all the water to the reservoir (plastic box). Make sure that the apparatus stays free of air bubbles.**

Run	P ₁ /kPa	P ₂ /kPa	P ₃ /kPa	P ₄ /kPa	Time /s
1					
2					
3					
Average					

Calculate the flow rate, Q, volume/time, from the average value of the time taken for 400 ml to flow through the apparatus. $1\text{ ml} = 1\text{ cm}^3 = 1 \times 10^{-6} \text{ m}^3$.

Use equation (1) and the cross-sectional areas that you calculated to work out the velocity of the water in the wide (v_0) and narrow (v) sections of the apparatus.

$v_0 =$ _____

$v =$ _____

Which is larger v or v_0 , is this what you expected?

If the apparatus was not constricted the pressure at point 2 (P_0) is equal to the average value of P_1 and P_3 . Use your average values of P_1 and P_3 to calculate P_0 :

$P_0 = 1/2(P_1 + P_3)$ _____

Use equation 2 and your values for P_0, v_0 and v to calculate a value for P , the pressure in the narrow section of the apparatus. The SI unit for pressure is the Pascal (Pa), $1\text{kPa} = 1000\text{ Pa} = 1000\text{ N/m}^2 = 1000\text{ kg s}^{-2}\text{ m}^{-1}$.

$P =$ _____

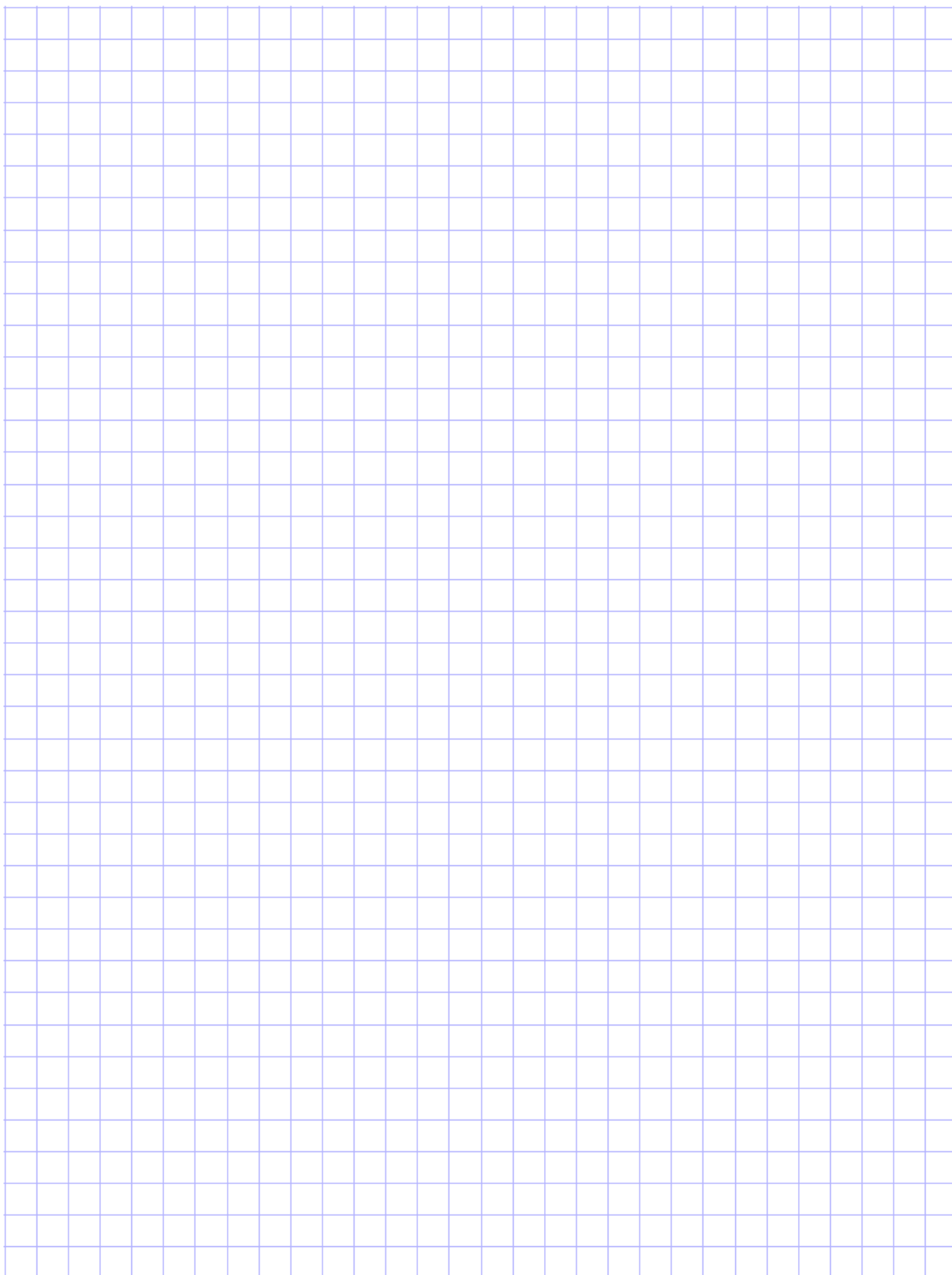
How does your value for the pressure in the constriction compare to the measured values P_2 and P_4 ? You might consider how precisely you can determine both the calculated and measured pressures.

Next measure the pressure as for five different pump supply voltages to the pump. Be sure to let the flow stabilise before taking your readings. Complete the table below.

Voltage /V	P_1 /kPa	P_2 /kPa	P_3 /kPa	P_4 /kPa	Average of P_1 and P_3 /kPa	Average of P_2 and P_4 /kPa
5						
6						
8						
10						
12						

When you have finished, allow the reservoir to run empty and tilt the Venturi apparatus to empty water from it. Once the apparatus is empty of water remove the pressure tubes from the sensor by gently twisting the white plastic collars that connected the hoses to the sensor (leave the tubes connected to the underside of the Venturi apparatus). Empty as much water as you can from the apparatus and then **all of the water into the sink in the laboratory.**

Plot the two average pressures on the same graph, as a function of pump voltage. Do this by hand on this page, or, use JagFit (see back of manual) and attach your printed graphs to this page. Label axes correctly and include units. *Note, your tutor will account for fitting done by hand.*



Comment on your graph, is it consistent with what you expected to happen?

What can you conclude from this part of the experiment?

UCD Physics Laboratory: Investigation of Archimedes' Principle

Student Name: _____

Student Number: _____

Lab Partner Name: _____

Demonstrator Name: _____

Lab Date/Time: _____

Introduction

All the technology we take for granted today, from electricity to motor cars, from television to X-rays, would not have been possible without a fundamental change, around the time of the Renaissance, to the way people questioned and reflected upon their world. Before this time, great **theories** existed about what made up our universe and the forces at play there. However, these theories were potentially flawed since they were never tested. As an example, it was accepted that heavy objects fall faster than light objects – a reasonable theory. However it wasn't until Galileo¹ performed an **experiment** and dropped two rocks from the top of the Leaning Tower of Pisa that the theory was shown to be false. Scientific knowledge has advanced since then precisely because of the cycle of **theory and experiment**. It is essential that every theory or hypothesis be tested in order to determine its veracity.

Physics is an experimental science. The theory that you study in lectures is derived from, and tested by experiment. Therefore in order to prove (or disprove!) the theories you have studied, you will perform various experiments in the practical laboratories.

First though, we have to think a little about what it means to say that your experiment confirms or rejects the theoretical hypothesis. Let's suppose you are measuring the acceleration due to gravity and you know that at sea level theory and previous experiments have measured a constant value of $g=9.81\text{m/s}^2$. Say your experiment gives a value of $g=10\text{ m/s}^2$. Would you claim the theory is wrong? Would you assume you had done the experiment incorrectly? Or might the two differing values be compatible?

What do you think?

¹ Actually, the story is probably apocryphal. However 11 years before Galileo was born, a similar experiment was published by Benedetti Giambattista in 1553.

Experimental Uncertainties

When you make a scientific measurement there is some ‘**true**’ value that you are trying to estimate and your equipment has some intrinsic **uncertainty**. Thus you can only estimate the ‘true’ value up to the uncertainty inherent within your method or your equipment. Conventionally you write down your measurement followed by the symbol \pm , followed by the uncertainty. A surveying company might report their results as 245 ± 5 km, 253 ± 1 km, 254.2 ± 0.1 km. You can interpret the second number as the ‘margin of error’ or the **uncertainty** on the measurement. If your uncertainties can be described using a Gaussian distribution, (which is true most of the time), then the true value lies within one or two units of uncertainty from the measured value. There is only a 5% chance that the true value is greater than two units of uncertainty away, and a 1% chance that it is greater than three units.

Errors may be divided into two classes, systematic and random. A **systematic error** is one which is constant throughout a set of readings. A **random error** is one which varies and which is equally likely to be positive or negative. Random errors are always present in an experiment and in the absence of systematic errors cause successive readings to spread about the true value of the quantity. If in addition a systematic error is present, the spread is not about the true value but about some displaced value.

Estimating the experimental uncertainty is at least as important as getting the central value, since it determines the range in which the truth lies.

Practical Example:

Now let’s put this to use by making some very simple measurements in the lab. We’re going to do about the simplest thing possible and measure the volume of a cylinder using three different techniques. You should compare these techniques and comment on your results.

Method 1: Using a ruler

The volume of a cylinder is given by $\pi r^2 h$ where r is the radius of the cylinder and h its height.

Measure and write down the height of the cylinder.
Don’t forget to include the uncertainty and the units.

$h = \quad \pm$

Measure and write down the diameter of the cylinder.

$d = \quad \pm$

Now calculate the radius.
(Think about what happens to the uncertainty)

$r = \quad \pm$

Calculate the radius squared – with it’s uncertainty!

$r^2 = \quad \pm$

One general way of determining the uncertainty in a quantity f calculated from others is to use the following method..

- From your measurements, calculate the final result. Call this f , your answer.
- Now move the value of the source up by its uncertainty.
Recalculate the final result. Call this f^+ .
- The uncertainty on the final result is the difference in these values.

Finally work out the volume. Estimate how well you can determine the volume.

(Show your workings)

$$V = \pm$$

Method 2: Using a micrometer screw

This uses the same prescription. However your precision should be a lot better.

Measure and write down the height of the cylinder.
Don't forget to include the uncertainty and the units.

$$h = \pm$$

Measure and write down the diameter of the cylinder.

$$d = \pm$$

Now calculate the radius.

$$r = \pm$$

Calculate the radius squared, along with it's uncertainty

(Show your workings)

$$r^2 = \pm$$

Finally work out the volume.

(Show your workings)

$$V = \pm$$

Method 3: Using Archimedes' Principle

You've heard the story about the 'Eureka' moment when Archimedes dashed naked through the streets having realised that an object submerged in water will displace an equivalent volume of water. You will repeat his experiment (the displacement part at least) by immersing the cylinder in water and working out the volume of water displaced. You can find this volume by measuring the mass of water and noting that a volume of 0.001m^3 of water has a mass² of 1kg.

² In fact this is how the metric units are related. A litre of liquid is that quantity that fits into a cube of side 0.1m and a litre of water has a mass of 1kg.

Write down the mass of water displaced.

\pm

Calculate the volume of water displaced.

\pm

What is the volume of the cylinder?

\pm

Discussion and Conclusions.

Summarise your results, writing down the volume of the cylinder as found from each method.

\pm

\pm

\pm

Comment on how well they agree, taking account of the uncertainties.

Can you think of any systematic uncertainties that should be considered? Can you estimate their size?

Requote your results including the systematic uncertainties.

\pm \pm

\pm \pm

\pm \pm

What do you think the volume of the cylinder is? and why?

My best estimate of the volume is

\pm \pm

because _____

UCD Physics Laboratory: Investigation of Rotational Motion

Student Name: _____ **Student Number:** _____
Lab Partner Name: _____ **Demonstrator Name:** _____
Lab Date/Time: _____

What should I expect in this experiment?

This experiment introduces you to some key concepts concerning rotational motion. These are: torque (τ), angular acceleration (α), angular velocity (ω), angular displacement (θ) and moment of inertia (I). They are the rotational analogues of force (F), acceleration (a), velocity (v), displacement (s) and mass (m), respectively.

Pre-lab assignment

What is the angular velocity of a spinning disk that completes 2 full revolutions in 10 seconds?

Introduction:

The equations of motion with constant acceleration are similar whether for linear or rotational motion:

Linear	Rotational	
$v_{average} = \frac{s_2 - s_1}{t_2 - t_1}$	$\omega_{average} = \frac{\theta_2 - \theta_1}{t_2 - t_1}$	Eq.1
$v_{average} = \frac{v_1 + v_2}{2}$	$\omega_{average} = \frac{\omega_1 + \omega_2}{2}$	Eq.2
$v_2 = v_1 + at$	$\omega_2 = \omega_1 + \alpha t$	Eq.3
$s_2 = v_1 t + \frac{at^2}{2}$	$\theta_2 = \omega_1 t + \frac{\alpha t^2}{2}$	Eq.4

Furthermore, just as a force is proportional to acceleration through the relationship $F=ma$, a net torque changes the state of a body's (rotational) motion by causing an angular acceleration.

$$\tau = I\alpha \quad \text{(Eq.5)}$$

The body's moment of inertia is a measure of resistance to this change in rotational motion, just as mass is a measure of a body's resistance to change in linear motion.

The equation $\tau = I\alpha$ is the rotational equivalent of Newton's 2nd law $F = ma$.

You will use two pieces of apparatus to investigate these equations. The first lets you apply and calculate torque, measure angular acceleration and determine an unknown moment of inertia, I of a pair of cylindrical weights located at the ends of a bar. The second apparatus lets you investigate how I depends on the distribution of mass about the axis of rotation and lets you determine the value of I , already measured in the first part, by a second method. You can then compare the results you obtained from the two methods.

Investigation 1: To measure the moment of inertia, I , from the torque and angular acceleration.

Place cylindrical masses on the bar at their furthest position from the axis of rotation. The bar is attached to an axle which is free to rotate. The masses attached to the line wound around this axle are allowed to fall, causing a torque about the axle



The value of the torque caused by the falling masses is $\tau = Fr$ where F is the weight of the mass attached to the string and r is the radius of the axle to which it is attached. Calculate the value of τ .

Mass, m attached to string (kg)	
Force, $F = m \cdot g$ (N)	
Radius, r of axle (m)	
Torque, $\tau = F \times r$ (Nm)	

In this session, you will calculate the angular velocity, ω , and the angular acceleration, α . Distinguish between these two underlined terms.

$\alpha =$

Using Eq.1, calculate the average velocity, $\omega_{average}$, during each rotation and fill in the table below.

If angular acceleration is constant, then $\omega_{average}$ is equal to the instantaneous velocity at the time half-way between the start and the end of a rotation, t_{mid} . Can you understand this? Explain.

Enter the values in the table below and **make a plot** of $\omega_{average}$ on the y-axis against t_{mid} on the x-axis.

Number of Rotation	$\omega_{average}$ (rad / s)	t_{mid} (s)
1		
2		
3		
4		
5		

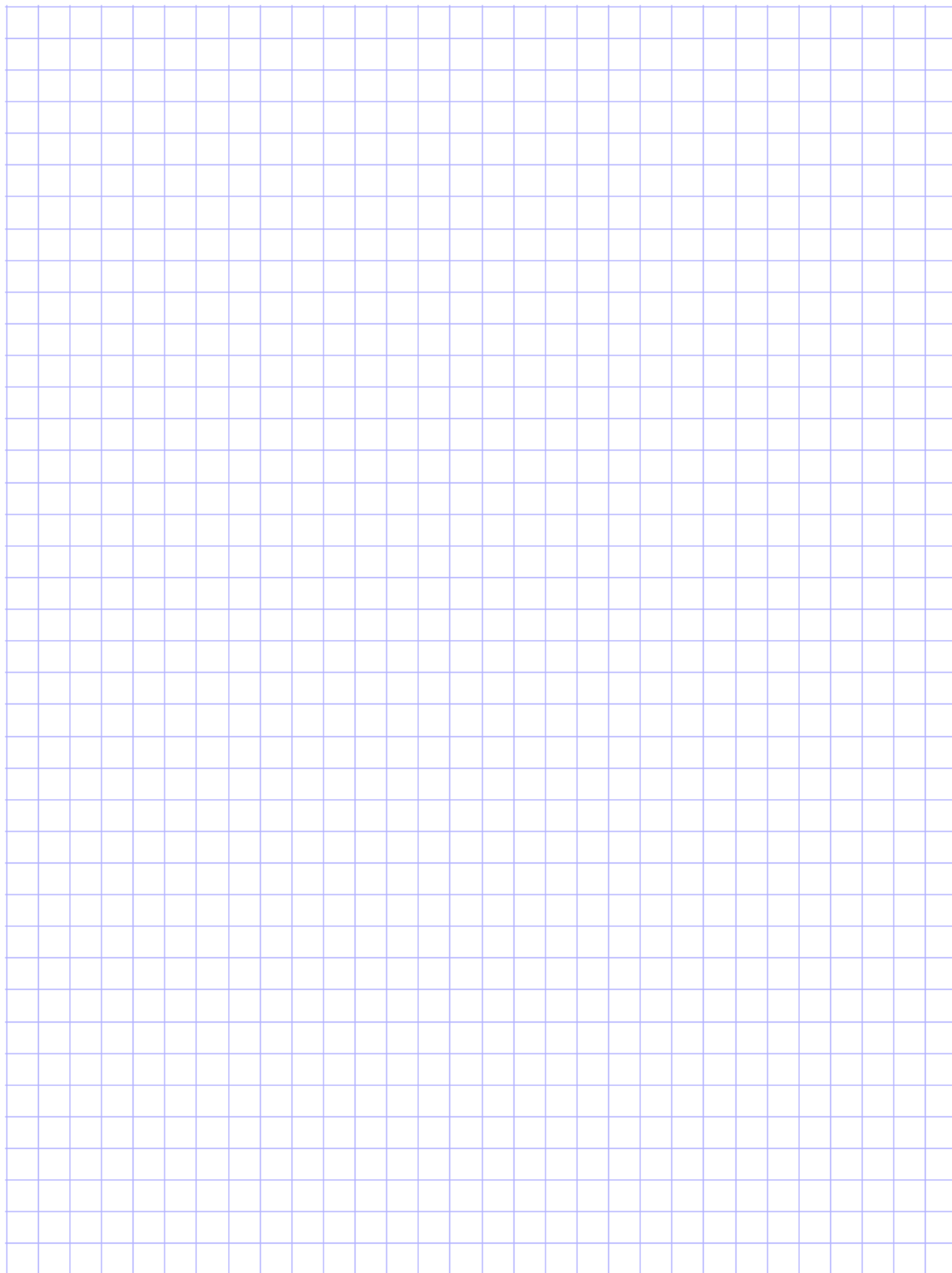
Since this graph gives the instantaneous velocity at a given time, Eq. 3 can be used to find the angular acceleration, α .

What value do you get for α ?

Now you know τ and α , so work out I from Eq. 5.

Create your graph of $\omega_{average}$ on the y-axis against t_{mid} on the x-axis.

Do the following plot by hand on this page, or, use JagFit (see back of manual) and attach your printed graph to this page. Important: take care to label axes correctly and include units. *Note, your tutor will account for fitting where done by hand.*



Investigation 2: To determine how the moment of inertia, I , depends on the distribution of mass in a body.

Take the metal bar on the bench and roll it between your hands. Now hold it in the middle and rotate it about its centre so that the ends are moving most. Which is easier? Which way does the bar have a higher value of I ?

Attach the weights and the bar to the rotational apparatus known as a **torsion axle**. This consists of a vertical axle connected to a spring which opposes any departure from the angle of rotational equilibrium.

Note: The apparatus is delicate. So as not to damage the spring, please keep the rod to within half a rotation from equilibrium.



When you rotate the bar, the spring causes a torque about the axis of rotation which acts to restore the bar to the equilibrium angle. Usually the bar overshoots, causing an oscillation to occur. This is exactly analogous to the way a mass on a linear spring undergoes simple harmonic motion. The period of the oscillations, T , is determined by the restoring torque in the spring, D , and the moment of inertia, I , of the object rotating, in this case the bar and cylindrical weights. They are related by:

$$T = 2\pi\sqrt{\frac{I}{D}}$$

The value of D is written on each torsion axle. Note it here.

--

To investigate the influence of mass distribution vary the position of the cylinders along the torsion bar, measure the period of oscillation, T , and use the equation above to calculate the moment of inertia, I for the combined system of cylinders plus rod. (To improve the precision with which you measure T take the average over 10 oscillations.)

r – Position of the cylinders along rod (m)	T – Period of oscillation (s)	I for the combined system of cylinder + bar (kgm^2)	I for the cylinders (kgm^2)
0.05			
0.10			
0.15			
0.20			
0.25			

Just as you can simply add two masses together to get the total mass (e.g. if the mass of a cylinder is 0.24kg and the mass of a bar is 0.2kg, then the mass of cylinder plus bar is 0.44kg) you can also add moments of inertia together. Given that the moment of inertia of the bar is 0.00414 kgm^2 , will let you fill in the fourth column in the table above.

Plot the value of I_{cylinder} against the position r .

Plot the value of I_{cylinder} against the position r^2 .

What do you conclude?

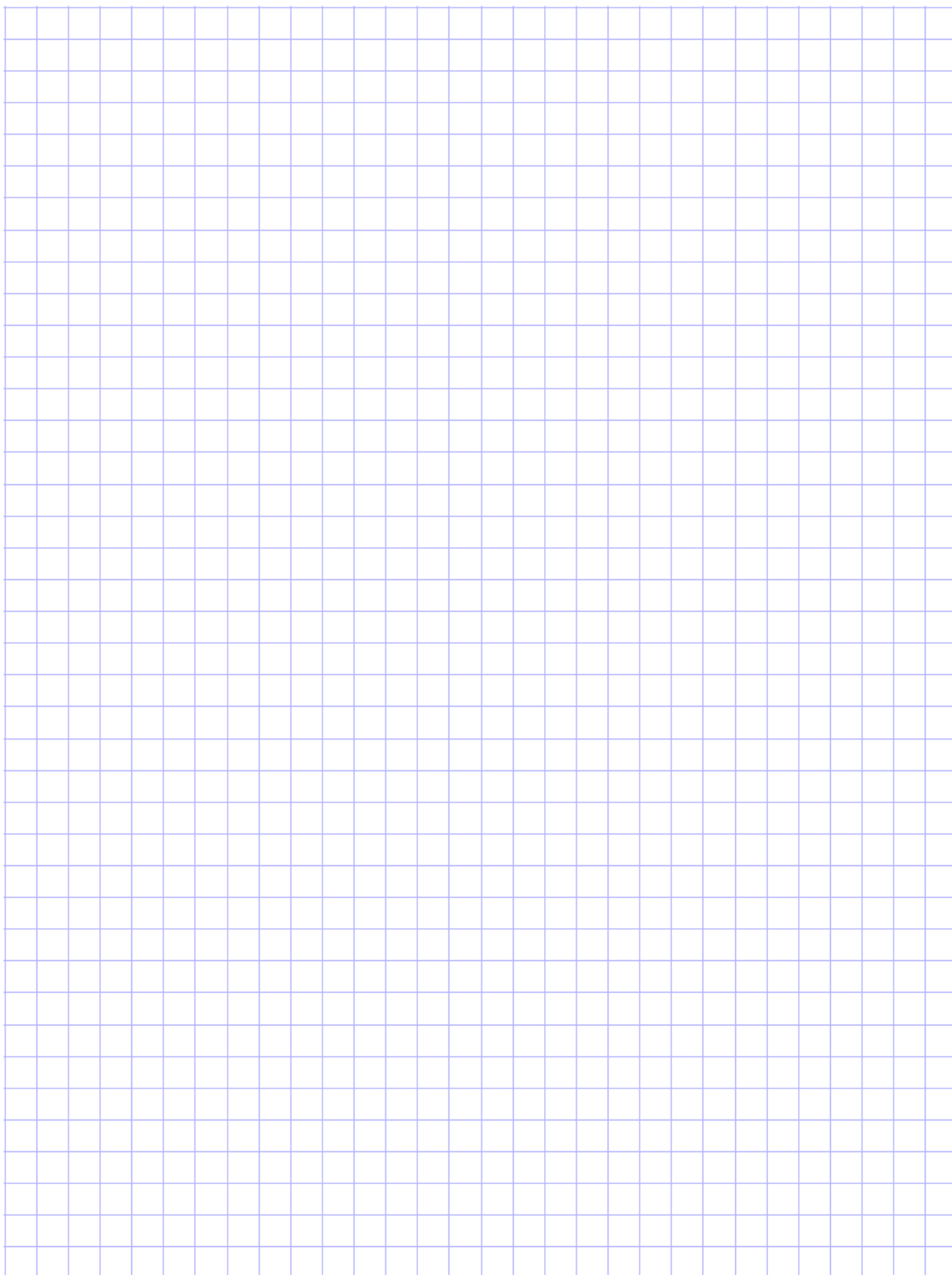
Create a graph of I_{cylinder} against the position, r .

Do the following plot by hand on this page, or, use JagFit (see back of manual) and attach your printed graph to this page. Important: take care to label axes correctly and include units. *Note, your tutor will account for fitting where done by hand.*



Create a graph of I_{cylinder} against the position, r^2 .

Do the following plot by hand on this page, or, use JagFit (see back of manual) and attach your printed graph to this page. Important: take care to label axes correctly and include units. *Note, your tutor will account for fitting where done by hand.*



The last measurement in the table above, with $r = 0.25\text{m}$, returns the bar + cylinders system to the orientation used in your first investigation. You have thus measured the moment of inertia of the bar + cylinder system in two independent ways. Write down the two answers that you got.

/ from investigation 1:

--

/ from investigation 2:

--

How do the two values compare? Which is more precise?

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Appendix 1. Graphing

Many of the experiments in the 1st Year laboratory involve the plotting of a graph. Graphs are very important in Physics as they provide a rich display of the results obtained in an experiment. One third of the human brain is devoted to images, and so we are well optimised to interact with graphs rather than with tables of numbers.

Plotting graphs by hand:

- (1) *Scale:* It is important to choose the scales so as to make full use of the squared page. The scale divisions should be chosen for convenience; that is, one unit is either 1, 2 or 5 times a power of ten e.g. 0.5, 5, 100 etc., but never 3, 7, 9 etc.
- (2) *Marking the points:* Readings should be indicated on the graph by a ringed dot \otimes and drawn with pencil, so that it is possible to erase and correct any unsatisfactory data.
- (3) *Joining the points:* In the case of a straight line which indicates a direct proportion between the variables, the ruler is positioned so that the line drawn will pass through as many points as possible. Those points which do not lie on the line should be equally distributed on both sides of the line. A point which lies away from this line can be regarded as 'doubtful' and a recheck made on the readings. In the case of a curve, the individual experimental points are not joined with straight lines but a smooth curve is drawn through them so that as many as possible lie on the curve.
- (4) *Units:* The graph is drawn on squared page. Each graph should carry title at the top e.g. Time squared vs. Length. The axes should be labelled with the name and units of the quantities involved.
- (5) In the case of a straight-line graph, the equation of the line representing the relationship between the quantities x and y may be expressed in the form

$$y = mx + c$$

where m is the slope of the line and c the intercept on the y -axis. The slope may be positive or negative. Many experiments require an accurate reading of the slope of a line.

Using JagFit

In the examples above we have somewhat causally referred to the '**best fit**' through the data. What we mean is, the curve which comes closest to the data points having due regard for the experimental uncertainties.

We can judge this really quite well by eye, but to do so isn't quantitative or reproducible between people necessarily, and so doing this manually isn't always the best way.

We can determine a straight line fit to data that varies due to random fluctuations using so-called 'least square fitting', but this requires a calculator/computer and sufficiently large data sets. At least 10 measurements are required to be usefully quantitative in this way, and more typically more than 30 measurements are needed.

A computer can make a difference where data sets are large enough then, and a plotting program called Jagfit is installed on the computers. Jagfit is freely available for download from this address:

<http://www.southalabama.edu/physics/software/software.htm>



If you are to use it, then double-click on the JagFit icon to start the program. The working of JagFit is fairly intuitive. Enter your data in the columns on the left.

- Under Graph, select the columns to graph, and the name for the axes.
- Under Error Method, you can include uncertainties on the points.
- Under Tools, you can fit the data using a function as defined under Fitting Function. Normally you will just perform a linear fit.

Three of the experiments in this manual were initially developed by the Physics Education Group, CASTeL, Dublin City University.

Appendix 2. Grading scheme

Grading is consistent with the UCD grade scale:

Net Score	lab	UCD level	UCD description
0 - 2		NG - G	wholly unacceptable
2 - 4		F - E	unacceptable - marginal
4 - 6		D - C	acceptable - good
6 - 8		B - A	very good - excellent
8 - 10		A+	excellent - exceptional

Demonstrators are asked to discuss with the 1st year labs academic coordinator, Ian Mercer, if they think their grading varies significantly from this reference.

Feedback

The net grade comprises three components for a report, the beginning, the middle and the end. Demonstrators mark this net grade as an integer (whole number) on the front of a report and also mark the three component grades within a report. The component grades are:

	Component of Report	Grade
1	Beginning – ‘Data and Preparation’	between 0 and 4
2	Middle – ‘Results’	between 0 and 4
3	End – ‘Conclusions and Implications’	between 0 and 2
Net grade		integer between 0 and 10

Demonstrators are not asked to otherwise annotate reports. Instead, the demonstrator feeds back to the class on say three main areas to improve at the start of the following lab session. Also, demonstrators respond to questions raised by individuals about their last graded report either during or after the lab session in which the report is returned.

The demonstrator submits the net (integer) grades for their class to the physics admin office immediately after their return of scripts/grades to a class, using the template excel sheet provided by the physics school admin office. Net grades are then uploaded by the school office within an additional week so as to be visible to students in their online grade centre.

Where unable to take a lab, the scheduled demonstrator finds a replacement aided by the lab manager, Thomas O'Reilly. The scheduled demonstrator primes their replacement for interaction with students on their recently graded report.

Three graded components

1. Preparation and data (the beginning)

A grade of between 0 and 4 awarded for a cumulative performance across the following:

- **Warm up.** Intro exercise/s.
- **Setup procedure.** Follow guided procedure to first useful data.
- **Method and range.** Take data in an appropriate manner and over a range of parameter space so as to allow for the most robust conclusions. This involves some critical thinking by the student and may for example involve checks or repetitions that expose hysteresis or a weakness in the apparatus.
- **Ordered data.** Record data in a clear and ordered way using the tables provided.

A grade of 4 is awarded for an exceptional performance only.

2. Results (the middle)

A grade of between 0 and 4 awarded for a cumulative performance across the following:

- **Plot** (distil) data. Plot, or otherwise distil as guided, all useful data from tables.
- **Clarity** of plot. Include axes labels, scale and correct units.
- **Slope and intercept.** Determine slope and intercept for a linear relationship. This generally involves assigning a straight line/s by eye, or by using 'JagFit' (see appendix 1). Either method is fine and the grader accounts for a reasonable fit by eye.
- **Relate to physical law.** Relate these variables to a physical law with consideration of errors where helpful. Where appropriate, systematic uncertainty and possible imperfections in an apparatus should also be considered.

A grade of 4 is awarded for an exceptional performance only.

Consider uncertainty in measurements. Use units correctly and consistently.

Whilst plotting is the main means of distilling data in our experiments, the Momentum experiment requires the distillation and interpretation of information by other means which include estimations of measurement uncertainty. The first three grades for this component are attributed to this.

For labs in this semester, we don't expect the student to propagate random errors by adding in quadrature. We do expect some critical thinking about the extent and source of errors.

3. Conclusions and implications (the end)

A grade of between 0 and 2 awarded for a cumulative performance across **conclusions** and **implications**.

A grade of 2 is awarded for an exceptional performance only. This may require the demonstration of some independent and critical thinking on the impact of measurement uncertainty on conclusions.

Tutor discretion

1. Reward diligence or critical thinking

It may be that exceptional diligence and/or critical thinking has led directly to students not completing a lab. To account for this, 2 net grade units can be awarded at the tutor's discretion. It remains that the overall student performance is considered in keeping with the UCD grade scale (see above).

By critical thinking, we mean thinking about the exercise that goes beyond regurgitation of material in the lab manual or delivered during the class. Generally, this is the mark of the stronger student.

2. PHYC10180

This module contains less maths than some others. For experiments such as gases and rotation, there are two parts. If students have been diligent but there is not enough time to complete both parts then the first part is sufficient.

3. Electrical experiments

These are designed as enquiry based and credit should be given for testing of even erroneous models for circuits. The grade should be awarded for addressing questions across the script and should be broadly in keeping with the UCD grade scale (see above).

4. PHYC20080

Whilst the style of these experiments varies, the grading distribution remains as given above. Where the intro contains no questions, the first component of grade is given for preparation to first useful data, range and ordered recording of data.