DEPARTMENT OF PHYSICS

UNIVERSITY OF CAPE TOWN

IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

PHY1025F

PRACTICAL

MANUAL

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PHY1025F Practical Manual

TABLE OF CONTENTS

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L1 – Reaction Time

Goals

1. Use a 1D kinematic equation to measure your reaction time
2. Investigate how a variety of stimuli may impact reaction time
3. Collect data and produce a well-formatted table

The deliverable for this practical is an abbreviated write-up including the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Reaction Time Measurement

Introduction

Reaction time is the time between a stimulus and your response. The stimulus is processed by your nervous system before you are able to react, and the time lag is your reaction time. Stimuli could be visual (sight), auditory (hearing), tactile (touch), olfactory (smell) or gustatory (taste).

In this experiment you will be measuring your reaction time when presented with visual, auditory and tactile stimulation. The only equipment you will need is a meter stick. Because the distance an object falls is a function of time, you can measure the distance the meter stick drops and use this to calculate your reaction time.

The formula for an object traveling at constant acceleration is:

$$x = x_o + v_o t + \frac{1}{2}at^2 \qquad (1)$$

where x_o initial position of the object
v_o initial velocity of the object
a acceleration of the object, in this case acceleration due to gravity, 9.8 m/s^2
t elapsed time

Procedure

Before actually performing each experiment, discuss with your lab partners the different type of stimulation (visual, auditory and tactile) and *make a prediction regarding how each might impact your reaction time*. Which type of stimuli will produce the fastest reaction? Which will be the slowest? Why?

Your partner should hold the meter stick. When your partner drops the stick, catch it as quickly as you can. Record the number of centimeters the stick fell before you caught it. You may take the measurement at the bottom, middle or top of your grasp, but BE CONSISTENT. Take at least three measurements for each type of stimulus (the more, the better). Make sure you are isolating only one stimulus, e.g. don't watch the ruler if you are testing for auditory response! Repeat the procedure for each partner. Record your own eaction times in a well-formatted table (See Page 29 for help with formatting).

Analysis

Once you have collected your data, convert the distance fallen to time (will need to rearrange Eq. (1) and capture your results in a second well-formatted table. Include only one sample calculation; the others can be done with a calculator. Be careful with your units and be sure to calculate average values for each stimulus.

Uncertainty

Answer the following questions:

1. What factors (sources of uncertainty) may have produced variation in your reaction time results? Are they big or small?
2. How could you minimize these factors?

Conclusions

Questions to consider when writing your CONCLUSIONS:

1. For which stimulus was your reaction time best? Why? Did it coincide with your prediction?
2. How did your reaction time differ from your partners? Was it a significant difference?
3. Do you think you could improve your reaction time? If so, how?
4. Don't forget to consider the standard discussion points for your conclusion (don't necessarily need to use all of them, see page 30 for more information).
    a. Quoting the final result.
    b. Comparing this result with others and making comments as appropriate.
    c. Discuss the uncertainty in the practical.
    d. Suggest ways to improve the experiment.

L2 – Hooke's Law

Goals

1. Investigate the relationship between an extension of a spring and the magnitude of the applied force
2. Drawing a best-fit line to graphical data and determining the slope of the best-fit line

The deliverable for this practical is an abbreviated write-up including the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Determining a Spring Constant

Introduction

It has been observed that the application of a force to a spiral spring will cause the extension of that spring. What is not clear is whether the relationship between the applied force and extension of the spring is linear, i.e., will doubling the applied force double the extension?

This relationship may be determined by plotting a graph of the *applied force* vs. *spring extension* and then, if the relationship is linear, the spring constant k can be found by applying Hooke's Law:

$$F = kx \tag{2}$$

where F is the magnitude of the applied force and x is the magnitude of the spring extension.

Note that when Hooke's Law is stated in vector form, the equation becomes

$$\vec{F} = -k\vec{x} \tag{3}$$

where the negative sign indicates the direction of the force exerted by the spring with respect to the displacement of the end of the spring, i.e., the spring reacts by opposing the extension x, while the spring constant, k, is always a positive number.

Procedure

You are supplied with a spiral spring suspended from a retort stand, a small bucket, a number of ball bearings of given mass, and a metre stick.

In this experiment a known force is applied to the spiral spring by hanging a mass m from the end of the spring. The magnitude of the force exerted on the spring is mg and the extension produced by the applied force is measured with the aid of the metre stick.

The mass of each ball bearing is approximately 13.7 grams. Confirm the mass of any one of the ball bearings by using a triple-beam balance.

Begin by attaching the bucket to the end of the spring and using the pointer on the end of the spring to record the height of the bucket above the table top. Now add the ball bearings one at a time, recording the new position of the pointer as each ball is added. Take as many readings as you can. Tabulate the data in a well-formed table.

Analysis

Using the attached instructions, plot the data on a graph of *force* (y-axis) vs. *extension* (x-axis).

Draw a line of 'best fit' by eye.

Note: If you obtain a straight-line graph that passes through the origin, then the extension is directly proportional to the force exerted on the spring. If the graph is a straight line, but does not pass through the origin, then the graph indicates that the extension is linearly related to the applied force, but is not directly proportional.

If it is established that the spring extension is directly proportional to the applied force, then the constant of that proportionality can be obtained from the slope m of the straight-line graph since the equation for a straight line is $y = mx + c$.

When you determine the slope of the best-fit line, do so by choosing two convenient points that are as far apart as possible on the line. When determining m, do not use some arbitrary pair of data points; you need to determine the slope of the best fit line – not the slope of a line between two arbitrary data points.

From the slope of the graph, determine the spring constant.

Uncertainty

Answer the following questions:

1. What factors may have produced variation in your measurements? Are they big or small?
2. How could you minimize these factors?

Conclusions

Questions to consider when writing your CONCLUSIONS:

1. Quote your calculated spring constant with appropriate units. Does this value seem reasonable? Why or why not?
2. How does your value compare to one from another group?
3. Are you confident in your result? How could you be more confident in your spring constant value?

L3 – Linear Motion

Goal

1. Investigate linear motion, specifically position, velocity and acceleration using Vernier GoMotion sensors.

There is no formal write-up required for this practical, but you will hand in a lab book in which you have tabulated and graphed data, and in which you will have made notes and answered specific questions about the two investigations done during the practical.

Part 1 – Acceleration of a Free Falling Object

Aim

The aim of Part 1 is to determine the acceleration with which a free-falling object falls, and to consider whether this agrees with the generally accepted value of the gravitational acceleration, *g*, in Cape Town.

Procedure

The apparatus is a Vernier GoMotion sensor that is able to record the position of a free-falling object; the computational device that controls the GoMotion sensor is able to calculate the relevant position vs. time and velocity vs. time graphs. (Use the **03 Linear Motion Part 1 Logger Lite Template** found on Vula.)

Pick your free-falling object from the available selection: a plastic cone, a net ball and a mini soccer ball.

Capture as many graphs as you need – at least six (6) – and from these determine the range of possible values of the acceleration with which the free-falling object fell. *The recommended method to determine the acceleration is to use the Linear Fit function on a selected portion of the velocity vs time graph*. Note that the answer you will get will not be a specific value, although you are welcome to determine the average of these values, but a range of values, i.e., the answer is an interval of numbers.

Analysis

Is the generally accepted value of the gravitational acceleration of g = (9.79824 ± 0.00044) m/s^2 within your measured interval? Comment either way.

Part 2 – Cart on an Inclined Plane

Aim

The aim of Part 2 is to investigate the position, velocity and acceleration vs. time graphs of a cart that goes up and down an inclined plane.

Procedure

The apparatus comprises of a cart on an inclined track, and a Vernier GoMotion sensor that is able to record the position of the cart (<u>with reference to the sensor</u>). At the bottom of the track there is a spring that allows the cart to 'bounce' back up the track. The desktop PC connected to the GoMotion sensor is able to calculate the relevant motion graphs. (Use the **PHY1025F Practical 3 Part 2** icon found on the desktop.)

Let the cart go from the top of the track (start the cart about 30 cm from the face of the sensor) and capture a set of graphs – position vs. time, velocity vs. time & acceleration vs. time – of the cart as it runs up and down the track.

Once you are happy with the captured motion graphs, carefully copy the three graphs – by hand – onto a single piece of graph paper and paste these in your lab book.

Analysis

Answer the following questions:

1. Is the acceleration always positive when the velocity is positive, and is the acceleration always negative when the velocity is negative? Why or why not?
2. Is the acceleration of the cart up the track the same as the acceleration of the cart down the track? Why or why not?

L4 – Flywheel

Goals

1. Investigate the relationship between linear motion and angular (rotational) motion; and specifically investigate the transfer of potential energy into linear kinetic energy, rotational kinetic energy, and thermal energy.
2. Verify the energy balance equation which is underpinned by the law of conservation of energy.

The deliverable for this practical is an abbreviated write-up including the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Conservation of Energy

Introduction

Consider the relationship between the angular velocity ω (speed of rotation), of an object like a flywheel, and the instantaneous linear velocity v of a point on the circumference of the rotating object. See Figure 1. The linear velocity v of a point on the circumference of the axle will depend on the angular velocity ω, and the distance of the point from the centre of rotation, i.e., the radius r of the axle.

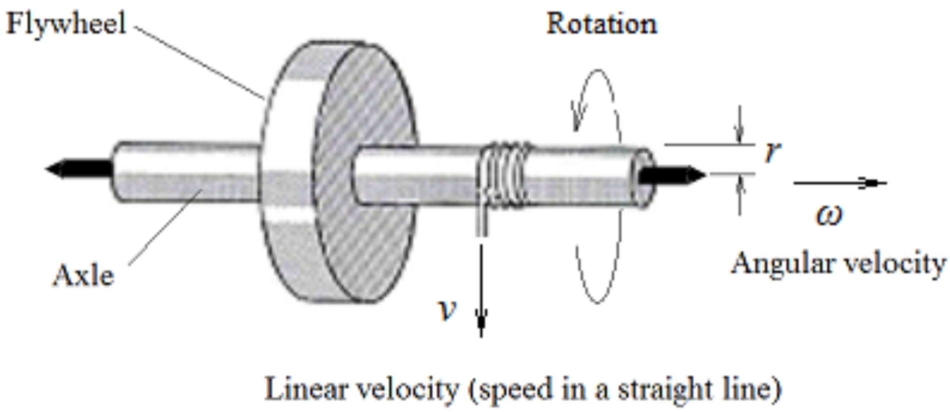

Figure 1: Diagram showing the relationship between ω and v

The relationship between the angular velocity ω and the linear velocity v is:

$$v = \omega r \tag{4}$$

where	v	linear velocity at a point on the rotating object (in m/s)
	ω	angular velocity of the object (in rad/s)
	r	distance of the point from the centre of rotation (in m)

Now consider the case of a mass connected to the flywheel as shown in Figure 2.

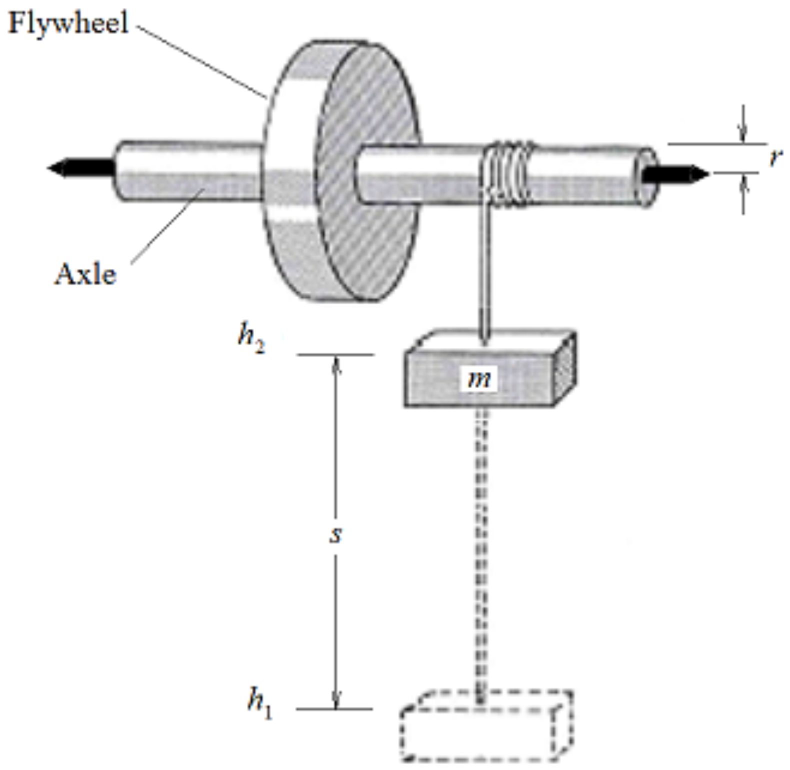

Figure 2: Diagram showing how the falling mass accelerates the flywheel

The mass m has a certain potential energy when it is at height h_2, and some of that potential energy is converted as the mass moves down through distance s to height h_1. The change in potential energy, ΔU_g, is converted into the kinetic energy of the falling mass, KE_{linear}, and the rotational kinetic energy of the flywheel, $KE_{rotational}$, with some of the energy being dissipated through friction, producing thermal energy, $\Delta E_{thermal}$. The system is defined as the flywheel and the falling mass with the assumption that all energy is being conserved; any non-conservative forces will contribute to the $\Delta E_{thermal}$ term. The resulting energy conservation equation is:

$$\Delta E = 0 \;\rightarrow\; \Delta U_g + \Delta KE_{linear} + \Delta KE_{rotational} + \Delta E_{thermal} = 0$$

and after some rearrangement (and ignoring $\Delta E_{thermal}$ for now)

$$mg(h_2 - h_1) = \frac{1}{2}m{v_f}^2 + \frac{1}{2}I{\omega_f}^2 \qquad (5)$$

where	m	mass of the falling mass
	g	gravitational acceleration
	$(h_2 - h_1)$	change in height until disengagement, i.e. $(h_i - h_f)$
	v_f	velocity of mass m at the point of disengagement
	ω_f	angular velocity of the flywheel at disengagement
	I	moment of inertia of the flywheel

The moment of inertia, I, of an object, around some given axis of rotation, is a proportionality constant between the applied torque τ and the angular acceleration α of the object around that axis. (In a sense it is the equivalent of mass m in linear motion, which is a proportionality constant between the applied force, $F$and the acceleration a of the mass, i.e., $F = ma$.) So, in general, $\tau = I\alpha$.

The moment of inertia of an object, around some given axis, depends on the mass of the object, as well as the way in which that mass is arranged around the axis of rotation; more specifically, I depends on the sum of the mass of each particle in the object, multiplied by the square of the radius of rotation of each particle around the given axis, i.e. $I_{tot} = \sum m_i r_i^2$

Substituting Eq. (4) into Eq. (5), we get

$$mg(h_2 - h_1) = \frac{1}{2}mv^2 + \frac{1}{2}I\left(\frac{v}{r}\right)^2 \quad (6)$$

Procedure

The apparatus to be used is shown in Figure 2.

Mass m is attached to a length of string and the free end of the string can be hooked onto a pin on the axle of the flywheel. The axle may be turned so as to wind the string around the narrow part of the flywheel (radius r) a number of times as shown. The mass applies a constant torque τ to the axle and when the mass is released from rest, it accelerates the flywheel (angularly), for as long as the string is connected to the axle.

- Using a triple-beam balance, determine and record the mass m.
- Using the Vernier calipers supplied to you, determine the diameter of the axle around which the string has been turned, then calculate and record the radius r of the axle.
- Determine and record the distance, $s = (h_f - h_i)$, through which the mass will fall while the string applies a torque τ to the flywheel. There are two possible ways to determine the distance.
    - Using a meter stick, measure the initial (h_i) and final position (h_f) of the mass.
    - Using the position vs. time graph produced by the GoMotion sensor, the initial position of the mass (h_i) will correspond to the lowest point on the graph and the final position (h_f) will correspond to the highest point on the graph.

For six (6) repeats, and using the GoMotion sensor provided, record and tabulate the velocity of the mass when it reaches height h_1, i.e., when the string is released from the axle. *Note: use a consistent starting point no closer than 15 cm from the GoMotion sensor*.

Table 1: Position h and velocity v values for the falling mass

Recording #	h_2 (m)	h_1 (m)	Velocity @ h_1 (ms^{-1})
1			
2			
3			
4			
5			
6			

Averages:

Analysis

Calculate the mean velocity ($\bar{v}$) from the tabulated readings. From the range of velocity values, estimate the uncertainty $u(v)$ in the measurement of the average velocity (at height h_1).

Using $g = 9.8\, ms^{-2}$ and $I = (31.0\ \pm 1.0)\times 10^{-3}\ kgm^2$, calculate ΔU_g, ΔKE_{linear}, and $\Delta KE_{rotational}$ at the moment that the mass reaches height h_1.

Calculate a value for $\Delta E_{thermal}$. The energy equation (Eq. (6)) incorporating non-conservative forces becomes:

$$mg(h_2 - h_1) = \frac{1}{2}mv^2 + \frac{1}{2}I\left(\frac{v}{r}\right)^2 + \Delta E_{thermal} \qquad (7)$$

Uncertainty

Answer the following questions:

1. What factors (sources of uncertainty) may have produced variation in your velocity measurements? Are they big or small?
2. How could you minimize these factors?

Conclusions

Questions to consider when writing your CONCLUSIONS:

1. Do these energies look reasonable and do they satisfy Eq. (6) (i.e. does ΔKE_{linear} + $\Delta KE_{rotational}$ = ΔU_g)?
2. What non-conservative forces contributed to your value for $\Delta E_{thermal}$? Did your $\Delta E_{thermal}$ value surprise you?
3. Don't forget to consider the standard discussion points for your conclusion
   a. Quoting the final result.
   b. Comparing this result with others and making comments as appropriate.
   c. Discuss the uncertainty in the practical.
   d. Suggest ways to improve the experiment.

L5 – Viscosity

Goals

1. Investigate the effect of the variables in hydrodynamic flow of a viscous liquid.
2. Calculate the viscosity of water.
3. Perform evaluation of uncertainty and compare to known results.
4. Consider whether some sources of uncertainty contribute more to the final uncertainty than others.

The deliverable for this practical is an abbreviated write-up including the following sections: PRELIMINARY INVESTIGATION, DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Aim

The aim of this experiment is to investigate the relationship between the flow of a liquid, the hydrostatic pressure, the length of the tube and the radius of the tube through which the liquid is moving.

Introduction

It has been observed that a pressure difference is required to enable the flow of a viscous fluid in long cylindrical tubes with a constant cross-section. The resulting flow rate (Q) is proportional to the radius of the tube to the power of four. This has important implications for air flow in lung alveoli and blood flow in the arteries, and this practical will help you understand the physics behind administering a saline drip to a patient.

The volumetric flow rate, Q, is the volume of liquid, ΔV, flowing in a time interval, Δt,

$$Q = \frac{\Delta V}{\Delta t} \tag{8}$$

The flow rate in a pipe of constant cross-section may be determined by Poiseuille's Law,

$$Q = \frac{\pi \Delta P}{8\eta L} r^4 \tag{9}$$

where ΔP is the pressure difference between the ends of the pipe, r is the constant radius of the pipe, L is the length of the pipe and η is the viscosity of the solution.

The pressure difference in this example is the hydrostatic pressure due to the depth of fluid Δh (also commonly referred to as the pressure head), and the density of the fluid (ρ_{water} =1 g/cm^3),

$$\Delta P = \rho_{\text{water}} g \Delta h \tag{10}$$

Apparatus

You are supplied with a 'header' tank (or a bucket filled with water), a metre rule, a tube clamp, a measuring cylinder, and a stopwatch. You also have four plastic tubes – where each tube has a different internal diameter of 2.5, 3.0, 4.0, 4.3 mm. Some of the tubes have adapters on the end, which you don't need to remove. There should be some towels nearby in the event of a spill.

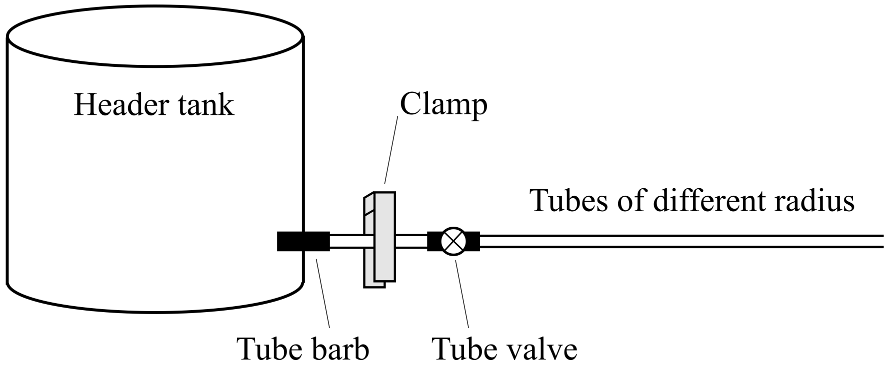

Figure 3: Experimental set up for viscosity practical.

Part 1: Preliminary investigation (15 minutes)

Answer the following questions *briefly* in your own words in your lab book. You can perform simple tests with the apparatus, but you don't need to record the actual data in your report.

1. If the valve and clamp are open, explain why raising the open end of the tube above the bucket stops the flow of water.
2. Why don't we need to consider atmospheric pressure, P_0, in calculating the pressure difference?
3. If we increased the viscosity, or internal friction η, of the fluid, what effect would this have on Q?

Part 2: Measuring the viscosity of water

Collecting data (30 minutes)

You are required to tabulate the time taken for a 50 ml set volume of the liquid to run through each horizontal pipe to find Q as in Equation (9). You can use the timers or a stopwatch to record the time. Replace the collected liquid back to the header tank after each run. Measure the length of one of the pieces of tubing, L, and the depth of the water in the bucket, Δh, with a metre ruler. To change the tubing:

- When the tube valve is parallel or in line with the tubing, it is open and water will flow through.

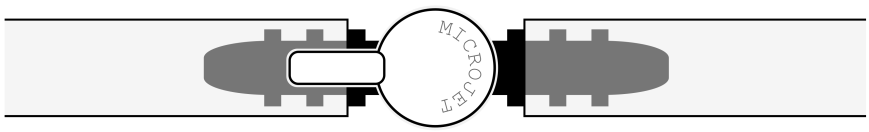

Figure 4: Diagram of an open tube valve (parallel to flow)

- When the tube valve is perpendicular to the tubing, it is closed. Carefully close the blue valve to stop the water spilling out.

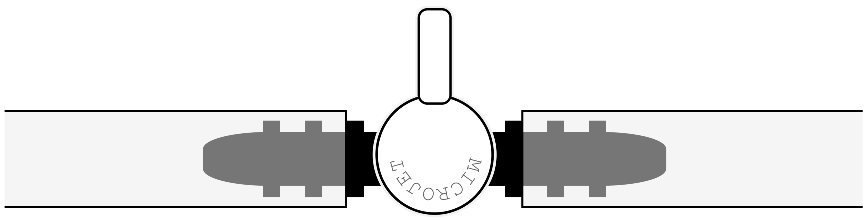

Figure 5: Diagram of a closed tube value (perpendicular to flow)

- At any time if you are worried about a leak, bring the open end of the pipe up above the height of the bucket, and ask a demonstrator for help if you are unsure.
- In an emergency, you can also apply the clamp around the short section of clear tubing coming out of the bucket to prevent your water spilling out. Use towels to mop up any spills.
- After the value is closed, carefully pull the long piece of tube away from the valve.
- Push the new tubing into place before opening the valve. Some of the different tubes have adapters to make the tubing fit on the valve more easily.

Analysis (45 minutes)

Calculate and tabulate values of Q using Equation (8) and r^4. Take care to use SI units when inputting your data.

Plotting Q vs r would give us a 4th order polynomial graph, which is difficult both to draw and interpret. Instead draw a graph (by hand) of Q vs r^4 in the form of y vs x. Try to plot the values of each axis in the same order of magnitude, so the scientific exponent is the same for all the labels on an axis. Remember to add a best-fit line.

Also plot the graph using the programme using **LinearFit** on the lab PCs – instructions are found in the Notes (page 34). Enter the data for r^4 (x) in column 1, and Q (y) in column 2. This programme fits a linear best-fit line to the data, in the form of $y = mx + c$ as shown in Equation (12). Record the values of m and c from the best-fit line to the data.

$$Q = \frac{\pi \Delta P}{8 \eta L} r^4 + 0 \tag{11}$$

$$y = \quad m \quad x + 0 \tag{12}$$

This is an example of "linearising equations" to simplify the interpretation and reading of a graph. Another advantage of linearising a complex or non-linear equation is that we can use the gradient, m, to calculate constants. In this case, you can calculate and quote the viscosity of water from the value of the gradient, m.

Discussion and Conclusion (30 minutes)

From your graphs and values, summarise the finding of this experiment and state the conclusion.

Consider the following questions:

1. Comment on whether your measurements agree with Poiseuille's Law (in other words, was the relationship between Q and r^4 linear)?
2. How does your value of the viscosity compare to the standard value of 1.0 mPa·s at room temperature of 20 °C and atmospheric pressure?
3. Are there are any factors which have influenced the uncertainty in your measurement?
4. Can you identify any one of these factors that you think contributed the most to the uncertainty?

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L6 – Thin Lenses

Goals

1. Use three methods to determine the focal length of a thin converging lens, and then to compare the results of each method.
2. Perform informal evaluations of uncertainty and to compare measured results.

The deliverable for this practical is an abbreviated write-up including the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Determining the Focal Length

Introduction

Thin lenses are used extensively in scientific and medical equipment, such as focusing a laser in an eye correction surgery. In order to find the focal length of a thin lens the method of 'no parallax' is often used.

Parallax in this context is defined as the apparent displacement of one body with respect to another when the position of the observer is changed. To illustrate this idea, hold two pencils at arm's length with one pencil a few centimetres behind the other, as shown in Figure 6. Close one eye, and while keeping the pencils still, move your head from side to side. Note how the position of the pencils relative to one another seems to change as you move your head.

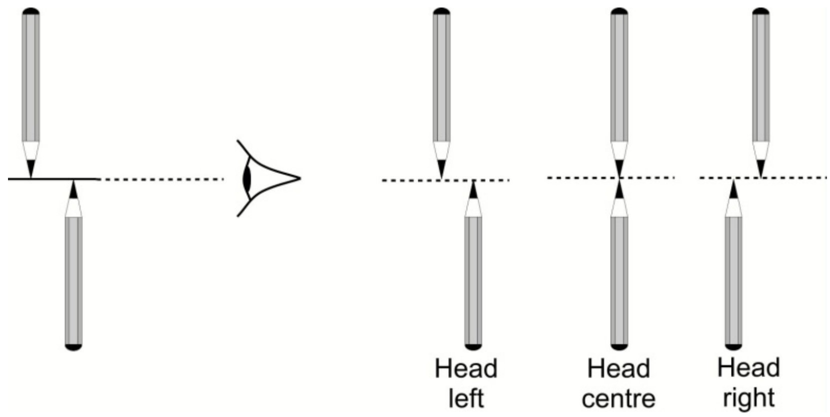


Figure 6: Demonstrating parallax error with two displaced objects

However, if you line the two pencils up as shown in Figure 7, there isn't a relative shift in the positions of the pencils as you move your head from side to side. At this stage, we say there is "no parallax" between the pencils and we can be confident that they are the same distance from the eye.

The same technique can be used to set two images (whether real or virtual) at the same distance from the eye, or, for that matter, an image and a pin, or perhaps an image and a crosswire.

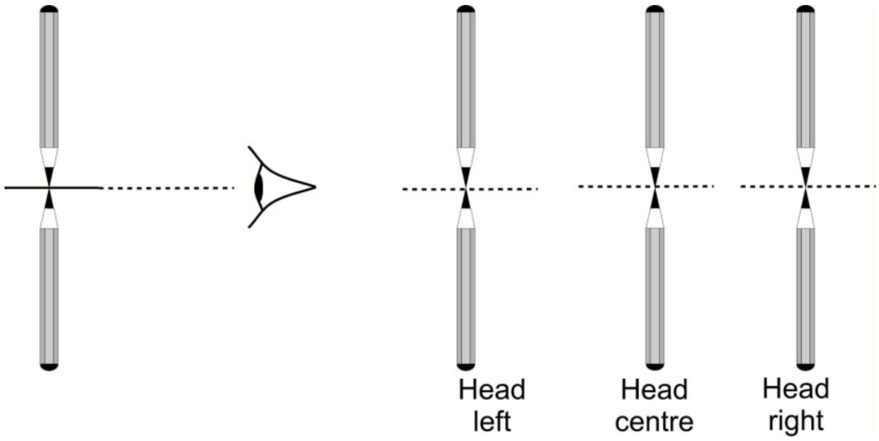


Figure 7: Demonstrating no parallax error when two objects are aligned

Procedure

Three methods will be used to determine the focal length of the converging lens:

Part 1 – Distant object method

Arrange the optical bench so that light from an illuminated object at least 10 m away (e.g. the windows at the far side of the laboratory) falls on the lens. Set up the white screen on the opposite side of the lens, adjusting its position until the image of the window is sharply focused on the screen.

Since the rays arriving at the lens from the window are approximately parallel, they will form an image at the lens' focal length. The distance between the lens and the screen is thus the focal length of the lens and you must record this distance to the nearest millimetre.

To evaluate the uncertainty in this measurement, simply look at the scale of the metre stick, and the geometry of the setup, and estimate the uncertainty. Quote the estimated uncertainty to one significant figure, e.g., ±2 mm, or ±3 mm, or ±4 mm, etc., and then write the result in the form $f_{dist\ object} \pm u(f_{dist\ object})$, where $u(f_{dist\ object})$ is the uncertainty.

Part 2 – Parallax method

Without moving the base of the apparatus and the lens, remove the screen and replace it with a pin. While looking from the pin side, and moving your head from side to side, adjust the position of the pin so that there is no parallax between the pin and a feature in the image of the window, such as the edge of the frame or a beam.

The pin now marks the position of the image, and the distance from the lens to the pin is the focal length.

As with the distant object method, determine $f_{parallax} \pm u(f_{parallax})$, once again, estimate the uncertainty and write the answer to one significant figure.

Part 3 – Method of conjugate foci

This method makes use of the lens equation:

$$\frac{1}{f} = \frac{1}{d_{object}} + \frac{1}{d_{image}} \tag{13}$$

where f focal length of the lens
d_{object} object-to-lens distance
d_{image} image-to-lens distance

Place the lens at the centre mark of the optical bench and the object-pin approximately 35 cm from the lens. Looking from the image side of the lens - and using the method of no parallax – move the image pin towards and away from the lens until the image pin is at the same position as the image itself. Adjust the height of the pins and the lens to see both the object pin and the image pin inverted at the same time, similar to as shown in Figures 1 and 2.

Record the distances d_{object} and d_{image}. It is not necessary to estimate the uncertainties.

Keeping the position of the lens fixed, move the object pin 3 cm further away from the lens. As before, locate the position of the image using the method of no parallax and measure the distances d_{object} and d_{image} once again.

Repeat the procedure by moving the object pin over a range of positions (closer to and further from the lens) until you have six sets of measurements for each position of the object pin. Avoid object distances shorter than the focal length of the lens, as found in Method 1.

For each position of the object pin, calculate f_i for *i* = 1, 2, 3, 4, 5, 6; and tabulate the calculated results as follows:

Table 2: Calculated results of f_i to determine $f \pm u(f)$ of a converging lens with the conjugate foci method

Calculation #	d_{object} (mm)	d_{image} (mm)	f_i value (mm)
1			
2			
3			
4			
5			
6			

Table 2 should show six different lengths – and it may be assumed that these are distributed normally about the mean – so use procedure outlined in the notes (page 35) to calculate the mean $\bar{f}$, and the standard deviation σ.

To determine the **standard uncertainty**, $u(f)$, in a measurement of this type, you must divide the standard deviation by the square root of the number of readings used (six in this case):

$$u(f) = \frac{\sigma}{\sqrt{6}} \tag{14}$$

When reporting this result, quote the uncertainty of this measurement to two significant figures, e.g., 1.4 mm, or 2.3 mm, etc., and then write the result in the form: $f \pm u(f)$.

Note: When you quote this result, write the mean f, to the same number of decimal places as the uncertainty:

For example: $f \pm u(f) \rightarrow$ 154.6 ± 3.8 mm.

Analysis

Be careful with your units. Compare the results obtained for the focal length from the three methods, consulting the additional notes (page 36) for guidance on how to do this.

Draw a ray diagram for each part, labelling the object, image and focal length.

Discuss which of the results you believe to be the most correct and state why you think so.

Uncertainty

Answer the following questions:

1. What factors (sources of uncertainty) may have produced variation in your measurements? Are they big or small?
2. How could you minimize these factors?

Conclusions

Questions to consider when writing your CONCLUSIONS:

1. Don't forget to consider the standard discussion points for your conclusion (don't necessarily need to use all of them)
    a. Quoting the final result.
    b. Comparing this result with others and making comments as appropriate.
    c. Discuss the uncertainty in the practical.
    d. Suggest ways to improve the experiment.

L7 – Speed of a Wave on a String

Goals

1. Use two methods to measure the speed v with which a wave moves along a stretched string, and to compare the results of the two methods.

The deliverable for this practical is an abbreviated write-up including the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Part 1 – Vibrating String

Introduction

In this method standing waves are generated in a string by a vibrator fed from a power function generator, as shown in Figure 8.

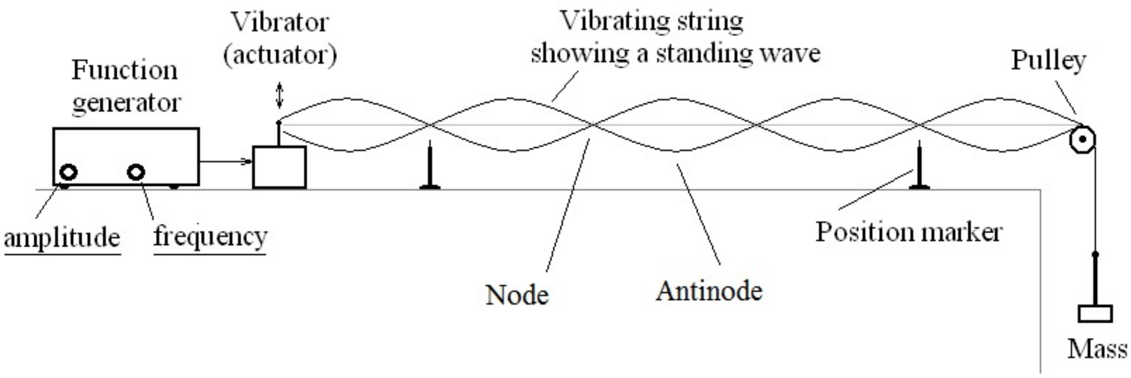


Figure 8: Apparatus used to generate standing waves.

The frequency and wavelength of a wave (f and λ respectively) are related to the speed, v, of the wave by the equation:

$$v = f\lambda \tag{15}$$

The string is effectively fixed at the "pulley end" and so the waves that are introduced onto the string by the vibrator are reflected at the pulley. These reflected waves interfere with the waves that are moving towards the pulley. At certain frequencies standing waves are produced and several nodes will be clearly visible on the string. Since the distance between adjacent nodes is half a wavelength (i.e. $\lambda/2$), it is possible to determine the wavelength of the waves under these conditions. A plot of f vs $1/\lambda$ should yield a straight-line graph, and from the slope m of the line it is possible to determine the speed v of a wave on the string.

Procedure

Connect the apparatus as in Figure 8 and adjust the power function generator to find frequencies at which there are standing waves on the string. For example, it is usual to find a standing wave with one node at the centre of the string at a frequency between 8 Hz and 11 Hz. Other standing waves can be found at integer multiples of that frequency.

Note:

a) The amplitude adjustment should be as small as possible. If the vibrator makes a harsh ***brrrr…*** sound, you are overdriving it.
b) Since the vibrator that generates the waves on the string is moving up and down, the point at which the string is attached to the vibrator is not a node.

To get the best results, measure the distance between the extreme left and right-hand nodes as shown in Figure 8, and then calculate the wavelength λ of a single wave.

Record the frequency f and wavelength λ for at least 6 standing waves.

Plot a graph BY HAND of f vs $1/\lambda$.

Now determine the slope $m \pm u(m)$ of the fitted line using **LinearFit** on the computers in the lab – instructions are found in the Notes (page 34). Note that $u(m)$ is the uncertainty associated with this measurement.

The slope $m \pm u(m)$ represents the speed of the wave, $v \pm u(v)$ on the string.

Part 2 – Mass/Tension Calculation

Introduction

The speed of a wave on a string is dependent upon the tension T in the string as well as the mass per unit length μ of the string:

$$v = \sqrt{T/\mu} \qquad (16)$$

By measuring the tension T in the string and the string's mass per unit length μ, it is possible to calculate the speed v of a wave on the string.

Procedure

Use a triple-beam balance to measure the mass of the 'mass piece' used to stretch the string and calculate the tension T in the string; assuming g = (9.80 ± 0.02) m s^{-2}.

Since only one kind of string is used in this experiment, use the triple beam balance to measure the mass of the given length of string, and use the metre stick to measure the length of that piece of string. Calculate the string's mass per unit length μ.

Finally, use equation (16) to calculate the predicted speed v of a wave on the string. Estimate what you believe the uncertainty in this result may be, e.g., 2%, 4%, 6%, etc.

Comparison of Results, Uncertainty & Conclusion

Include the standard discussion points for your UNCERTAINTY and CONCLUSION, such as compare the results of the two methods, comment on the two results and which you consider to be more correct, compare your results with other groups, discuss any possible sources of discrepancies and how you would minimize them.

L8 – Electric Field Mapping

Goals

1. Investigate the nature of a two-dimensional, static electric field by:
    a. Determining the electric potential at various points in the field.
    b. Plotting the equipotential lines in the field.
    c. Considering the gradients ('downhill' slopes) between the equipotential lines.
    d. Calculating the electric field at various points.

The deliverable for this practical is an abbreviated write-up including the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS.

Plotting the Electric Potential

Introduction

The concepts of an electric field $\boldsymbol{E}$ and an electric potential V in a region in space are not two different 'things', they are simply two inter-related mathematical representations of the same phenomenon. In the static fields that will be considered in this practical, these two representations are related by the equation:

$$\Delta V = -\boldsymbol{E}\Delta\boldsymbol{s} \tag{17}$$

where (consider $y = mx + c$), you can see that if you know how the electric potential, ΔV, changes in a region in space, $\Delta\boldsymbol{s}$, then you can determine the electric field, $\boldsymbol{E}$, which is represented by the 'downhill' gradient of the change in potential.

As can be seen in the example in Figure 9, once the equipotential lines have been plotted in a region – here projected onto a two-dimensional plane with (x, y) co-ordinates – the field can be visualised by arrows, with the base of the arrows on the equipotential line, and the direction of the arrows being orthogonal (at right angles) to the equipotential line at that point.

The arrow points 'downhill' (or from a high potential to a low potential), and the length of the arrow depends on the 'steepness' of the field at that point. When the equipotential lines are close together, the gradient is steep, and when the equipotential lines are further apart, the gradient is 'not so steep'.

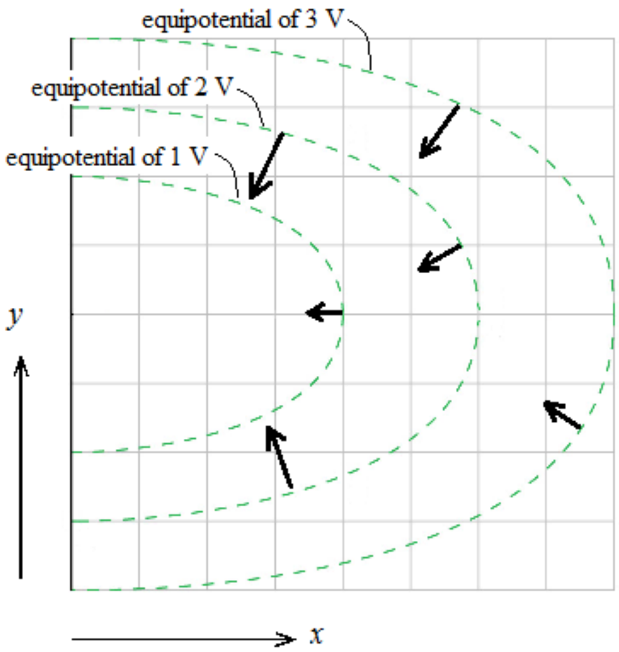


Figure 9: Example of plotted equipotential lines used to visualise the field

The apparatus consists of a signal generator, a digital multi-meter (DMM), two metal shapes and a clear Perspex tray in which there is a layer of water (3 mm to 4 mm deep). The signal generator, set to a frequency of approximately 100 Hz and an output voltage of 5 V RMS, is connected to the metal shapes as shown. The digital multi-meter is used to read the potential at various points in the water; and the co-ordinates of each point is determined from a sheet of graph paper which is placed under the tray. The selected metal shapes are placed in the water as shown in Figure 10.

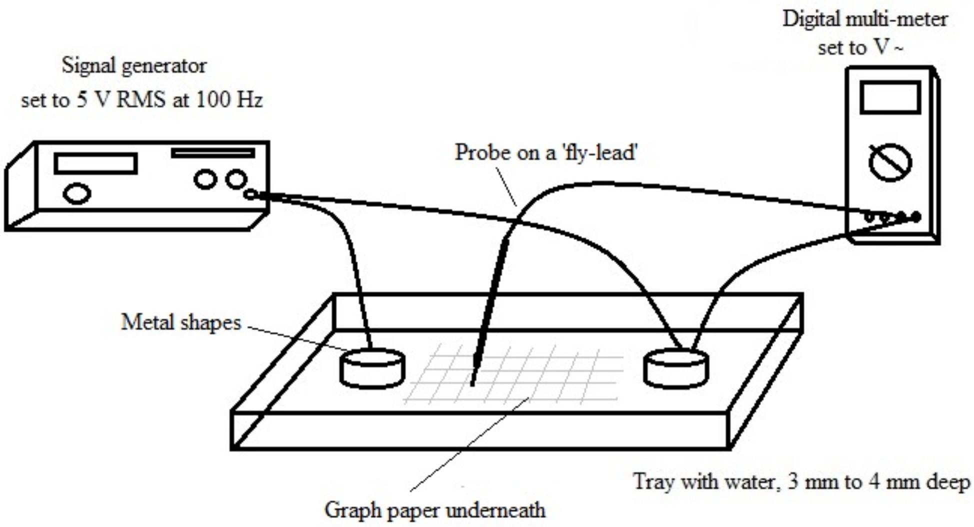


Figure 10: Apparatus used to read electric potentials

Note: It will be easier to track an individual electric potential value if you set the DMM to read only one decimal place. Use the RANGE button to control the number of decimal places.

Procedure

For one of the two configurations shown in Figure 11 take voltage readings at a number of points on the plane, sufficient to plot the equipotential lines on a sheet of graph paper.

After completing the equipotential lines, draw the electric field lines (as described in the introduction), sufficient to inform the reader that you have a clear grasp of what the $\boldsymbol{E}$ field looks like.

For a selected configuration, calculate the value of the $\boldsymbol{E}$ field at 3 different locations by measuring ΔV and Δs and using Equation (17).

Uncertainty & Conclusion

Include the standard discussion points for your UNCERTAINTY and CONCLUSION, such as discuss any possible sources of discrepancies and how you would minimize them, comment on your E-field results, discuss the relationship between the electric field and potential, comment on the different configurations, etc …

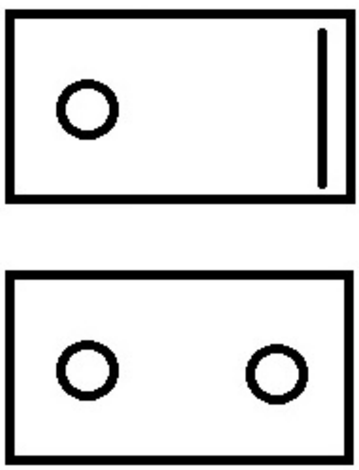


Figure 11: Configurations to determine the E-field.

N1 – Notes for the Reaction Time Practical

Introduction

The purpose of the PHY1025F practicals is to develop skills in a Physics context that will be relevant for your future in the medical profession. These practicals are designed to work on the following skills: Discovery (exploring concepts), Measurement (taking data), Graphs (displaying data), Identifying relationships (manipulating data and variables), Uncertainty (measurements are not exact, identifying and propagating uncertainty) and Drawing Conclusions (summarizing a result based solely on what is observed).

Your grade for the PHY1025F practicals will be based on your lab report. Each week, you will be given an 8-page lab book where you will complete your write-up and then hand it in at the end of each practical session. Due to time constraints, you will not always be expected to complete a full lab report, but you will always have the following sections: DATA, ANALYSIS, UNCERTAINTY, and CONCLUSIONS. Your lab book should contain any measured data in a well-formatted table with labels, an example of any calculations performed, copies of any completed graphs, a discussion of the uncertainty in the practical, and a clear and concise summary of the practical drawn directly from your observations. All work should be completed in the lab book; any rough work will be ignored while marking as long as it is clearly indicated.

Planning an experiment

There is no fixed 'recipe' by which experiments in physics are performed but please note the following:

DO:

> Discuss what you need to do with your partners.
>
> Get a feel for how the apparatus works; if you are uncertain, call a demonstrator.
>
> Set a page or two aside in your lab book for ROUGH NOTES and make lots of notes that can be used in your report.
>
> Draw up a table in which to record the readings you will take; this table will provide a focus for the work. Take the necessary readings and check to see if the data you have gathered will be adequate to meet the goals of the experiment.

Important: ALL relevant information must be captured IN YOUR LAB BOOK…, not on scraps of paper or note pads. You will not be awarded marks – neither will you lose marks – for neatness.

DO NOT:

> Waste time copying the instructions that are in the manual…; you will not get marks for reproducing the information you have been given.
>
> Start writing the report before you have collected the relevant data AND you have confirmed that the collected data are adequate for the task at hand.

Writing a laboratory report

The purpose of a laboratory report is to communicate the aim, the process and the result of an experiment to an outside audience.

There are many acceptable ways to structure a laboratory report and while each component of a report described below need not have its own heading – some components can be combined with others – all of the components referred to should be addressed in a full lab report.

Title of the report: The title should be short and descriptive. Include the date as well as the names of those who worked with you.

Aim: State clearly and concisely what value was to be determined, or what phenomenon was to be investigated.

Introduction and Theory: The report should give the reader the theoretical underpinning of the experiment. Any relevant equations should be included in this section.

The theory given here lays the foundation for the later interpretation, analysis and discussion of the data collected during the experiment.

Apparatus: Show the apparatus used in simple labelled diagrams, sketches and/or circuits. Label the diagrams/sketches/circuits as Figure 1, or Figure 2, etc., as the case may be.

Note:

- it is not necessary to make detailed drawings of minor details like knobs on instruments and the shapes of boxes and widgets on stands;
- it is not necessary to draw an exploded view of the apparatus, and
- it is not necessary to provide a 'parts list'.

Method: The method describes, in your own words, the procedures that were followed when doing the experiment. These are the procedures used to obtain data as well as those used to analyse that data.

DO:

Write paragraphs in the past tense, using an impersonal style. For example:

The apparatus used is shown in Figure 2... Five readings were taken and these were recorded in Table 1... The linearised data are shown in Table 2... A graph to show the relationship between A and B is shown in Figure 3... And so on...

DO NOT:

Write in point-for-point form (yes, we know what you were taught at school).

Do not present the method as though you are providing a recipe. For example, do not write:

- *Fetch a teabag,*
- *Put it into a cup,*
- *Add hot water...*

Readings (Data): The readings taken (data) are usually presented without comment or analysis in tables. Here are key points to consider when doing so:

(i) The table must have a title (e.g*., Table 1: Measurements of the width of the cylinder)*. If you use more than one table in your report, number them in sequence, e.g., Table 1, Table 2, etc.
(ii) Each column in the table must have a heading and appropriate units.
(iii) Record the readings carefully. Remember, for example, that 36.0 cm is not the same as 36 cm. In the first case you are reading to the nearest millimetre, while in the second case you are only reading to the nearest centimetre.

For example:

Table 3: Readings taken to determine the spring constant

Applied force F (N)	Reading on metre stick (mm)	Extension x (mm)	Spring constant $k = F / x$ (N m^{-1})
0.000	122	0	n/a
0.100	163	41	2.44
0.201	204	82	2.45
0.298	250	128	2.33
0.400	283	161	2.48

Analysis and calculations: Show all the relevant calculations and make sure that the purpose and method of every calculation is clear to the reader. If there is a lot of repetition then show the method once and present the results in a table.

When doing calculations, quote units and write the answers to an appropriate number of significant figures. Significant figures are:

- All non-zero digits (e.g., 54 has two significant digits while 456.78 has five significant digits).
- All zeros appearing anywhere between two non-zero digits (e.g., 302.05 has five significant digits).
- All trailing zeros, where the number has a decimal point (e.g., 36.65000 has seven significant digits).
- Leading zeros are not significant (e.g., 0.0003 has only one significant figure).

Do not confuse significant figures with decimal places. The number of decimal places refers to the number of figures after the decimal point, e.g., 46.320 has five significant figures, but three decimal places; while 0.0040 has two significant figures, but four decimal places.

Evaluation of uncertainty: The evaluation of uncertainty is a key aspect of all experimental sciences. The concept of uncertainty will slowly be developed during the semester, but some questions will always be the same. You should address the following questions for every practical in the UNCERTAINTY section: 1. What factors (sources of uncertainty) may have produced variation in your measurements? Are they big or small? 2. How could you minimize these factors? The answers to these questions should help formulate your CONCLUSIONS.

Interpretation, Discussion and Conclusion

In the final components of the report you are expected to summarise the work by:

- Quoting the final result.
- Comparing this result with others and making comments as appropriate.
- Discuss the uncertainty in the practical.
- Suggest ways to improve the experiment.

For example, if your aim was to measure *g* you should, in a sentence, state the method that was used and give the result. For example, you may say:

> *A simple pendulum was used to determine the value of the earth's gravitational acceleration in Cape Town. The result of the experiment was that g was determined to be (9.790 ± 0.052) m s^{-2}, with a coverage probability of 68%. This result agrees within experimental uncertainty with the given value for g in Cape Town which is (9.79824 ± 0.00044) m s^{-2}.*

Be careful not to mix facts with opinions and avoid meaningless phrases such as "this was a successful experiment." Finally, the explanation that some or other result was influenced by "human error" is discouraged; if a human error has been made you are expected to correct that error by repeating the experiment.

Graphs and best-fit line

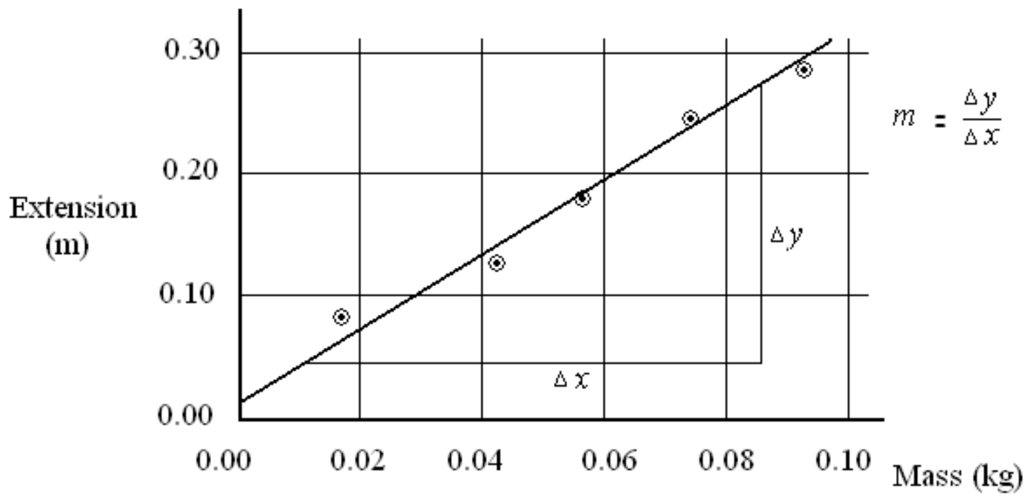
Graphs are essential for the successful communication of experiments, so draw them as large as possible. Every graph has to have a title describing the purpose for which it has been presented (e.g.*, Figure 3: Plot to determine the viscosity of the sample of oil*), and if there is more than one graph, number them sequentially, e.g., Figure 1, Figure 2, etc.

The general rules for plotting graphs are:

- When asked to plot the graph of say ***P*** vs. ***Q***, it means that ***P*** must be on the vertical axis (*y* - axis) and ***Q*** must be on the horizontal axis (*x* - axis).
- Each axis should be labelled with the name of the variable and the units.
- Axes should be marked in scaling factors of 1, 2, 5, or these to powers of ten. Scaling factors such as 3 or 4 usually make the scales difficult to read and should be avoided.
- Use a ⊙ or × to show the data points…, not a ● (blob).

For example:

Figure 1.2: Graph of extension of the spring versus mass attached to determine the spring constant



In a lot of experimental work you will need to draw a line of best fit by eye.

Please note:

- the best fit line <u>does not simply join the data points;</u>
- the best fit line has to model the trend in the data; and
- it is possible that the best fit line may not even go through any of the data points as shown in the example above.

N3 – Notes for the Linear Motion Practical

The Logger Pro and Logger Lite Software

Vernier Software develops educational data-collecting interfaces and the corresponding software. There are two levels of the software that interfaces with the Go!Motion sensor: Logger Pro (for purchase) and Logger Lite (freely available). For the linear motion practical, we will be using both versions of the software (Logger Lite for Part 1 and Logger Pro for Part 2).

For these two parts of the Linear Motion practical, templates have been already created in order to minimize the setup of the software. The Part 1 template (entitled: **03 Linear Motion Part 1 Logger Lite Template**) is available on Vula for download. The Part 2 template (entitled: **PHY1025F Practical 3 Part 2**) will be available on the desktop PC in PHYLAB1. There is also a Logger Lite version (entitled: *03 Linear Motion Part 2 Logger Lite Template*) available on Vula if you would prefer to use your laptop for Part 2.

In order to use Logger Lite on your laptop (PC or Mac), you will need to download the software from the Vernier website (http://www.vernier.com/products/software/logger-lite/) and then install it on your computer. [It will also be available on the course Vula site.] Hopefully you have done this before arriving to the lab.

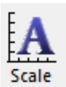
Using Logger Pro and Logger Lite

The Logger Pro and Logger Lite software is fairly straight-forward to use, but here are a list of useful commands and features.

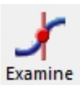
From the toolbar:

… to start collecting data

… to stop data collection (templates will automatically stop reading after an allotted time)



… to scale your graph automatically



… for the cursor

… to save data in Logger Lite Format

From the menu (more common):

`File … Save`	… to save data in Logger Lite format
`Data … Clear All Data`	… to clear data
`Analyze … Autoscale`	… to scale your graph automatically
`Analyze … Examine`	… for a cursor
`Analyze … Linear Fit`	… to fit a line to the selected data (select data using cursor)

From the menu (less common):

`File … Export As`	… to save as CSV or text file (for later analysis in Excel, etc)
`Insert … Graph`	… to add a velocity or acceleration graph
`Page … Auto Arrange`	… to automatically arrange graphs on the page
`Experiment … Data Collection`	… to adjust data collection parameters (pre-set if using templates)

N5 – Notes for the Viscosity Practical

LINEARFIT

LinearFit can be used to calculate the slope $m \pm u(m)$ and the intercept $c \pm u(c)$ of the best fit straight line.

To start the program, click on the LinearFit shortcut on the desktop, as you do with any program running on Windows. (If you need to log-in to the PC, the log-in is "phylab" with no password.) The program will open and present the page as shown in Figure 12.

Type the x and y values into the appropriate columns and LinearFit will automatically calculate $m \pm u(m)$ and $c \pm u(c)$.

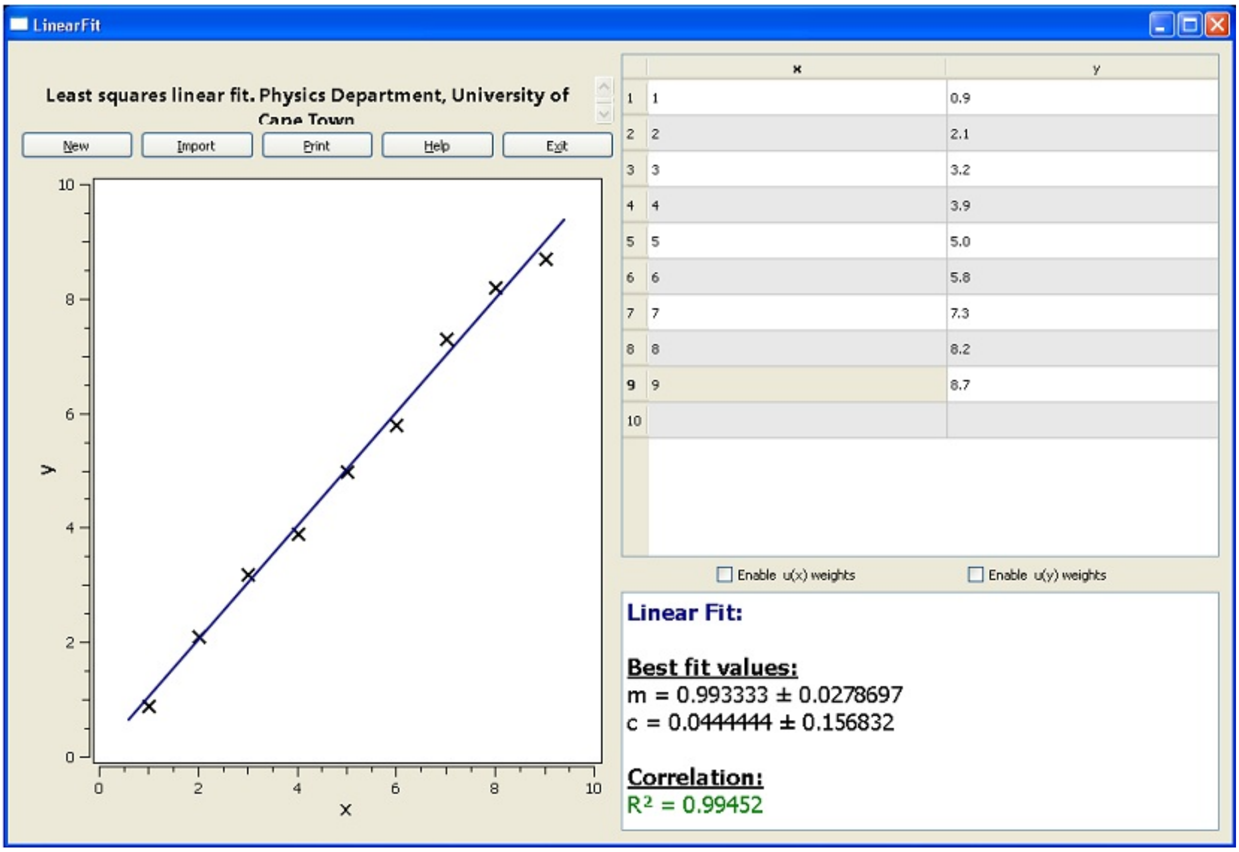


Figure 12: Data input and fitting screen of LinearFit

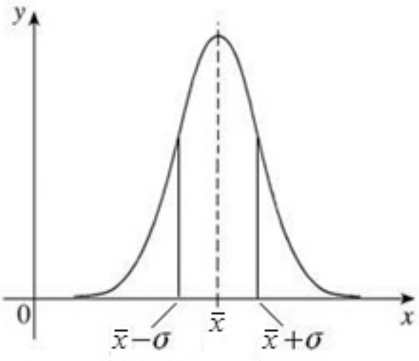
N6 – Notes for the Thin Lenses Practical

TYPE A evaluation of uncertainty

In a TYPE A evaluation of the uncertainty, a statistical method is used to infer the value of the uncertainty associated with a measurement by quantifying the "scatter", or the "spread" in the values of a **set of data**.

The case where the data are a set of readings of the form: x_1, x_2, x_3,…

A histogram of the readings shows a distribution around some mean value $\bar{x}$ that can be represented by a symmetrical bell-shaped curve (referred to as a "Gaussian") where:



$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left[\frac{(x-\bar{x})^2}{2\sigma^2}\right]},$$

$\bar{x}$ is the mean, and

σ is the standard deviation.

Figure 13: Normal or 'Gaussian' distribution function

When the relevant set of readings, x_1, x_2, x_3,…, x_n, for n readings, are plotted as a histogram, and the histogram allows one to fit a curve similar in shape to a normal distribution, then the best approximation of x is $\bar{x}$, and the standard uncertainty $u(x)$ is the **experimental standard deviation of the mean,** $\frac{\sigma}{\sqrt{n}}$ of the fitted curve.

Formulae for a TYPE A evaluation of uncertainty where the distribution is Gaussian

Consider an experiment in which a set of readings, x_1, x_2, x_3, ….x_n, where n is the number of readings and x_i is the i^{th} reading, has been taken. If there is a scatter in the values of these readings, then it can be reasonably assumed that the distribution of the readings 'fits' a Gaussian probability density function.

Using this assumption*, there are three values required to calculate the uncertainty in the measurement:

- the **mean** $\bar{x}$ (sometimes the symbol μ is also used for the mean)
- the **standard deviation** σ, and
- the experimental standard deviation of the mean which, when the distribution of the values of the mean of the readings is normal, is the **standard uncertainty** $u(x)$.

The following equations are used to calculate the parameters used to determine the uncertainty associated with the measurement:

Mean of the data: $$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (18)$$

Standard deviation: $$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (19)$$

Standard uncertainty:
or the experimental standard deviation of the mean

$$u(x) = \frac{\sigma}{\sqrt{n}} \tag{20}$$

Note:

1) *The assumption that the distribution of the values of the readings is normal validates the statement that "the **experimental standard deviation of the mean** is the **standard uncertainty** $u(x)$" for the majority of cases. However, it is important to realise that a different approach may be required where the distribution of values is not 'normal'.
2) Because a Gaussian distribution was assumed, the probability that the measurand lies **within one standard uncertainty** of the best approximation, is **68%**.

Comparing results

To say that two results are "close" or "nearly the same" is meaningless in the context of laboratory work. The results of any two experiments can only be meaningfully compared if the intervals associated with each of the results are known.

More specifically:

- If the intervals that represent the results of two measurements overlap, then we say these two results "**agree within experimental uncertainty**."
- If the intervals that represent the results of two measurements do not overlap, then we say these results "**do not agree within experimental uncertainty**."

For example, say three students measure the period T of a pendulum and they each quote the result as follows:

$$T_1 = (5.73 \pm 0.41) \text{ s}$$
$$T_2 = (5.62 \pm 0.10) \text{ s}$$
$$T_3 = (6.28 \pm 0.25) \text{ s}$$

The three measurements may be presented in the form of intervals on a number line:

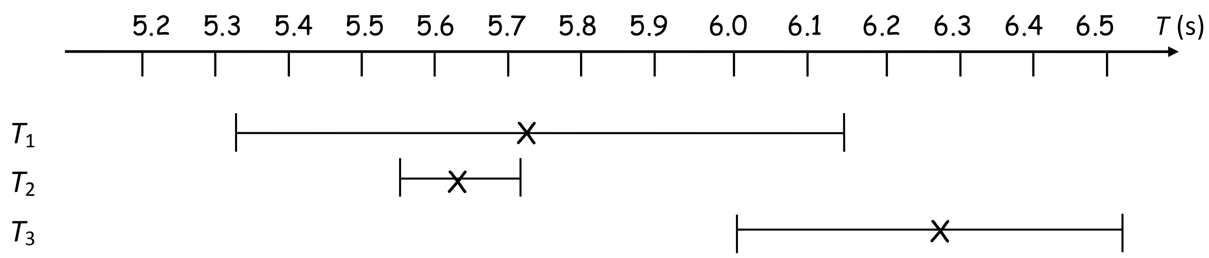


Figure 14: Comparison of results

- Note that the intervals associated with T_1 and T_2 overlap, and therefore "these two results **agree** within experimental uncertainty".
- The intervals associated with T_1 and T_3 also overlap so "these two results **agree** within experimental uncertainty".
- However, the interval associated with T_3 does not overlap with the interval associated with T_2 and therefore "these two results **do not agree** within experimental uncertainty."