Paper 4 Personal Investigation

This section looks at the coursework marking descriptors and shows example extracts of good practice. The first group of example extracts are from candidates (A–E) who were awarded Distinction on this component. This high mark will involve good quality responses throughout the range of descriptors.

The lower grades, whilst possibly scoring mid to low marks on each descriptor, typically score well in some areas and poorly in others. The final example is a complete Pass grade script for comparison.

Where candidate work is shown, some notes from the teacher are also visible. The comments are individual and do not reflect the moderator's view. Such annotations are extremely helpful when moderating candidate work. Candidates A to E gained full marks for the skills being exemplified by the extracts. All these extracts come from continuing accounts, however, and do not necessarily score all the marks for that descriptor within the extract shown.

Extracts have been included from the following investigations:
A: resonant frequency of a wine glass
B: energy losses in a car tyre
C: damping
D: the sweet spot of a tennis racket
E: electromagnets
F: the acoustics of a rod.

Initial Planning

Mark Scheme

Criteria for Component 4 Personal Project	Marks
Initial Planning	
The plan contains a title, a statement of the aim and an outline of initial experiment(s). There is little or no elaboration.	0
The plan contains a clear title and aim, with at least one research question. There is an outline of initial experiment(s) with some background physics that helps to interpret or develop the practical scenario. There is a sensible risk assessment (where relevant). At least one pilot experiment has been performed. Largely appropriate apparatus has been requested. There is a brief summary of how the investigation might develop.	2
The plan contains a clear title, aim and a number of clearly worded research questions. There is an outline of initial experiment(s) in a sensible sequence with substantial background physics that helps to interpret or develop the practical scenario. Some of the background physics has been researched and is novel to the candidate. There is a sensible risk assessment and written guidelines for maintaining safety (where relevant). Pilot experiment(s) are used to help develop the plan, for example in improving accuracy or precision or in checking a prediction. The plan contains experimental details and describes what will be measured and controlled, and uses clear diagrams. The apparatus chosen is suitable for every task. Some ingenuity has been shown, for example apparatus has been modified or new apparatus devised. There is a summary of how the practical work might develop, related to the research questions.	4
Maximum mark 4	

General Comment

The plan requires a clear title and aim. It should give some questions to be researched with initial experiments outlined along with some details of apparatus, measuring equipment and a basic risk assessment. How the practical work might develop should be clearly shown.

Here are two examples of high-scoring plans from candidates A and B.

Example Candidate Response – Candidate A

Candidate A is investigating the resonant frequency of a wine glass and although short, the plan covers most of the marking points well. There is a basic plan and then the more detailed start of the work.

A copy of this was handed in well before the experimental period and served as a basis from which to develop the actual expts. carried out in the lab.

INVESTIGATION PLAN

Student name: **Teaching set: Pre-U Teachers:**

Aim: To investigate the parameters which determine the frequency at which a wine glass shatters i.e. the resonant frequency of the glass.

Working Title: Resonance and shattering of a wine glass

Outline of initial experiments:

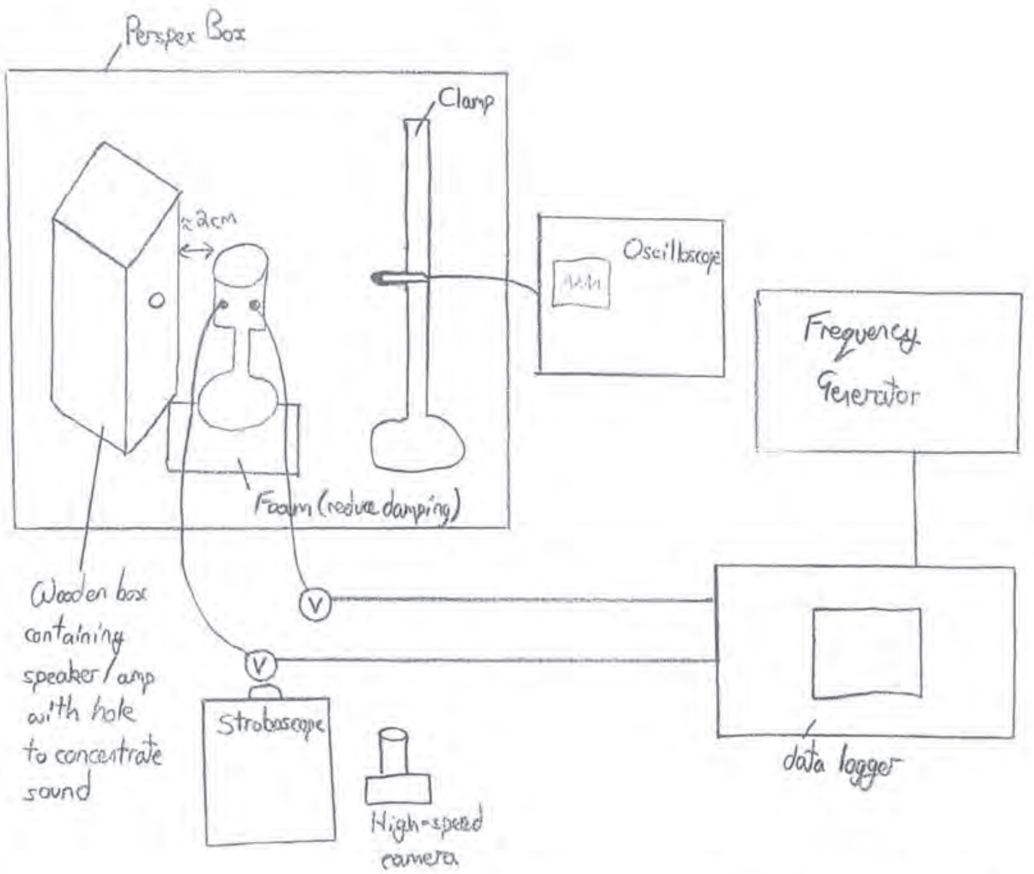
- It may be very difficult to actually shatter the wine glass/es as most are not very pure so have a range of resonant frequencies and also a very high degree/ amplitude of resonance is needed to actually shatter the glass. Therefore I will investigate the frequency of maximum resonance of the glass instead.
- I expect the resonant frequency will depend upon: glass radius, thickness of glass walls, the type and amount of fluid inside, curvature of the glass, height of the glass walls, dimensions of the glass stem, faults/cracks in the glass i.e. purity, temperature, Q factor, mass of the glass, the material the glass is standing on.
- There are many factors here – too many to investigate in 2 weeks – so I will concentrate on a few that I consider the most important (although more than one parameter may vary in some cases so I will need to try and isolate the necessary parameters involved). ✓
- The factors I initially intend to investigate are:
- firstly just observe the vibrational modes of the glass and gain a rough idea of the frequencies and amplitudes required for resonance.
- glass radius
- glass wall thickness
- liquid viscosity in the glass
- amount of liquid in the glass ✓

Sensible initial choice of parameters.

Procedure:

- Take a standard wine glass for preliminary trials of observing the phenomenon
- Ping the wine glass with a metal rod. Place the wine glass next to a microphone connected to an amplifier (the power of which may need to be adjusted according to the pilot trial) and an oscilloscope. Use the signal produced on the oscilloscope to gain a rough idea of the natural frequency (where amplitude of oscillator's signal is much higher).
- Disconnect microphone and connect amplifier to frequency synthesizer.
- Add 2 piezoelectric crystals to the wine glass; one to either side, each connected to the voltmeter (2 for reliability of results), connected to a data logger (to record voltmeter readings). i.e. ~~[illegible]~~ Audacity
- Start the frequency synthesizer at a frequency a little lower than that obtained by the oscilloscope
- Keep amplitude constant and gradually increase frequency
- Note the frequency at which a maximum voltage is detected; this is the resonant frequency.
- Repeat this, varying the different factors mentioned above.
- I will observe the vibrational modes of the glass using a high speed camera and/or a stroboscope ✓ In practice small amplitudes → v. difficult to detect.

Diagram of initial experiment arrangement:



'Systems diagram' ✓

List of apparatus requirements: Materials?

- Wine glasses of identical (or as similar as possible) dimensions but different radii
- Wine glasses of identical dimensions but different thicknesses
- Fluids: water, ethanol, acetone, propanol, glycerol, benzene, sulfuric acid, mercury (to see effect of density on resonant frequency) modified after discussion
- Perspex box (to carry experiment out inside)
- Very sensitive Piezoelectric crystals (to detect motion of glass)
- Metal rod (to obtain rough resonant frequency)
- Frequency synthesizer (to regenerate the resonant frequency)
- 50W and 100W amplifier (so the sound generated is loud enough to cause resonance of a significant amplitude)
- Data logger (to record signal generated by resonance)
- Microphone (very sensitive) (to record rough resonant frequency)
- Ear Plugs (sounds may be continuously loud and high pitched)
- Clamp stand
- Wooden box containing a hole to contain speaker/ amplifier
- Oscilloscope (as another way to record signal generated by resonance)
- 2 Voltmeters
- Measuring cylinder and a syringe
- Foam (to stand wine glass on to reduce damping)
- High speed camera (to observe oscillations)
- Stroboscope (as another way to observe oscillations) ✓

Risk assessment:

- Possibility of glass shattering; carry out experiment in a Perspex box
- May pick up pieces of glass when I handle apparatus if it shatters; wear thick safety gloves ✓
- Flashing light from stroboscope may cause disturbance to any epileptic people and possibly dizziness after a while; use it for short periods of time and survey class members to ensure none are epileptic ✓
- Voltages/ currents are not particularly high so little danger of short circuit due to this
- Liquid may spill on electrical equipment to cause short circuit or damage to equipment/ skin, especially if corrosive; be very careful with handling liquid and immediately clean up any spillages, wear safety gloves
- Glass shattering may damage equipment/ wires; ensure all apparatus is well-insulated and protected
- Repeatedly being exposed to loud/ high pitched sounds may damage ear drums; wear ear plugs and provide them for other class members also
- Experiments with mercury will have to be done in a fume cupboard, under supervision, wearing gloves, glasses and lab coat. ✓✓

Rough breakdown of sequence of work over 2 weeks:

- Monday week 1: investigate modes of vibration and observe phenomenon
- Thursday: Make any changes to apparatus required, investigate effect of varying radius of glass
- Friday: continue with radius
- Friday: investigate effect of adding different liquids
- Saturday: continue with liquids
- Monday week 2: investigate effect of different amounts of liquid
- Thursday: continue with liquid amount
- Friday: investigate thickness
- Saturday: continue with thickness

In practice (and due to music commitments) she came in on many occasions outside normal class time. ✓

- This breakdown is however very rough and in the large time gaps between experiments I will attempt to come into the lab outside of lesson time to carry out more experiments,

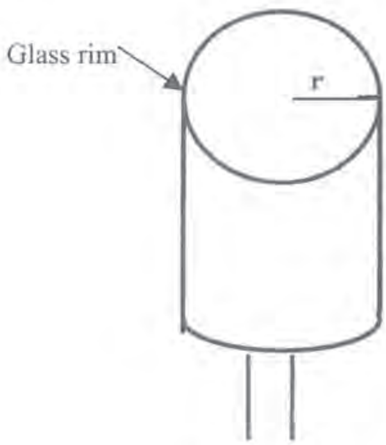
RESONANCE AND SHATTERING OF A WINE GLASS

AIM: To investigate the parameters, which determine the frequency at which a wine glass shatters i.e. the resonant frequency of the glass.

PRE-EXPERIMENTAL THEORY- 1

- *Constructing a very simple model to begin with:*
- *When sound waves hit glass at a particular frequency, they transfer energy and drive the molecules in the glass to vibrate at the same frequency.*
- *When this driving frequency is equal to the natural frequency of the glass, the glass molecules will vibrate at maximum amplitude i.e. the glass will resonate.*
- *As the compressive oscillations travel around the glass' circumference, they meet and form standing waves (so long as there has not been significant attenuation or path deviation due to cracks/other factors).*
- *I expect, at the fundamental frequency, the wine glass will resonate with 4 nodes (from research) – I will expand on this theory later on in my experiment (when I get onto looking at the glass' vibrational modes)*

CHANGING GLASS RADIUS



- *When a standing wave forms at the fundamental frequency, a pulse travels around the glass circumference and reinforces with another pulse; this distance, ($2\pi r$) must be a whole number of wavelengths*

$$2\pi r = n\lambda$$

As: $$f = \frac{v}{\lambda}$$

$$n\frac{v}{f} = 2\pi r$$

$$f = \frac{nv}{2\pi r}$$

- This suggests: $$f \propto \frac{1}{r}$$

i.e. as the radius of the wine glass increases, the resonant frequency will decrease with and inverse proportionality relationship, however as the radius increases, the curvature and height of the wine glass may increase which may also affect the frequency.

This is a very simplified model which, again, I will expand on later on in the investigation when I have a clearer idea of the behaviour of the glass.

Yes – this assumes v is constant and independent of frequency.

Not really noticeable
Here it was.

CHANGING GLASS THICKNESS

- *Increasing the thickness of the glass walls means the walls are stiffer and less able to flex/ oscillate. This suggests that as the wall thickness increases, the fundamental frequency should increase.*
- *However, as the thickness increases, the moment of inertia may also increase, so there will be more mass for the molecules to displace, which will attempt to slow down vibrations and decrease fundamental frequency.* Correct conclusion.
- *It is unclear which factor will dominate.* ✓ Good.

ADDING LIQUID

- *The liquid absorbs energy as the glass oscillates, dampening the oscillation. This may cause the liquid to vibrate along with the glass.*
- *Adding liquid increases the number of molecules that must vibrate and increases the mass that must be displaced when the water molecules vibrate.*
- *This means the liquid molecules suppress/ prevent vibrations (slowing them down) so the natural frequency should decrease as the liquid level increases.*
- *The change in frequency may depend upon the surface area of liquid exposed to the glass or the volume of liquid in the glass.* ✓✓
- *Damping may suppress all the modes of vibration below the liquid level so that significant vibrations only occur above the liquid level – a larger amplitude of vibration may occur above the liquid level. The liquid may be creating a boundary condition - i.e. damped oscillations below the liquid level and undamped oscillations above the liquid level – and it may impose a node at the liquid level, which would also change the wavelength/ frequency of oscillation.* Good discussion of relevant physics.
- *Tilting the glass may change the natural frequency because particular/ different nodes may be dampened.* Interesting.
- *The effect of adding a more dense/ viscous liquid should mean it absorbs more energy, there is more mass to displace and there is a larger damping effect. This should also decrease the resonant frequency.* two different things.

PRELIMINARY EXPERIMENTS

- **I started with a standard wine glass to see if I could observe any resonance of the glass.**
- **There were no piezoelectric sensors in the physics department so I tried using the pickup from an old stereo player connected to an oscilloscope.**
- **This showed very little response to the glass vibrations and only when I tapped the glass rather forcefully did the oscilloscope register a slight change in signal. There was also a great deal of background noise. This could be partially due to the orientation of stereo channels; I assumed one channel would respond to vertical and one to horizontal oscillations, however it may have been more complex than this. Also, the pickup may**

* Speaker provided was not in wooden box, just an average speaker
not have been sensitive enough for the glass vibrations, which were of very small amplitude.
* Chances of smashing glass are very small (resonance is barely observable) so Perspex box not needed.

- I tried attaching two small magnets to either side of the glass and placing a coil, connected to an oscilloscope, as close as was possible to see if this would pick up a stronger signal for the glass oscillations. i.e. using e-m- induction.
- There was again a great deal of background noise and the slight resonance displayed may have been due to the resonance of the coil itself. Also the damping of the magnets on the glass walls may have been significant, reducing the amplitude of vibration a great deal; as the signal depends upon voltage, which depends upon the amplitude of vibration, this will suppress the oscilloscope's signal a lot.

- The wine glasses provided for my preliminary trials were all of small radius, stem and were fairly thick i.e. not the best dimensions for significant resonance according to some research. I need to find a thin, tall (reduce damping) glass with a larger radius.

- The wine glasses provided were also all of different radius, curvature, stem height, wall height, thickness etc. This means it'll be very difficult to measure the effect of changing dimensions of the glass such as radius/ thickness as it will be extremely difficult to change one of these parameters independently (and making the glasses of appropriate dimension myself isn't a feasible option given the time and equipment restrictions). Yes.
- Firstly, I will have to focus on actually obtaining a significant, recognizable degree of resonance. Then I may go on to investigate the way in which the wine glass resonates in more detail; looking at how different parts of one glass vibrates (because the glass' dimensions/ curvature change at different heights down the wall), maybe looking at the amplitude of vibration as a function of height. I may also look at the vibrations of the glass when it is orientated differently e.g. on its side.

RISK ASSESSMENT

- Flashing light from stroboscope may cause disturbance to any epileptic people and possibly dizziness after a while; use it for short periods of time and survey class members to ensure none are epileptic
- Voltages/ currents are not particularly high so little danger of short circuit due to this
- Liquid may spill on electrical equipment to cause short circuit or damage to equipment/ skin, especially if corrosive; be very careful with handling liquid and immediately clean up any spillages, wear safety gloves
- If I experiment with mercury when looking at different liquids (densities), it will need to be done under supervision in a fume cupboard, wearing glasses, gloves and lab coat.
- Glass shattering may damage equipment/ wires; ensure all apparatus is well-insulated and protected (although I don't know whether I'll get to this stage)!

Example Candidate Response – Candidate B

Candidate B is investigating the energy losses in a car tyre. The plan offers a different approach to considering the problems and gives a clear time plan.

Overview / Summary of Project

The project has been based around researching moment of Inertia and in particular, in a car wheel. The project consisted of 4 individual experiments listed below.

① Comparing the experimental and theoretical value for the moment of Inertia of a hollow cylinder. ✓

② Finding the moment of Inertia of a car wheel by rolling down a slope. ✓

③ Finding the moment of Inertia of a car wheel by cutting the wheel in half, dividing the cross section up into small sections and summing the ~~mr²~~ moment of Inertia of each small section. ✓

④ Investigating the thermal energy lost when stretching a piece of rubber. This is similar to a car tyre being ~~compressed~~ loaded and unloaded as it drives down the road. ✓

Energy Losses in a Car Tyre.

MOMENT OF INERTIA.

definition?

$MoI = \Sigma mr^2$

moment of Inertia of wheel.

work out volume using cross section × circumference.

Thickness of steel?

vernier callipers

How to get surface area of cross section

Autocad

moment of Inertia by cutting in half. ③

How to cut in half?

angle grinder

safety!!

② moment of Inertia by rolling down slope

How to construct slope?

$G.P.E = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

mgh

$\omega = \frac{v}{r}$

– measure mass

– v = average velocity × 2 = $\frac{\text{distance}}{\text{time}} \times 2$

① How well does theoretical value of moment of Inertia of hollow cylinder agree with experimental value.

Moment of Inertia = $\frac{1}{2}m(R_1^2 + R_2^2)$

derivation?

Modelling car tyre as hollow cylinder.

How well does this agree with experimental value obtained by practical experiments ② and ③

④ Hysteresis of Rubber

Energy given out is area between loading + unloading

work out energy put into system

temperature rise?

$Q = mc\Delta T$

mass

change in temp.

measurable?

Rotational Energy in 4 car wheels at 30 mph? at 75 mph?

Rotational kinetic energy $= \frac{1}{2}I\omega^2 \rightarrow \omega = \frac{v}{r}$

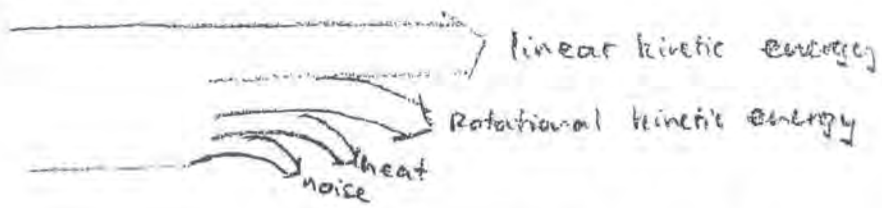
Advantage of Nitrogen filled tyres?

C4 Stro... S...

Nice overview demonstrating his well organised approach

ENERGY LOSSES IN A CAR TYRE

My project did not start off with my current working title. Initially I was interested in investigating the inefficiencies of a push kart which I had recently built for a school competition. I initially planned to roll the push kart down a slope as shown and calculate the energy lost.



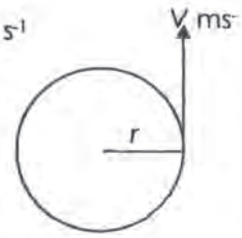
The energy losses would be due to several factors such as air resistance, rolling resistance and rotational kinetic energy built up in the wheels. This led me to look at kinetic energy stored in rotating objects. I have done some research into this which I have outlined below.

Research of Background Physics

The following has been taken from my lesson notes and explanation notes given out by the Physics Department.

Rotational Motion

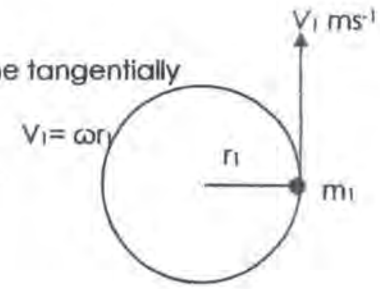
Angular Velocity (ω) = $2\pi \div T$ s^{-1}
Circumference = $2\pi r$
$V = 2\pi r \div T$
$V = \omega r$



Rotational KE

Rotational KE = $\frac{1}{2}mv^2$ – taken at a point in time tangentially

KE of point particle shown = $\frac{1}{2}\ m_1 v_1^2$
$= \frac{1}{2} m_1 (\omega r_1)^2$



Derivation of Total KE formulae

This is the sum of an infinite number of point particles taken along the radius.

$$\begin{aligned}\text{Total KE} &= \tfrac{1}{2}\ m_1 v_1^2 + \tfrac{1}{2}\ m_2 v_2^2 + \tfrac{1}{2}\ m_3 v_3^2 \\ &= \tfrac{1}{2} m_1 (\omega r_1)^2 + \tfrac{1}{2} m_2 (\omega r_2)^2 + \tfrac{1}{2} m_3 (\omega r_3)^2 \\ &= \tfrac{1}{2} \omega^2 (m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2) \\ &= \tfrac{1}{2} \omega^2 \Sigma^{i=n}_{i=0} m_i r_i^2\end{aligned}$$

From doing this research and understanding rotational momentum, I realised that a bike wheel was difficult to measure due to its uneven mass distribution. I became interested in looking at a car wheel and realised that there was more to the inefficiencies in a car tyre (such as the hysteresis of the rubber) than just the rotational energy dissipated every time the car decelerated. This led me on to the other part of my investigation; the energy lost when the rubber is compressed and extended again. I did some further research into this and this is outlined below.

The Hysteresis of Rubber

I read through a page from the Salter Horner's physics text book entitled "Polymers." This derived the formulae to calculate how many "pieces" make up a polymer chain. It was unclear what a "piece" was defined as so I used *The Cambridge Guide to the material World* to look this up. I discovered that in natural rubber (polyisoprene) that it refers to the monomer involved. In the case of natural rubber it is $H_2C{=}C(CH_3)-C(H){=}CH_3$ which from my chemistry knowledge I can name as cis-1,4-polyisoprene. The stereoisomer of this compound is more commonly known as gutta percha which is a lot less elastic (used in shell of golf ball). These monomers only align if the rubber is under tension and the elasticity of rubber is derived from these kinks.

The area in the middle of a hysteresis curve is the energy dissipated in the rubber. $\Delta E = m.c.\Delta T$ (m=mass, c=specific heat capacity) (taken from Reference 1)

↳ explanation?

Research Questions

clear research questions.

1. If the car wheel was to be modelled as a hollow cylinder, how close would the calculated MOI be to the experimental value?
2. How can the MOI of a car wheel be measured?
3. What is the Moment of Inertia of a car wheel?
4. What is the rotational KE of all 4 car wheels running at 30mph? What is it at 75mph?
5. How much thermal energy is lost through the hysteresis of the rubber when a car wheel is compressed?

PILOT EXPERIMENTS:

Determining a Hysteresis Graph for a Rubber Band ⇒ this later changed

Aim: To determine if a noticeable hysteresis curve can be detected by performing a force extension graph for a rubber band to which a force is progressively applied in small increments then taken away in a similar manner.
This experiment is useful to enable me to determine the order of magnitude for the energy lost in just a simple elastic band and to see if it was a measurable amount.

I later changed this pilot to comparing the theoretical and experimental values of the moment of inertia of a hollow cylinder. This pilot allowed me to see wether this technique would work (of using angular velocity sensor) and to understand moment of inertia better

Apparatus List: Clamp Stand, 4 pieces of approx 1" cubed soft (light) wood, 2 similar elastic bands, scissors, strong bulldog clip, scales precise to nearest gram, masses in 10g increases up to about 150g, 1m ruler with mm divisions.

Method:

- Cut elastic band to form one straight piece of elastic.
- Set apparatus up as shown.
- Measure un-stretched length of rubber band to nearest mm.
- It is not necessary to wear goggles for this experiment.
- Add 10g and measure new length.
- Keep adding a further 10g and measuring new length until first band fails.
- Plot a force/extension graph and determine where the limit of proportionality is. — load and unload slowly
- Replace first elastic band by ~~second~~ elastic band.
- Repeat procedure of adding masses and recording length.
- When the elastic band approaches the limit of proportionality stop adding masses.
- Take the masses off one by one and measure the length of the band after each weight has been taken off and continue until all the masses have been taken off.
- Plot graph of force/extension.
- The area inside the hysteresis curve is the energy lost – measure this by addition of the squares inside this area.

OK!

How will you know?

proof?

calculations to explain what range of meters to use (milliameter or microammeter, micrometer, vernier calliper, etc.)

OUTLINE OF INITIAL EXPERIMENTS

1. Measuring the Moment of Inertia of a Car Wheel
2. Calculating the Moment of Inertia of a Car Wheel
3. Measuring the Temperature Rise of a Piece of Car Tyre

1. Measuring the Moment of Inertia of a Car Wheel

Aim: To measure the linear velocity of a car wheel after being rolled down an incline. From this the moment of inertia of the car wheel can be calculated.

Variables: The dependant variable is the linear velocity at the bottom of the slope. The independent variable is the height of the wheel.

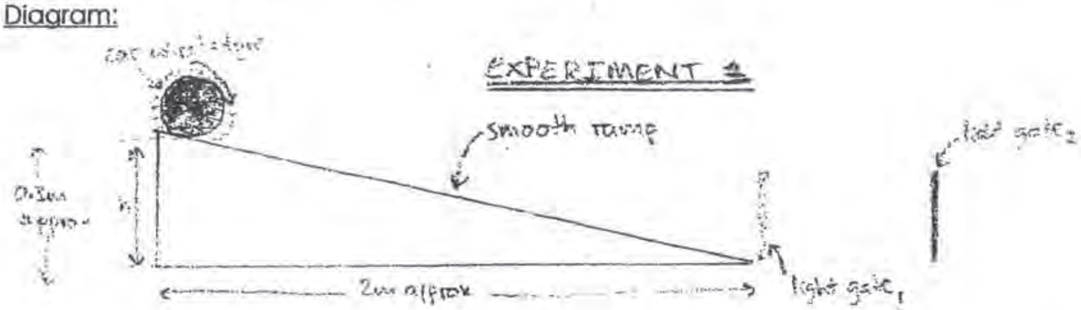
Description of Experiment:

- I intend to roll a car wheel down an inclined slope approximately 2m long and one end about 0.3m off the floor.
- The car wheel will have to be found or bought and it must not have had uneven shoulder wear as this will cause it to pull to one side.
- I will be able to weight the car wheel to find out it mass.
- From this I can calculate the GPE that the car tyre has at the top of the slope.

- If friction and air resistance are excluded then all of the GPE will be turned into rotational KE and linear KE.
- Using two light gates the linear velocity at the bottom of the incline can be measured.
- If the linear KE is calculated, the rotational KE gained can also be calculated.
- If the rotational KE gained is known then the moment of inertia can be calculated.
- This experiment will need to be repeated several times and an average taken.
- The wheel will need to be let go from the same place each time on the incline. It may be more accurate to not start right at the top but to start a few cm down the incline.
- It will need to be stationary when let go.
- If there is not a ramp of the correct size available to me, I will construct the ramp myself.
- If there is not a light gate available of the correct size then I will have to use an alternative method or modify the equipment.
- This is a relatively safe experiment although care should be taken to not let the wheel drop onto anyone's feet or roll into anything that it could damage. It may also be dirty/oily so care should be taken not to let it rub this dirt onto any parts of the science school. I should also make sure that the wheel doesn't roll into any light gates and damage them. If I construct the ramp myself then there will be further safety aspects to consider such as use of power tools.

Safety.

Diagram:



✓

Apparatus List: Ramp about 2m long and a height difference of about 0.3m, light gates, meter ruler with mm divisions, car wheel, mass balance. Also an appropriate space is needed to perform experiment.

2. Calculating the Moment of Inertia of a Car Wheel

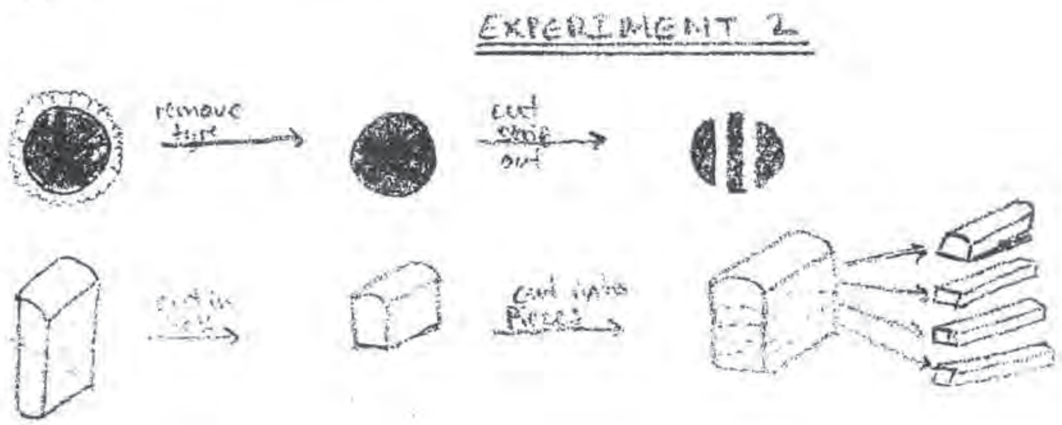
Aim: To calculate the moment of inertia of a car wheel by summing the moment of inertia of all the small segments through its cross section.

Variables: The independent variable is the distance out from the radius. The dependant variable is the mass.

Description of Experiment:

- This has been left to be done after Experiment 1 as this involves cutting up the car wheel.
- Re-weigh the wheel or use mass from Experiment 1.
- Using an angle grinder, cut about a 2cm strip out of the middle of the car tyre.
- Cut this across ways in half.
- Cut this half of the wheel up in approximately 2cm cubes radiating out from the centre of the wheel.
- Calculate the circumference round the wheel for the middle of each of these cubes.
- Weight each cube, and then multiply by the number of cubes that is required at that radius to make a complete revolution around the wheel.
- Repeat this for each cube.
- I will weigh the tyre and in order to simplify the experiment I will presume the mass of the tyre acts at a fixed point out from the radius and include this in my model.
- The mass of the air in the tyre can also be estimated and included in the model.
- Model this as point particles on a piece of light inextensible string.
- Calculate the moment of inertia.
- I will have to carry this out at home as pupils are not allowed to use angle grinders to carry out this sort of procedure at school.
- This will be the most dangerous of all the experiments as a hand held angle grinder is being used. I will need to wear goggles while using it and be aware that the metal will be hot and have sharp edges after it has been cut. I will wear gloves and using a sanding blade on the angle grinder, sand down and sharp edges.

Diagram:



Apparatus List: Angle Grinder with cutting and sanding blade approx 7", goggles, mass balance, tape measure, marker pen, gloves.

3. Measuring the Temperature Rise of a Piece of Car Tyre

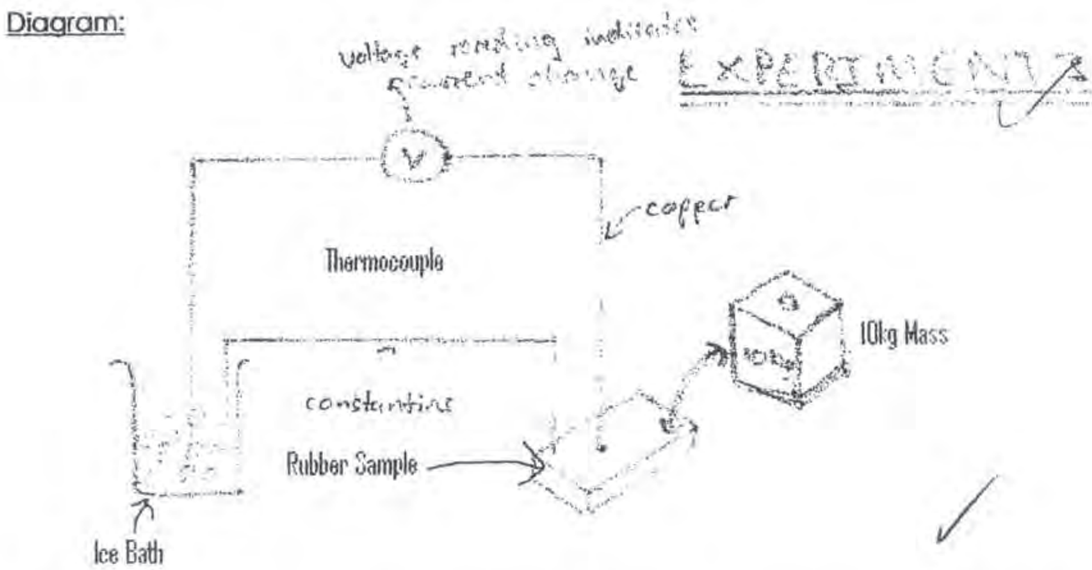
Aim: To measure the thermal energy given out of a piece of car tyre after a mass has been added then removed several times.

Variables: The independent variable is the work done on the rubber. The dependant variable is the temperature rise of the rubber.

Description:

- Source a piece of tyre rubber approx 50x50mm.
- Look up the specific heat capacity from either a book or speak to the manufacturer.
- Weigh the sample.
- Set up a thermocouple and calibrate with water of a know temperature.
- Record the initial temperature of the rubber using the thermocouple.
- Add a known mass about 10-15kg then remove. Repeat this several times in succession.
- Record the new temperature of the rubber.
- Try to insulate the tyre to minimise heat loss to surroundings.
- Calculate the energy given out to surroundings using the equation $\Delta E = m.c.\Delta T$
- The main safety concerns are the electrical equipment and the heavy masses involved. Care should be taken when lifting the masses.

Diagram:



Apparatus List: Thermocouple, ice bath, thermometer, piece of rubber tyre, mass balance, several 10kg masses, insulation material.

Time Planner:

To be done in lesson time	To be done out of lesson time	Week 1						Week 2					
		1	2	3	4	5	6	1	2	3	4	5	6
Measuring MOI	Set up Slope + Apparatus	■											
	Modify kit if needed		■										
	Take Readings			■									
	Calculate Moment of Inertia												
Calculating MOI	Weight Wheel + Mark out cut lines				■								
	Cut up Wheel					■	■						
	Plot Graph of mass/area for each segment												
	Deduce Moment of Inertia												
Hysteresis of Rubber	Set up Apparatus							■	■				
	Callibrate Thermocouple									■			
	Take Readings										■	■	
	Plot Graph of Force/Δtemp												
Cost to Motorist	Make sensible estimations												■
	Calculate Cost												■

Very clear plan of how time organised.

Example Candidate Response – Candidate D

This example from candidate D is aimed at investigating the sweet spot of a tennis racket and although all the marks were awarded, it reminds us that we are looking for a close fit to the descriptors and not necessarily for perfect answers.

What affects the efficiency of the bounce of tennis balls on tennis racket? ✓

The aim of the investigation:

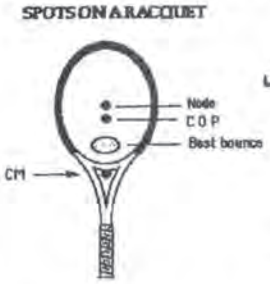
I am very interested to investigate on this topic as I started to learn playing tennis last year and have found some difficulties on hitting the ball effectively. ✓

Initial research on the topic

Sweet spot

Sweet spot also known as the power region is defined as the region on the racket face where the coefficient of restitution (COR) is maximum. Coefficient of restitution is the ratio of velocities after and before the impact. It is given by the formula

going beyond syllabus



$$C_R = \frac{V_2 - V_1}{U_2 - U_1}$$

When COR is equal to one, the collision is elastic. When the value is smaller than 1, the collision is inelastic. ✓

The sweet spot is also defined as the point where the oscillations are a minimum. This would be the node on the standing wave ✓ Good

The sweet spot can be found by using the dropping method. The sweet spot is given by the formula $\sqrt{\frac{\text{Bouncing height}}{\text{Drop height}}}$. It is known that the COR tends to be the largest when the ball drop onto the part that is closer to the throat but not at the centre. This is because the string is the softest at the centre of the head and the frame is stiffer near the clamped point.

May be found using

The other definition is called the centre of percussion which is a point on the racket face where there is no vibration when there is a right combination of rotational and translational racket motion collides with a ball of any speed. The centre of percussion of a racket is given the formula

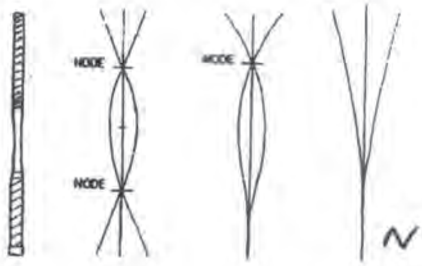
$$q = \frac{I}{Mr}$$

✓ Where q is the distance from the axis of rotation to the centre of percussion, r is the distance form the axis of rotation to the centre of mass, I is the moment of inertia and M is the mass of the racket.

Standing wave

When the handle is clamped, and the racket is struck, fundamental frequency of vibration would be produced. The fundamental frequency has no nodes. The next higher

one node?



N

reference?

form of oscillation has one node and if we assume the racket to be uniform the frequency would be around 6 times higher than the fundamental. If the racket is not clamped, it would form a two nodes oscillation and would have 6 times as high frequency as the fundamental. This increase in frequency is generally regarded as unsatisfactory as it would result in a loss of ball control and tennis elbow.

When the ball hits the node of a free-free racket and a free-clamped racket, there would be no oscillations. The node point is the sweet spot on the tennis racket.

For a flexible racket, the fundamental frequency is around 100Hz and for a stiffer frame its around 180 Hz.

Where did you get this info. from? References?

Research questions

How to measure the efficiency of bounce?

How does the string affect the efficiency of the bounce?

How does the length of the handle affect the efficiency of the bounce?

How does the strike position on the racket head affect the efficiency of the bouncing height?

What is the hysteresis of tennis string? These are all covered

Clear initial research questions

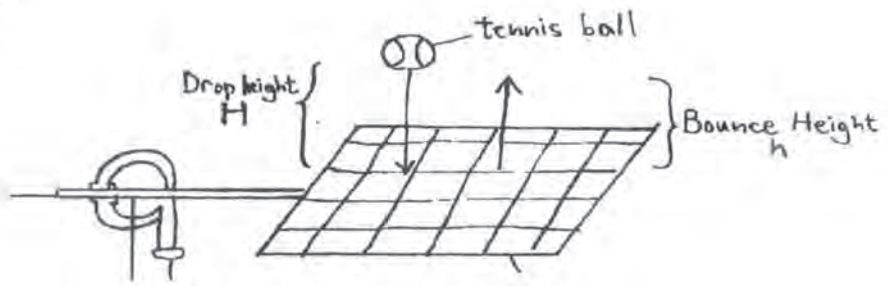
An outline of the initial experiments:

Aim: To find out whether the length affect the efficiency and to see what height I should be using to get the most accurate and precise results

Apparatus list: 1x Squash racket, 1x ruler, 3x G clamp, 1x tennis ball

Method: Squash or tennis?

- clamp the squash racket firmly on the table
- use a clamp and stand to hold the ruler firmly right next to the racket
- Make sure the ruler is in line with the racket to show accurate readings – How? Ensure it is vertical –
- Drop the tennis ball onto the tennis racket
- Alter the length but keep the drop height constant to get different readings
- Plot a table of drop height and bouncing height
- Work out the efficiency of the tennis ball



$$Efficiency = \frac{Gain\ in\ G.P.E.\ after\ bounce}{Lost\ in\ G.P.E.\ before\ bounce} \times 100\%$$

$$Efficiency = \frac{mgH}{mgh} \times 100\%$$

physics driving experiment.

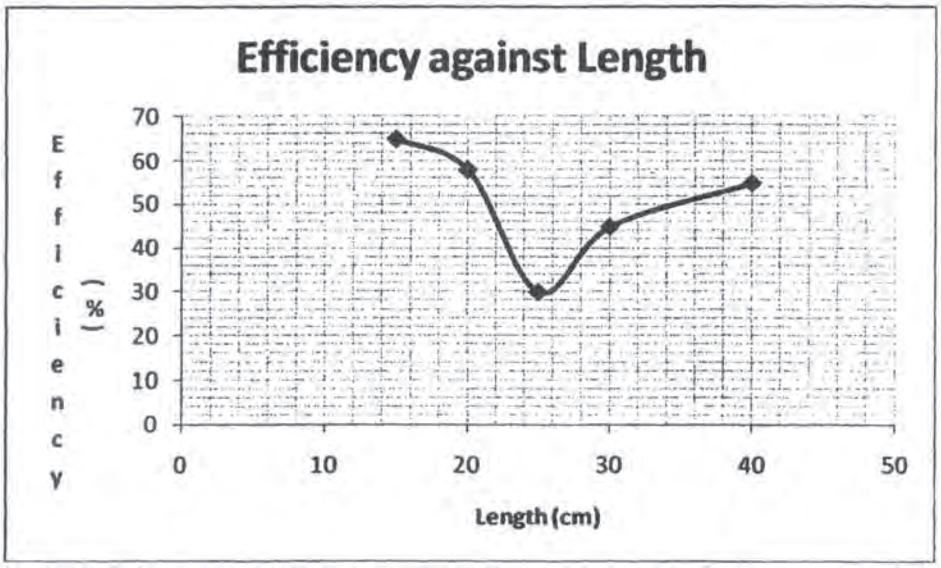
$$Efficiency = \frac{H}{h} \times 100\%$$

Why were these not repeated?

Results:

Drop Height (cm)	*Bouncing Height (cm)*	*Length (cm)*	*Efficiency (%)*
40	26 ±?	15	65
40	23	20	58
40	12	25	30
40	18	30	45
40	22	40	55

Could have included more lengths.



only if you analyse your uncertainties and repeatability? !

There is a noticeable difference in the bounce height for the same drop height in the three different areas. The differences in the bouncing height are due to the energy loss. As the ball is dropped from height h, the gravitational energy, mgh should all be transferred to kinetic energy. When the ball bounces off the racket, energy is loss on the racket. If the bouncing height is much less than the dropping height, it suggests that the tennis racket has absorbed the energy which means the energy is transferred.

Tennis balls

Risk Assessment

I have used a squash racket instead of a tennis racket and I found out that using a squash racket is not as good as the surface area of the racket face is not as big and the bouncing height is not as high. In the very beginning of the experiment, I tried to use a stand and clamp to hold the position of the racket but it failed. Therefore I switched to use a G clamp to clamp the racket on the table instead. Also when I clamped the racket on the table, I could barely firmly clamp it with one G clamp. Therefore later in the experiment, I had used three G clamps in order to stable the position of the racket and avoided it from vibrating. Also, make sure the tennis racket is clamped onto a table which is in the corner of the room as no one would hit it accidentally and causing injury.

Good

Pilot performing

Outline of Initial Experiments

1. *Finding the hysteresis of tennis string*
2. *What is the energy loss of the tennis ball when it hits a surface?*
3. *Does the length of the handle affect the efficiency of the bounce of a tennis ball on the racket?*

Finding the hysteresis of tennis string

Aim: To plot a hysteresis graph for a tennis string and work out the energy lost under the curve

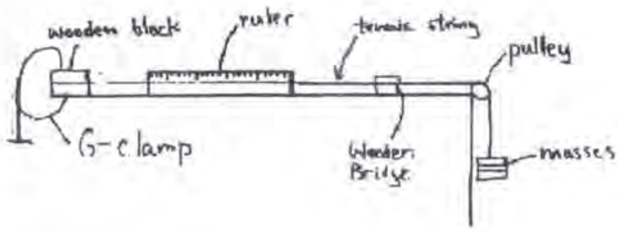
What length?

Apparatus: 2x wooden block, 1x tennis string, 10x masses, 1x pulley, 1x goggle, 1x ruler, 1x G clamp, 1x sponge

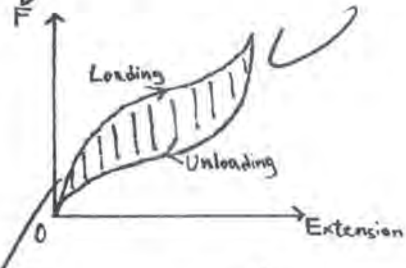
Independent variables: ?

Method:

- Secure the tennis string between the two wooden blocks
- Place the tennis string on the pulley
- Put the masses at the end of the tennis string



- Place a wooden bridge over the string for H&S?
- Place the ruler next to the string
- Place the sponge underneath the masses safety
- Observe the change in length each time the mass is put at the end of the string
- Plot a table of F and Extension
- Repeat the procedure when masses are unloaded
- Plot a table of F and contraction
- Plot the two datas on a graph of F against Length
- The area between the curves are energy lost



Risk Assessment:

Throughout the experiment goggle has to be worn in case the string breaks. The sponge underneath the masses is to prevent accidents when the string breaks and the masses fall onto the ground. Sponge can absorb the energy and lower the noise produced when the masses fall onto the ground. The wooden bridge over the string is also to prevent the string from slapping people or myself when it breaks. This experiment should be conducted on a table where not many people would pass by as it is a quite dangerous experiment.

What is the energy loss of the tennis ball when it hits a surface?

compression

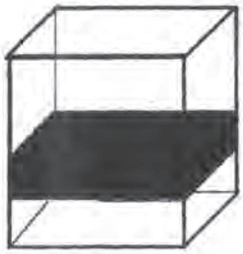
Aim: To find out the energy loss of the tennis ball by plotting a force extension graph

Apparatus: 1x box, 1x tennis ball, 1xruler, 20x 100g mass

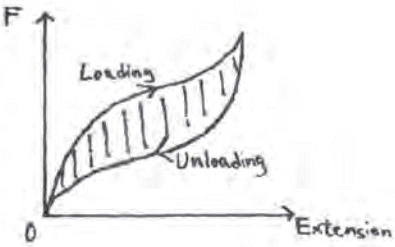
Method:

box

- put a tennis ball inside a rectangular prism as shown on the right
- put a mass onto the ball each time and record the change in diameter of the ball
- unload the masses one by one
- Record the change in height again
- Plot a graph of force against extension
- The area under the two curves shows



Risk Assessment: Place the masses carefully into the box and avoid the masses go onto your fingers. Also try not to put several masses at the same time onto the ball as this may cause accident. Such as?



Good – all relates to research question

Does the length of the handle affect the efficiency of the bounce of a tennis ball on the racket?

of oscillation of racket?

Aim: To investigate whether the length would alter the frequency and how the frequency of the rackets affects the efficiency of the bounce of tennis ball

Apparatus: 1x G-clamp, 1x tennis racket, 1x video camera, 1x ruler, 1x tennis ball,

Method:

- Model a tennis racket handle using a wooden plank
- Clamp the plank firmly on the table
- Measure the time for 5 oscillations Why 5?
- Then divide the number by 5
- Since $f = \frac{1}{T}$, divide the number by 1 to get the frequency X !
- Repeat the above procedure form different length.
- Then plot a frequency length graph
- Plot a log-log graph to prove whether the relationship is exponential or not X No! prove law log-linear for expo?
- Then divide the tennis racket into different parts as shown on the right
- trial? Drop the ball onto different part on the tennis racket
- Record the bouncing height and work out the efficiency
- $Efficiency = \frac{bouncing\ height}{drop\ height} \times 100\%$
- Plot a graph of efficiency and area
- We can deduce from the graph where the sweet spot is

A rough breakdown of how the two week investigation period will be spent

ɔe done	Week 1						Week 2					
	1	2	3	4	5	6	1	2	3	4	5	6
y length experiment												
ake readings	■											
ght experiment												
		■										
dings			■									
tions				■	■							
st experiment												
						■						
dings							■	■				
is of tennis string												
									■			
dings										■		
ations											■	■

More evidence of planned approach.

Reference

- The physics of Sports, by Angelo Armenti,Jr, published by Springer- Verlag 1992, p.139-166
- http://www.racquetresearch.com/sevencri.htm

Reference – good detail

For planning – see later. Clear diagrams + use of ingenious methods

Organisation

Mark Scheme

Organisation during the two weeks of practical work	
The work is written up only once a week or when the candidate is prompted. Notes of practical methods lack detail, records are generally incomplete, and the record of the work is poorly organised and difficult to follow. There is little evidence that the results of each experiment have been analysed and interpreted before work on the next experiment begins.	0
The work is written up more than once a week. Records are largely complete so that it is possible to follow what was done each day. There is evidence that some analysis and interpretation of each experiment has taken place before work on the next experiment begins, but there is little evidence of further research to help interpret the results.	1
The work is written up at least every two days. Practical methods are described clearly. Records are clear, well-organised and complete, making clear what work was completed each day and how the ideas evolved. The analysis of each experiment is completed (e.g. graphs are plotted and the mathematical relationships and uncertainties discussed) and results are interpreted (with the help of further research where necessary) before work on the next experiment begins. Where appropriate, the plans for later experiments are adapted in response to the results of earlier experiments.	2
Maximum mark 2	

General Comment

In this section we need evidence of regular writing up of the work, showing clear methods and records with logical progress, and perhaps modifications, to the next investigation.

Example Candidate Response – Candidate A

This is an excerpt from a "day by day" diary showing clear methods, good records and progress through the work. The candidate is investigating the resonant frequency of a wine glass.

DAY-BY-DAY DIARY
22/2/10

- I found a much larger wine glass with thinner walls, larger radius and a taller stem.
- I could not find another pickup from an old stereo player, however I purchased a guitar "sound enhancer," containing piezoelectric sensors. These are not ideal as they are rather large (possibly not sensitive enough and they may damp the glass too much) but I will try them out.
- A teacher suggested that I try the old pickup again, feeding it into a phone input on a hifi pre-amp. This is possible but the connections are complex so the lab technicians firstly need to make a cable to connect this.

- Whilst waiting for the lab technicians to make a cable for the pre-amp and also for the piezoelectric sensors, I do not want to waste time; I will investigate the resonance of the glass by recording the sound produced when the glass is hit by a metal rod and using Fourier analysis off the frequency analyzer "audacity" to determine the resonant frequencies/ harmonics. ✓
- This may, however, record the resonance of the air column not the glass but could make an interesting comparison.

Presumably by reading from peak on F.T.?

- To obtain an idea of resonant frequencies of different types of glass I recorded the resonant frequencies of all the glasses available to me, however they all had very different dimensions so this was not a very conclusive experiment;

Glass type	Diameter at top /cm	Diameter at bottom /cm	Length of stem /cm	Height of cup of glass /cm
Fat (very large change in curvature)	7.0	1.0	5.5	9.0
Thin (almost straight throughout)	4.5	1.0	4.5	12.0
Large (control) (large change in curvature)	7.0 (but gets fatter – 10.5 at fattest)	1.0	11.0	25.0
Small (straight)	7.0	4.0	7.0	13.0
Straight	5.0	2.0	6.0	10.0

Glass type	Resonant frequency, f, /Hz			Average f /Hz
Fat	4312	4321	4310	4314

Table could be presented more clearly.

Thin	4085	4085	4087	4086
Small	5333	5326	5334	5331
Straight	4867	4867	4867	4867
Large	6319	6643	6652	6538

sig fig's?

- **Although it doesn't give a lot of information, the data suggests the range of frequencies I will be working with; there is a relatively small range of resonant frequencies for glasses of fairly different dimensions (although the effects of different parameters may cancel each other out).**
- **Not much more can be taken from this data as so many parameters were changed at once. It may prove useful when comparing to the resonant frequencies obtained by the other methods mentioned above.**
- **However, these frequencies seem surprisingly high compared to those I expected (in the high hundreds).**

↳ justification?

- **I also recorded the resonant frequencies with different volumes of water in the glass.**

Table next page.

Theory - 2

- ***Hitting the glass transfers energy to the molecules of the medium inside, causing them to vibrate. The speed of their vibrations may determine the resonant frequency but also the frequency with which the glass itself vibrates may determine this – it is unclear which will dominate. When the glass is tapped, the sound emitted will be the natural frequency of the glass/medium system.***
- ***If the frequency depends of glass vibrations, it will decrease, when water is added, as water is denser than air so its vibrations are slower.***
- ***If frequency depends on the air column resonance, as more water is added, the resonant frequency should increase as the length of the air column decreases.*** Good
- ***Considering vertical vibrations of the air/water, the relationship should follow:***
- $l = \frac{n\lambda}{4}$ *so* $f = \frac{nv}{4l}$ ***l=length of closed air column, v = speed, f = frequency, λ = wavelength***

- ***However, I am changing the proportions of air and water in the glass but the water may be resonate as well at different frequencies, so the relationship may not be this simple.***

Water height /cm	Resonant frequency, f /Hz			Average f /Hz
0.0	6319	6643	6652	6538
7.0	6244	6415	6110	6256
1.0	6234	6499	6646	6460
16.0	5573	5602	5576	5584
20.0	4567	4890	4997	4818
24.0	4312	4125	4200	4212

~~Error~~ = +/- 0.5cm for height of water (taking curvature into consideration), +/- 0.5Hz Must be bigger than this looking at range of repeat values.

- **The results clearly show that as volume of water increases (as the length of the air column decreases), frequency decreases but the relationship is by no means clear; more data points and further investigation is needed to suggest anything more than a general trend.**
- **This suggests the vibrations of the glass, not the air column, are responsible for the resonance, not the air vibrations.** ✓

- **However, before I go any further analyzing this effect, I need to assess the way I am measuring resonant frequency (and maybe try a different way); these frequencies seem awfully high compared to the sound I'm hearing!** ← Yes. **Maybe I'm picking up the wrong resonance.**
- **Also at times, the resonant frequency was difficult to determine as there were peaks of very similar amplitude at different frequencies, however I did take repeat readings.**

<u>24/2/10</u>

- **I started by trying to detect and record the resonance of the wine glass using the piezoelectric sensors.**
- **The resonance was difficult to detect due to mains/external voltage interference, the small amplitude of vibration of the glass and there was also a very significant damping of the sensors themselves; when the glass was tapped with a metal rod with the sensors attached, the tone produced was of a much lower pitch than the tone when the glass was struck without the sensors. The sound was of much lower amplitude and decayed much more quickly with sensors.**
- **Also, maybe the speaker was too low amplitude, as I could not "see" any resonance of the glass.**

- **Instead, I tried detecting the resonant frequency with my ears using a** – i.e. listening for max volume **vibration generator; I fixed the glass by clamping its stem and lightly pressing the generator onto it.**

- **A clear resonant frequency could be detected over a range of approximately 1Hz. The damping of the clamp was not very large.**

Example Candidate Response – Candidate C

This example of this skill area comes from candidate C, investigating damping. We see a good response to gain both marking points.

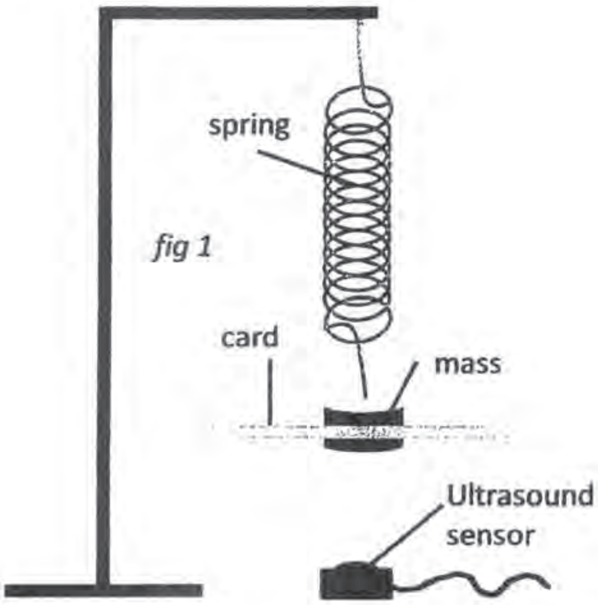
Damping, forced oscillations and resonance in a mass-spring oscillator

Damping

22/02/10

Initial Experiment

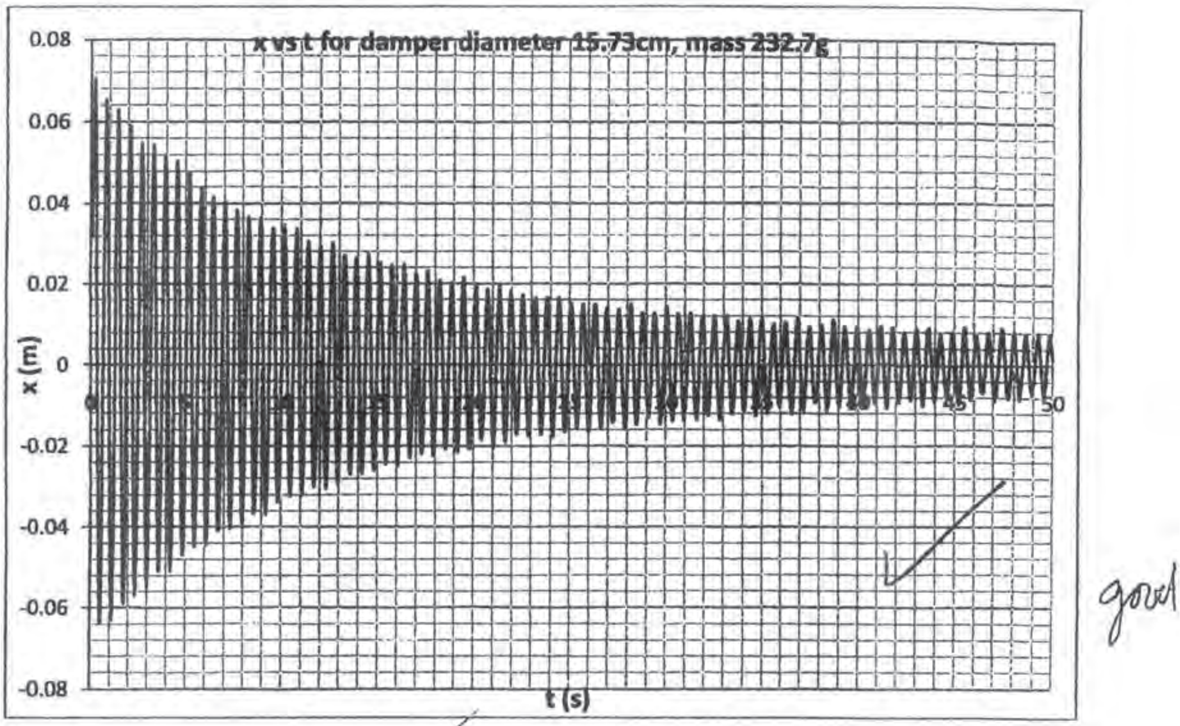
Experiment:



The Experiment:
- Zeroed the position sensor at equilibrium position
- Displaced the system downwards and released
- Began the ultrasound sensor measuring at 25 measurements/second for 50 seconds (I used this setting throughout my practical work)
- Repeated procedure for *several* different sizes of circular card (also used CDs), and for each measured the mass of the card + metal mass together (as this changed for the different amounts of card by a significant amount)
- I repeated my results three times for each size of card

bullet points ok if thorough.

Results:
An example of the graph of position vs. time is given



- By inspection I can see this has the characteristic *form* (I cannot conclusively say it is) sinusoidal curve for SHM, however also there is a decaying 'envelope' which slowly reduces the amplitude
- Even by qualitative analysis I can see that as I increase the area of the damper the steepness of the curve increases
- Hopefully I can theoretically find a relationship

Finding the k value for my spring:

- Initially took one reading and used this to calculate value
- However I decided the uncertainty on this value was far too large considering the extent I would potentially use it in later work
- Decided that minimising uncertainty for this value would be very important

Experimental set-up:
- Set up spring with mass hanging off the end, placed an ultrasound senor vertically below
- Varied the mass (and therefore the force) on the spring, and measured the displacement from the sensor (y in fig 2)
- See fig 2 below:

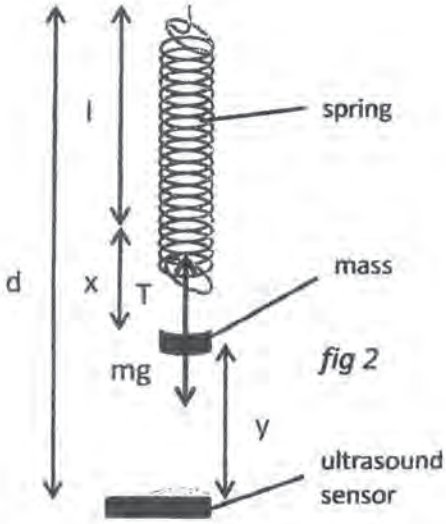


fig 2

Theory:

- Hooke's law states that $F = -kx$, i.e. that the force on a spring is proportional to the displacement, therefore here the force T due to the spring is equal to –kx, where k is the stiffness I wish to measure
- In this diagram, by resolving forces, we can see at equilibrium $T = mg$
- Therefore combining, $mg = kx$
- However, I only measured y, where $y = d - (l + x)$, therefore I must rearrange and substitute to find a relationship between mg and y:
  $mg = k\big(d - (l + y)\big)$
  $mg = -ky + k(d - l)$
- This is a linear relationship, and if I measure y(m), and then plot mg vs –y, I should get a very accurate value for the stiffness of my spring
- We can see this relationship on the graph shown below ✓ a bit complex essentially hooke's law?

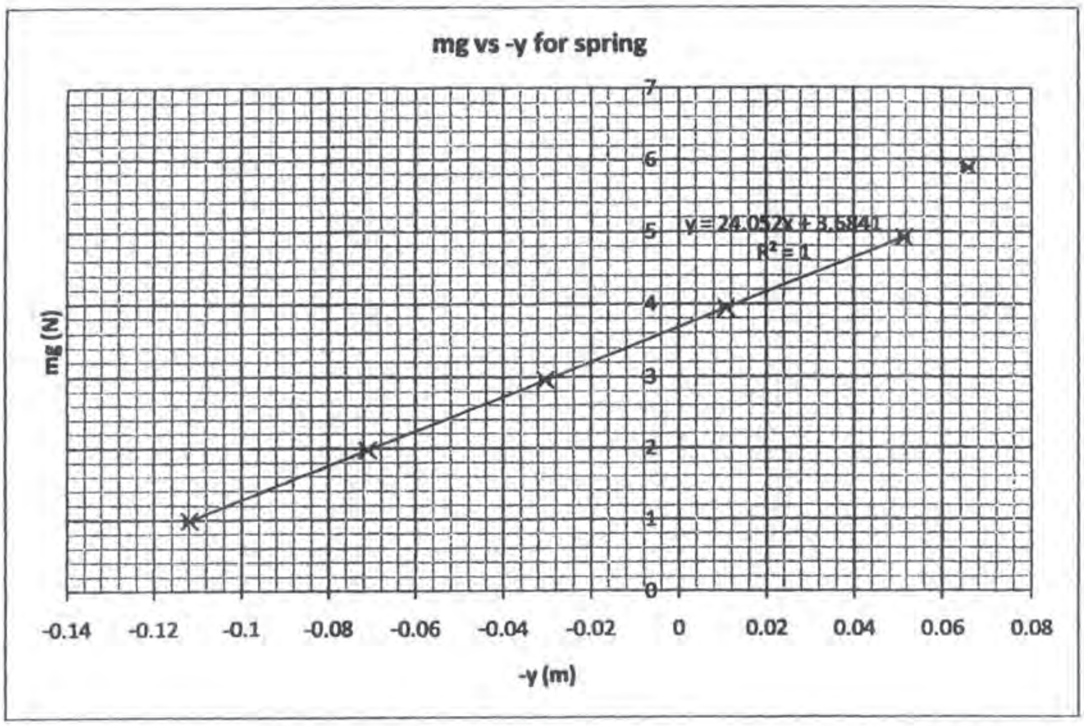
Interpretation

- The graph is very strongly linear with an R^2 value of 1 to a number of decimal places ✓
- The final data point clearly does not lie on this straight line, as the spring has reached its limit of proportionality here – therefore I must not load the spring with more than about 500g for Hooke's Law to still be valid
- The gradient I measured for k is 24.052 unit?

The Uncertainty

- I measured mass using very accurate scales, accurate to ±0.1g ✓ assumed calibrated?
- Part of the assumption of Hooke's Law is that a spring is massless, therefore I ignore this in my calculation
- The ultrasound position sensor was accurate to within ±1mm again calibration?
- I used this to place error bars on my graph
- I used this to calculate the maximum and minimum possible gradients allowed by these error bars as 24.34 and 23.78 respectively
- Therefore allowing for error my measured value for k is $24.05Nm^{-1} \pm 0.3Nm^{-1}$ ✓

ok unit here



✓ ok for extracting k.

Example Candidate Response – Candidate E

In this example, investigating electromagnets, both the planning and organisation descriptors score heavily in only six pages (the total script is only 22 sides and gained a Distinction).

What Affects the Strength of an Electromagnet?

Aim

To investigate the different factors which could potentially affect the strength of an electromagnet, such as:

The use of an "air" core and a ferro magnetic core

Changing the number of turns of the wire

Using different type of wire and wire thickness

Changing the configuration of the turns, such as multiple layers configuration

Changing how spread out the turns is ✓

Breakdown of Sequence of Work

Day	Activity
Monday (22/02/2010) – lab time	Pilot experiment 1
Between	Reading about field lines and write up
Thursday (25/02/2010) – lab time	Pilot experiment 2
Between	Write up
Friday (26/02/2010) – lab time	Development towards "pilot experiment 3"
Between	Write up
Saturday (27/02/2010) – lab time	Development towards "pilot experiment 3"
Between	Research 1
Monday (01/03/2010) – lab time	Pilot experiment 3
Between	Write up
Thursday (04/03/2010) – lab time	Experiment 4
Between	Write up
Friday (05/03/2010) – lab time	Experiment 5 and 6
Between	Write up
Saturday (06/03/2010) – lab time	Experiment 6
Between	Research 2
Monday (08/03/2010) – lab time	Experiment 7 and 8
Post lab time	Write up

Risk assessment

Risk	Risk Level	Action taken
A solenoid with high current passing through could become overheated and can cause burns	Low	Avoid passing high current through this wires
An electric drill used for winding wires could cause injuries with sharp drill bits	Low	Use power tools with care
Strong magnetic field of a	Low	Avoid touching conductive

solenoid collapsing could generate a large back e.m.f. which could cause electrocution		terminals of the solenoid when the field is collapsing

Sensible consideration of risks.

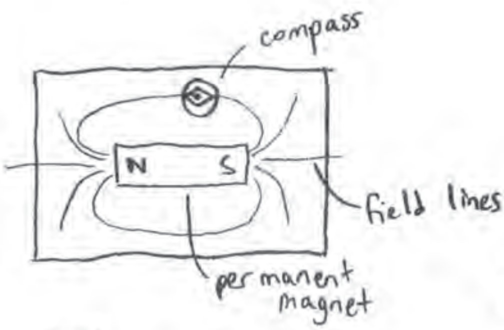
Pilot Experiment 1

The first pilot experiment was done to confirm that a coil of wire with current passing through does create a magnetic field which resembles those of a permanent magnet. This was done by putting a permanent magnet onto a piece of paper then using a compass to draw the field lines. This was then repeated using a coil of wire a plastic air core with 100 turns of 1×10^{-3} m diameter copper enamelled wire with 1 amp.

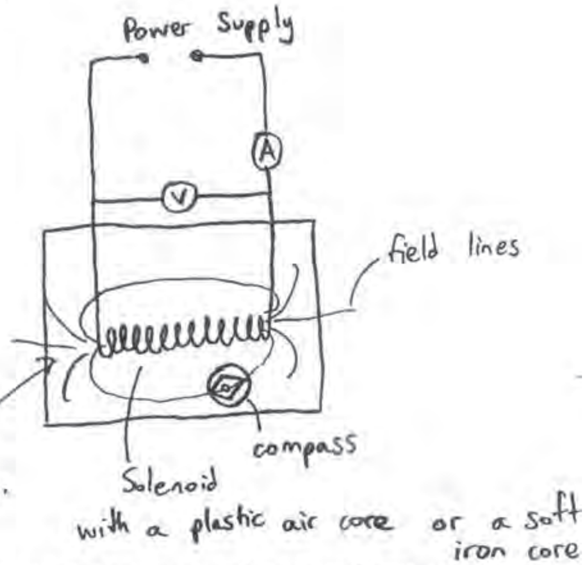
Apparatus

- 1 Soft iron magnetic core
- 1 Plastic air core
- 2 Multi-meters (for measuring current and voltage)
- 1 Power supply
- Enamelled wires of different type and diameter
- Multiple pieces of paper

Diagram



rough drawing.



Result

For both the permanent magnet and the "air" coil, similar field lines were produced confirming that a coil of wire with current passing through does create a magnetic field which resembles those of a permanent magnet.

qualitative comparison

Pilot Experiment 2

The second pilot experiment was done to confirm that the magnetic field strength of an air coil[1] can be varied and the difference can be measured by drawing the field lines[2] and comparing them.

[1] 100 turns of 1×10^{-3} m diameter copper enamelled wire and a plastic air core
[2] Using the method described in "Pilot Experiment 1"

I tried varying the voltage and the number of turns.

Result

Parameter being varied	Change in the field lines
Voltage (0.20 V to 0.40 V)	Unclear / Not noticeable
Voltage (0.20 V to 0.60 V)	Unclear / Not noticeable
Number of turns (100 to 80)	Unclear / Not noticeable
Number of turns (100 to 60)	Unclear / Not noticeable

This experiment shows that either the strength of an air coil cannot be altered or drawing[3] and comparing the field lines is not a valid method of measuring the field strength of an air core.

agreed.

Has not given a clear explanation of how the comparison was made. How was 'strength' compared?

Research 1 ✓

I found out that the magnetic field strength of an air core or a solenoid can be calculated from an equation derived from an idealised case for the Ampere's Law[4].

$$BL = \mu NI$$

$$B = \mu \frac{NI}{L}$$

Where:

B = the electromagnetic field strength at the centre of the solenoid (Tesla)

N = number of turns of the coil

I = current flowing through the coil (Amp)

L = length of the coil (meter)

μ = permeability of the electromagnet core material

Pilot Experiment 3

As a different way of measuring the field strength, I have decided to use a magnetic flux density ~~unit~~ meter[5], which measures in Tesla, to measure the strength of the air core[6], "B" vs. "I". ✓

In the equation, "B" represents electromagnetic field strength at the centre of the solenoid. Assuming that the field strength at the end of the core is the same as the field strength at the centre, I measured the field strength at the end of the core. This is because it is impractical to measure the field strength at the centre of a relatively small core radius with a relatively large probe.

$B_{end} \sim \frac{B_{centre}}{2}$

[3] Using the method described in "Pilot Experiment 1"
[4] http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/solenoid.html and http://en.wikipedia.org/wiki/Electromagnet ✓ research + reference
[5] This instrument measures the magnetic field strength. It requires checking of zero before it is used. ✓✓ zero errors
[6] Same as the one used in "Pilot Experiment 2", 100 turns of 0.001 m diameter copper enamelled wire and a plastic air core

✓ I have also noticed that the field strength reduces **very** quickly as the distance from the end of the core increases. Therefore it is very important to make sure that the probe is **touching the end** of the core at all times.

After I tried with several different setups for this experiment, I have decided to clamp the coil and the probe to a stand so that the probe is touching the end of the coil at all times.

See diagrams under "Experiment 4"

✓ If the equation holds then "B" should be linearly proportional to "I" for a solenoid with 100 turns of 1×10^{-3} m diameter copper enamelled wire and a plastic air core.

Apparatus

- 1 Plastic air core
- 1 Amp meter
- 1 Power supply
- Enamelled copper wire
- Magnetic flux density unit
- Power drill

ranges of meters?

Diagram

See diagrams under "Experiment 4"

Result

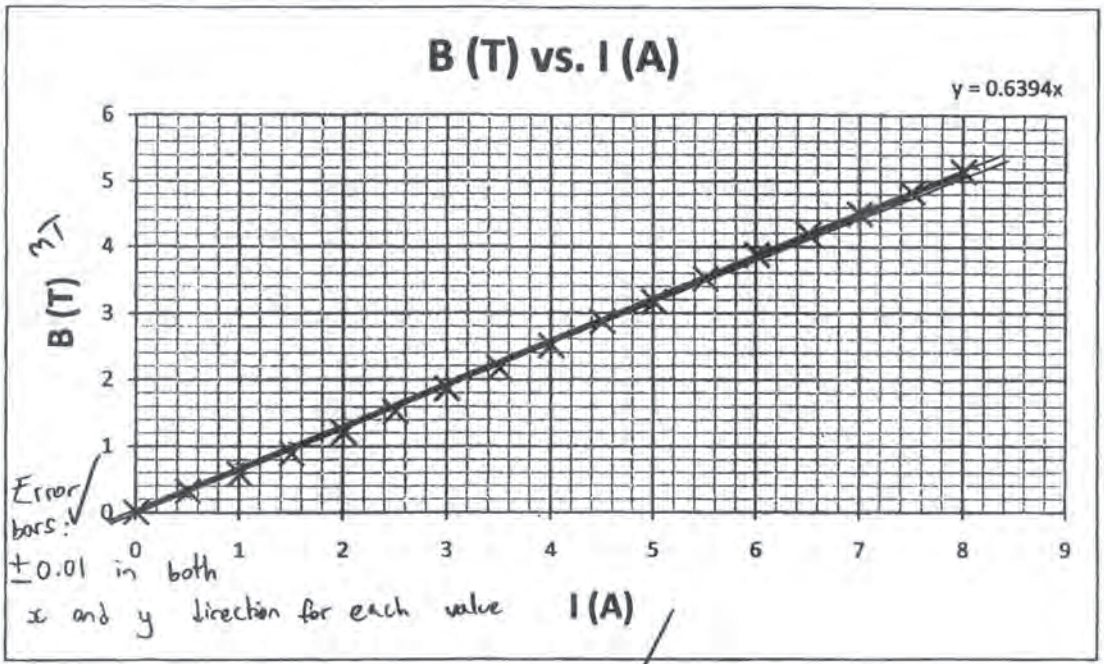
"N" = 100 and "L" = $1 \times 10^{-3} \times 100 = 0.1$ m

mT?

N	L (m)	I (A)	B(T)
100	0.1	0.0	0.00
100	0.1	0.5	0.32
100	0.1	1.0	0.58
100	0.1	1.5	0.89
100	0.1	2.0	1.21
100	0.1	2.5	1.53
100	0.1	3.0	1.87
100	0.1	3.5	2.17
100	0.1	4.0	2.51
100	0.1	4.5	2.87
100	0.1	5.0	3.17
100	0.1	5.5	3.52
100	0.1	6.0	3.88
100	0.1	6.5	4.19
100	0.1	7.0	4.50
100	0.1	7.5	4.83
100	0.1	8.0	5.15

↑ 1 s.f.?

He has recorded in T throughout – the B values should all be mT. This will not affect relationships but will affect any derived constants (e.g. μ_r).



The graph shows a linear relationship between "B" and "I". This confirms that "B" is proportional to "I". This experiment also confirms that the method used in "Pilot Experiment 2", drawing[7] and comparing the field lines is not a valid method of measuring the field strength of an air core.

The value of μ can also be worked out by rearranging $B = \mu \frac{NI}{L}$ to get

$$\mu = \frac{LB}{NI}$$

Notice that the gradient of the graph = $\frac{B}{I}$

Since $\frac{L}{N} = \frac{0.1}{100} = 1 \times 10^{-3}$ m

$\mu_{air\ core} = 0.639 \times 1\times10^{-3} = 6.39\times10^{-4}\ TmA^{-1}$ c.f. $\mu_0 \sim 1.25 \times 10^{-6}\ Hm^{-1}$

<u>Uncertainties</u>   N.B. if $\mu = \frac{2LB}{NI}$ is used with B in mT the data provided gives: $\mu_0 = 1.28\times10^{-6}\ Hm^{-1}$

"N" is the number of turns. I counted them more than once to make sure that N±0

"L" was also measured by a ruler with the smallest division of 1 mm. L±10^{-3}

"B" was measured using a magnetic flux density unit. In this experiment, B±0.01   i.e. the data <u>IS</u> good!

"I" was measured by an amp meter. I±0.01

Therefore by considering the highest possible and the lowest possible value of $\mu_{air\ core}$, the uncertainty of $\mu_{air\ core}$ can be calculated.

[7] Using the method described in "Pilot Experiment 1"

i.e. constants

μ_{max} & μ_{min} from extremes of data.

$\mu_{air\ core} = \frac{LB}{NI} = \frac{(0.1 \pm 10^{-3}) \times (5.112 \pm 0.01)}{(100 \pm 0) \times (8 \pm 0.01)}$ = 6.32x10^{-4}, 6.46x10^{-4} = 6.39x10^{-4}±6.84x10^{-6} TmA^{-1}

This is low but reasonable

% uncertainty = $\frac{6.84 \times 10^{-6}}{6.39 \times 10^{-4}} \times 100 = 1.07\ \%$

This is very low and because there may be other uncontrolled variables or other uncertainties; such as the magnetic density flux unit may be a lot more inaccurate because there were many other magnetic objects around the probe at the time of use. The % uncertainty may be as high as 10 % in reality.

Experiment 4

Now that I have found a way of measuring "B" consistently and more accurately, I can try changing other variables to confirm that the equation, $B = \mu\frac{NI}{L}$, holds for all conditions. And if not then which conditions does the equation not hold.

In this experiment I tested if there is still a linear proportionality between "B" and "I" if the core is magnetic.

I used a coil with 100 turns of 1x10^{-3} m diameter copper enamelled wire and a soft iron core.

Apparatus

- 1 Soft iron magnetic core
- 1 Amp meter
- 1 Power supply
- Enamelled copper wire
- Magnetic flux density unit
- Power drill

Quality of Physics

Mark Scheme

Quality of Physics	
The physics used is mainly descriptive. Most of it is copied and is of limited relevance to the research topic. Some calculations are performed successfully but there are also many errors and the misuse of units is common.	0
There is some use of Physics but there are omissions in its application to the interpretation of results. Some of it is copied and the references given, but it is put together with little coherence or direct reference to the research topic. Some calculations are performed successfully but there are some errors.	2
In most cases where it is appropriate, physics principles have been used to interpret results, perform calculations or make predictions. The physics is usually explained, draws on the content of the taught course, and is related to the project. Understanding is demonstrated and the physics has not just been copied verbatim from a text or website. There are some errors in calculations and in explanations.	4
Wherever appropriate, physics principles have been used to interpret results, perform calculations or make predictions. The physics is explained and goes beyond the requirements of the taught course. It includes some relevant quantitative arguments and is related to the project. Sound understanding is demonstrated and the physics has not just been copied verbatim from a text or website. There are no errors in calculations or in explanations.	6
Maximum mark 6	

General Comment

Here we are looking at the Physics involved and how it is used to explain the work. For the highest marks we are looking for evidence of a sound understanding and an extension beyond normal book work. Accurate, appropriate calculations are needed and no errors should be apparent in mathematics, or in explanations offered, for the top mark. This is particularly difficult to illustrate since the evidence appears throughout the scripts.

Example Candidate Response – Candidate B

Some analysis and moment of inertia calculations from this candidate who was investigating energy losses in car tyres.

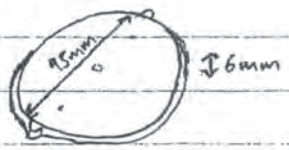
Analysis of Pilot Experiment.

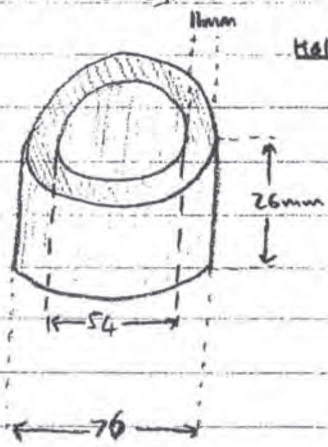
Modulus of Gradient for Just Base Plate = 8·5

Modulus of Gradient for Base Plate and Hollow Cylinder = 2·0

BASE PLATE

HOLLOW CYLINDER





mass = 122g

mass = 471g

Hung mass = 10g.

Radius of string spindle = $\frac{29\text{mm}}{2}$

= 14·5mm.

Torque = 0·1 × 0·0145

= 0·00145Nm ✓

Experimental Value.

$\Gamma = I \times \frac{d\omega}{dt}$ ✓

Moment of Inertia of Base Plate = $\frac{\Gamma}{(d\omega/dt)}$ = $\frac{0.00145}{8.5}$ = ~~0.000264 kgm⁻²~~ 1·7059 × 10⁻⁴ kgm²

Moment of Inertia of Base Plate and Cylinder = $\frac{0.00145}{2.0}$ = ~~0.00145 kgm⁻²~~ 7·25 × 10⁻⁴ kgm²

Moment of Inertia of Hollow Cylinder = ~~0.00145 − 0.000341~~ 1·7059×10⁻⁴ − 7·25×10⁻⁴ = ~~0.0011 kgm²(sf)~~ = 5·54×10⁻⁴ kgm² ✓

~~Theoretical Value.~~

Percentage Error = 15% + 8% = 23%

Compounding of errors incorrect? Should add absolute not % uncertainties.

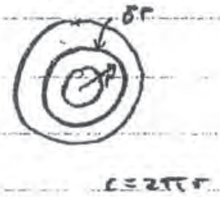
Moment of Inertia max = 5·54 × 10⁻⁴ × 1·23 = 6·81 × 10⁻⁴ kgm²

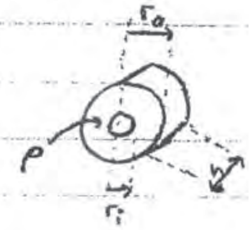
moment of Inertia min = 5·54 × 10⁻⁴ × 0·77 = 4·27 × 10⁻⁴ kgm².

✓

Derivation of Moment of Inertia formulae for hollow cylinder.

Using a similar principal to $I = \Sigma mr^2$,





$\delta V = 2\pi r\ \delta r\ h$

$\delta m = \delta v\ \rho$

$= 2\pi r h\ \rho\ \delta r$

$$I = \int_{r=R_i}^{r=R_o} \delta m r^2$$

$$I = \int_{r=R_i}^{r=R_o} 2\pi r h \rho \delta r\ r^2$$

$$I = 2\pi\rho h \int_{r=R_i}^{r=R_o} r^3\ dr$$

$$I = 2\pi\rho h \left[\frac{r^4}{4}\right]_{R_i}^{R_o}$$

$$I = \frac{\pi\rho h}{2}\left(R_o^4 - R_i^4\right)$$

Then to simplify to an expression in terms of m, R_o and R_i,

$\rho = \frac{m}{v}$

$v = \pi R_o^2 h - \pi R_i^2 h$

$= \pi h(R_o^2 - R_i^2)$

$m = \rho\pi h(R_o^2 - R_i^2)$

$I = \frac{\pi\rho h}{2}(R_o^2 - R_i^2)(R_o^2 + R_i^2)$

$I = \frac{1}{2}m(R_o^2 + R_i^2)$

mass = 471g = 0.471 kg. ($\pm$0.5g)
height = 26mm = 0.026m. ($\pm$0.5mm)

r_1 = 27mm r_2 = 38mm ($\pm$0.5mm)
= 0.027m = 0.038m.

Theoretical Value:

Area of $r_2 = \pi r_2^2$
$= \pi \times 0.038^2$
$= 0.004536\,m^2$ (4sf)

Area of $r_1 = \pi r_1^2$
$= \pi \times 0.027^2$
$= 0.002290\,m^2$ (4sf).

Area of Metal = $4.536\times10^{-3} - 2.290\times10^{-3} = 2.246\times10^{-3}\,m^2$

volume of metal = $2.246\times10^{-3} \times 0.026 = 5.839\times10^{-5}\,m^3$

density = $\frac{0.471}{5.839\times10^{-5}} = 8066\,kgm^{-3}$

$I = \frac{1}{2}\pi\rho h\,(r_2^4 - r_1^4)$

$\times h$?

$I = \frac{1}{2}\pi\, 8066\,(0.038^4 - 0.027^4)$

$I = 5.11\times10^{-4}\,kgm^2$ checked - did include h in calculation!

Theoretical value = $5.11\times10^{-4}\,kgm^2$

Experimental Value = ~~4.1...×10^-3~~ $5.54\times10^{-4}\,kgm^2$

nice comparison

$\frac{\text{theoretical}}{\text{experimental}} \times \frac{100}{1}$ = 92.2%   7.8% discrepancy using $I = \frac{1}{2}m(r_1^2 + r_2^2)$

$= 0.5 \times 0.471\,(0.027^2 + 0.038^2)$

$= 5.1 \times 10^{-4}$ kgm^2 ⇒ agrees with other formulae.

max uncertainty of $r_2 = \frac{0.5}{38} \times 100 = 1.32\%$

max uncertainty of $r_1 = \frac{0.5}{27} \times 100 = 1.85\%$

max " of $m = \frac{0.5}{471} \times 100 = 0.11\%$

~~max Percentage error = 1.06×10^-3 (0.0185^2 + 0.0132^2)~~

~~= 1.60×10^-3 ... 0.0185~~

~~= 0.11~~

uncertainty: $0.11 + (1.85 \times 2) + (1.32 \times 2)$

$= 6.45\%$ uncertainty.

Compounding appears to be ok.

6%

Example Candidate Response – Candidate A

Some good work on the wine glass resonance from candidate A,

- **Next lab session, I intend to model the wine glass with a cylinder. I can then compare the resonant frequencies of different cylinders whilst varying parameters such as thickness/ radius more easily and successfully (it is easier to find cylinders of similar dimensions than it is for wine glasses as there is not the added complication of curvature/ stem/glass height)**

what tubes ?
Materials etc...?

- **I began by recording the resonant frequencies of open tubes of different dimensions;**

Diameter/cm	**3.70**	**2.20**	**1.85**	**2.00**	**6.10**
Height/cm	**7.50**	**7.55**	**15.10**	**30.30**	**150.50**
Thickness/mm	**2.99**	**0.94**	**1.89**	**2.59**	**2.34**
Resonant frequency/kHz	**2.487**	**2.317**	**3.120**	**3.112**	**0.487**

← 4 sig fig?

- **These results are not very reassuring with the theory I have stated above; no clear correlation is evident although for the tube with a much larger height, there is a much lower resonant frequency (however the 2 tubes of similar diameter but where one is thicker and twice the height give almost identical resonant frequencies, but these factors could be canceling each other out).**
- **I think I may again need to adjust my theory!**
- **I think the resonance I am observing is still that of the air column (especially as I am using my ears to detect the resonance). This is reinforced by a little research; most of the resonant frequencies that I find from previous experiments to make glass shatter are within a range of 500-1000Hz, which suggests I am picking up the wrong resonant frequency; I am still picking up the air resonance.**

Some singers achieve f > 1kHz

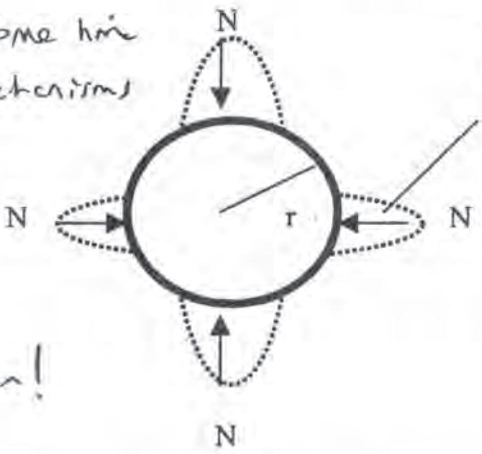
- **All the resonances I've been picking up are at much higher frequencies than those expected (an opera singer can break a glass from singing but can't sing at a frequency of 3kHz – more like 1000Hz), which suggests that either I am picking up a different resonance altogether and/or just missing the fundamental frequency.**
- **The computer program "Audacity" also gave a much higher fundamental frequency than seems sensible; 6000Hz. Maybe this again picked up a different resonance or possibly one of the higher harmonics of the resonance had a higher amplitude than the fundamental (I obtained resonant frequency values from taking the peak on the harmonic spectrum of largest amplitude).**

ok.

Theory - 4

- ***The frequency I am interested in is that heard when I hit the glass with a metal bar as it should excite the glass by forcing it to vibrate with the modes mentioned in the diagram above.***
- ***However, I think that the resonant frequency will depend on not the thickness (I have been misled and confused by the previous theory) of the glass but again, the radius because it is the large-scale flexural motion that I'm interested in – which causes it to shatter.***

Yes. After some time considering different mechanisms and effects she has narrowed down to the likely candidate for resonant destruction!



The arrows represent the overall movement of the glass rim.

- ***A pulse reinforces with the next pulse after traveling around the glass circumference ($2\pi r$) which, for the pulses to interfere constructively and resonance to occur, must equal a whole number of wavelengths;***

$$2\pi r = n\lambda$$

$$f = \frac{nv}{2\pi r} \therefore f \propto \frac{1}{r}$$ ***which is the relationship I originally hypothesized.***

- ***It is this pulse traveling around the glass that causes the nodes/ antinodes.***
- ***However, v is the speed of flexural waves, which research has suggested is proportional to the square root of the frequency, so the speed v, may change with frequency.*** reference?
- ***Further research suggests the radius of curvature of the glass becomes negligible as the frequency increases - the stresses around the circumference due to the curvature are less important than the bending/ flexural stresses applies. This means the glass' structure can be approximated to that of a plate/sheet. It yields the equation:*** reference?

$$v = \sqrt{1.8c_L tf}$$

v=flexural wave speed, K is a constant,
c = longitudinal wave speed (constant for a given material)
t = thickness

- ***Suggesting:***

Developing a useful model based on good physical ideas and sensible analogy.

$$f = \frac{n\sqrt{1.8c_L tf}}{2\pi r} \therefore f_0 = \frac{1.8n^2 c_L t}{4\pi^2 r^2} \therefore f_0 \propto \frac{t}{r^2}$$

i.e. frequency and radius have an inverse square relationship, frequency and thickness are proportional.

- *Research suggests: at the fundamental frequency, the glass will resonate with 4 nodes.*
- *This is easy to visualize and seems reasonable as (when considering horizontal vibrations), there are 2 planes of vibration so the glass flexes inward in one plane (creating 2 nodes) and then does the same for the second plane.*

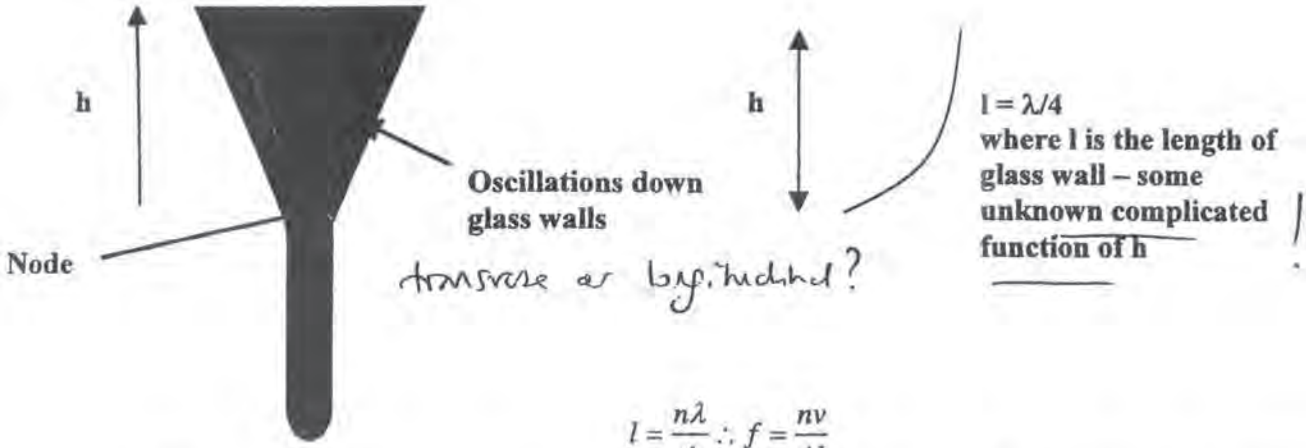
- *I think the flexing is due to the transverse wave traveling around the glass so every time "n" (in the equation $2\pi r = n\lambda$) increases by 1, we have another resonant frequency i.e. when $2\pi r = \lambda, 2\lambda, 3\lambda, 4\lambda$...*
- *As n increases by 1 wavelength, λ, we introduce 2 nodes into the system.*
- *This suggests the higher modes of vibration of the glass will have 6 nodes, 8 nodes, 10 nodes etc.*
- *As we don't obtain a resonance with 2 nodes (it would involve the glass flexing in 1 plane but not the other); at the fundamental frequency - 4 nodes occur i.e. when $2\pi r = \lambda$ [2λ ?] So we obtain: 6 nodes when $2\pi r = 2\lambda$, 8 nodes when $2\pi r = 3\lambda$ etc. so we should obtain n nodes when $2\pi r = \frac{(n-2)}{2}\lambda$* isn't it $2\pi r = n\lambda$ for $n = 2, 3, 4 \ldots$?
- *Expanding this expression to involve frequency again (using the flexural wave speed equation) gives a much more complex set of resonant peaks suggesting resonant frequencies will not be as simple as integer multiples of the fundamental;*

n^2 ?

$$f = \frac{1.8(n-2)^2 c_L t}{16\pi^2 r^2}$$

- *However, this model is still greatly simplified – the problem is much more complex than this; the glass is like a (non-uniform) 3-D version of a tuning fork so may have many different types of complex vibrations.*
- *The horizontal vibrations at various points down the glass wall, all of which may have different resonant frequencies, may contribute different amounts to the overall observable resonant frequency of the glass. The glass is fixed at the bottom, so the amplitude/ effect on the natural frequency of resonance may decrease lower down in the glass.*

- *I have not yet considered possible vertical vibrations down the glass, possibly creating a whole new resonance system (or just contributing to the mode observed) – one in which there is a node at the bottom of the glass (as it is fixed) and an antinode at the top, rather like in a closed tube (although again, I'm sure it's not this simple).*



$$l = \frac{n\lambda}{4} \therefore f = \frac{nv}{4l}$$

- *This suggests resonance when:* $\quad$ *but* : $v = \sqrt{1.8 c_L t f}$ $\quad$ i.e. for transverse waves.

$$\therefore f = \frac{1.8 n^2 c_L t}{16 l^2} \therefore f \propto \frac{t}{l^2}$$

- ***which suggests that the resonant frequency also depends upon the length of glass wall – f(height) - as well as thickness and radius.***
- ***These nodes may not be observable as the glass will probably be less flexible in the vertical direction.***
- ***However, a few preliminary experiments show that adding water changes the resonant frequency, which suggests vibrations lower down in the glass must be significant. I intend to investigate this in more detail.*** Good
- ***The overall resonant frequency should be a combination of the effect of height, radius and thickness (and probably many other factors).***

This may be true for waves travelling up/down or circumferentially

- **All my methods of measuring the natural frequency so far have resulted in me finding that of the air, not the glass.**
- **I need to concentrate on observing the modes of vibration of the glass (not air) before testing any more parameters further.**
- **Tapping the glass on the side with a metal rod and producing the similar tone on the frequency generator gives a frequency of roughly 450Hz (which I should have obtained from the computer program).**
- **This is the frequency that I want to be working with (contrary to any earlier thoughts), as tapping the side should excite the modes of vibration shown in the diagram, not those of the air in the glass.** ✓
- **I need a way in which to monitor the actual vibration of the glass but it is difficult as the amplitude of vibration is so small and most methods are not sensitive enough to detect it or they dampen the vibration too greatly to detect resonance.**
- **I tried shining a laser beam onto the glass edge (just grazing it slightly) and looking at firstly the refracted ray then the reflected ray to see if – any variation of the motion of the beam occurred at a frequency of around 450Hz (creating a sort of interferometer). However, no such motion was observed; maybe the laser beam was too wide or maybe this was just not sensitive enough equipment.** ✓

- **I also thought of trying filming the glass with a high-speed camera and using a stroboscope to find the resonant frequency but the school does not stock stroboscopes of high enough frequencies; if I can get hold of one then I will try this method.** Yes it does!

She tried many practical methods – including use of a stroboscope – but failed to detect the actual vibrations.

Example Candidate Response – Candidate C

Finally, perhaps an extreme example of two days write-up from candidate C studying damping.

Theory for Damping:

I initially supposed damping force was proportional to v (velocity):

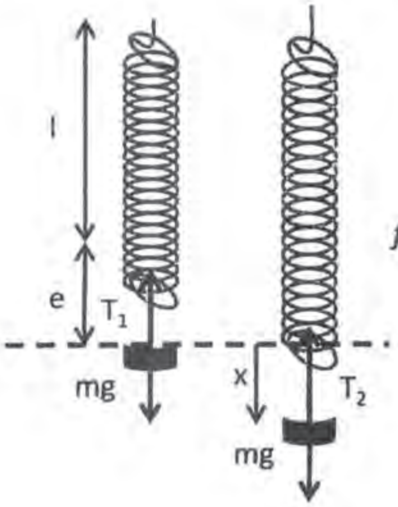


fig 3

If I first derive the equation of motion for SHM without damping:

Assumptions:
- the mass is a particle, i.e. mass concentrated at a point
- spring is massless
- Hooke's law is valid

Theory:
By resolving forces in the left diagram: $mg = T_1 = ke$
And to the right diagram: $F_{resultant} = mg - T_2$

Applying Newton's Second Law to the diagram on the right:
$m\ddot{x} = mg - k(e + x)$
and since $mg = T_1 = ke$:
$m\ddot{x} = ke - k(e + x)$
$m\ddot{x} = -kx$

standard shm.

Suppose I model the damping force proportional to velocity and in the opposite direction:
$F_{damping} = -bv = -b\dot{x}$
b is an arbitrary constant which is dependent, amongst other things, to the area of the damper.
I then combine this into our initial statement of N2:
$F = m\ddot{x} = -kx - b\dot{x}$
$m\ddot{x} + b\dot{x} + kx = 0$

To solve: This is a 2nd order linear homogeneous differential equation with auxiliary equation:

$m\lambda^2 + b\lambda + k = 0$

with solutions

$$\lambda = \frac{-b \pm \sqrt{b^2 - 4mk}}{2m}$$

good

Depending whether these solutions are real or imaginary, they yield fundamentally behaviour in the oscillator.

Initially I chose to investigate the cases when $b^2 - 4mk < 0$

In this case I have two imaginary solutions:

$$\lambda = \frac{-b}{2m} \pm i\frac{\sqrt{4mk - b^2}}{2m} = \frac{-b}{2m} \pm i\sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$

Which gives us the following relationship between x and t:

$x = e^{-\frac{b}{2m}t}(Asin\Omega t + Bcos\Omega t)$ (n.b. this is a standard results)

Where $\Omega = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$

What does this tell us?

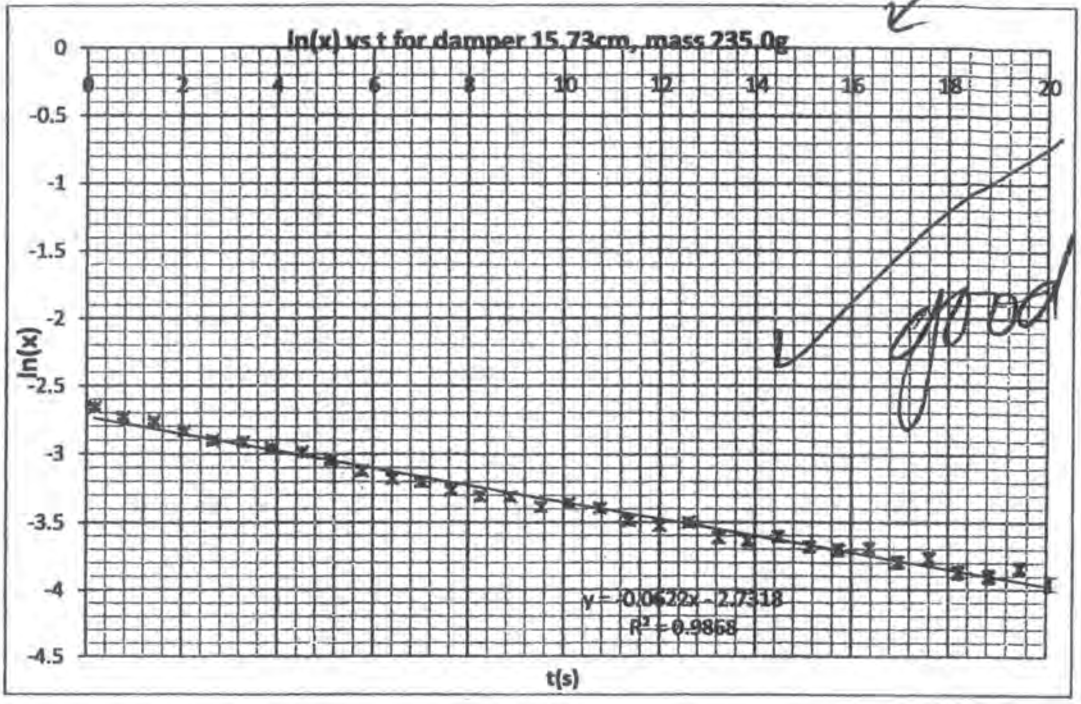
- Here I am modelling damping with cardboard displacing air, and it is clear that the larger the area of the card, the more air displaced
- Therefore there should be a linear relationship between the damping force and the area.
- Therefore the constant b is very likely to have a linear dependence on the area
- My results have shown that the decay 'envelope' is related via a negative exponential to b, and therefore the area
- It should therefore be possible to show this relationship, and if I can experimentally derive b for a given system, I could derive the equation for that system and check how good our assumption about the damping term is. ok

Manipulating the results:

- To analyse the decay envelope, I first had to isolate all the points of maximum displacement so that I had a single decay curve, and I had to find a systematic way as I was dealing with large amounts of data
- My solution was to use to excel to extract only values which had a value either side which was smaller (and for the consecutive value to also be smaller to prevent anomalous readings being selected)
- I found then plotted ln(x) vs t for this data, and the graph below is an example:

good

actual label?



The claim that ln(x) would be proportional to t it appeared was *only valid up to about 20 seconds* at which point it curved away, therefore I only plotted the first 20 seconds. All the data had similar, very high R^2 values, implying a very strong correlation.

Now if I refer back to my formula from before:

$$x = e^{-\frac{b}{2m}t}(A\sin\Omega t + B\cos\Omega t) = e^{-\frac{b}{2m}t}(C\cos(\Omega t - \varepsilon))$$

Where $C = \sqrt{A^2 + B^2}, \varepsilon = \tan^{-1}\frac{A}{B}$ *(proof in appendix 1)*

well beyond course level.

I can say that the equation for the envelope traced by the decay of the maximum displacement has the following form:

$x = Ce^{-\frac{b}{2m}t}$ (as max value $\cos(\Omega t - \varepsilon) = 1$)

And taking natural logs:

$$\ln x = \ln C - \frac{b}{2m}t$$

Thus if I plot ln(x) vs t I should get a gradient of $-\frac{b}{2m}$

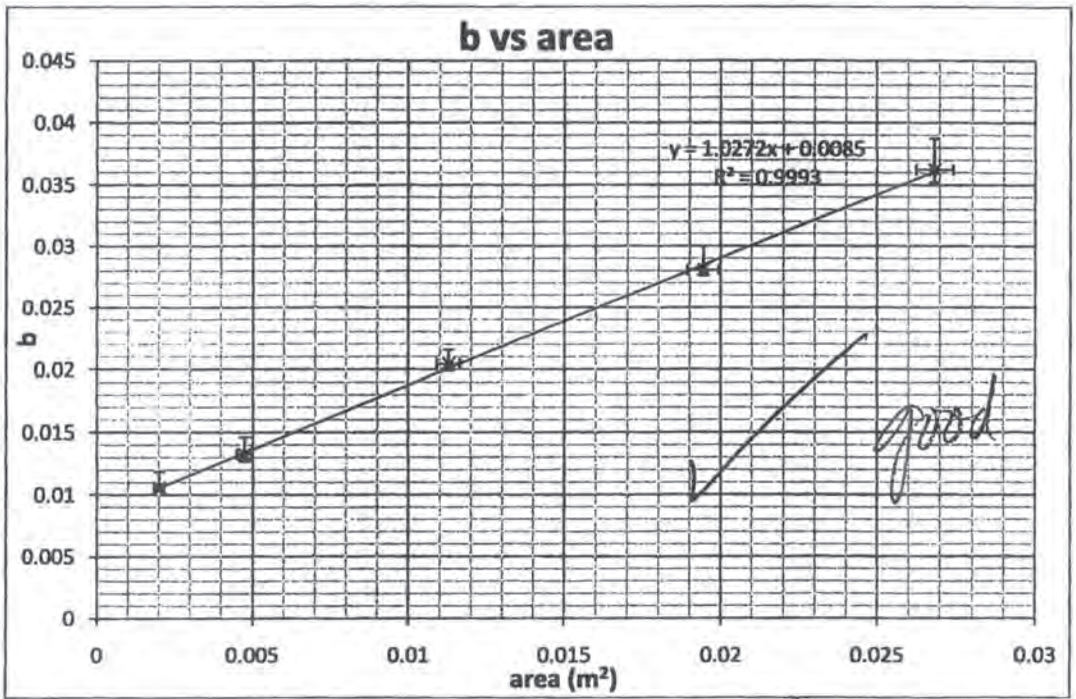
By multiplying the gradient by $2m$, I gain a value of b for the system

good

The Effect of Area on b: I carried the procedure as described above, repeating for my three different sets of data for each area, and produced the following table of data:

		Area (m^2)				
		0.0020	**0.0047**	**0.0113**	**0.0194**	**0.0268**
Gradient value	1	0.0268	0.0306	0.0451	0.0564	0.0802
	2	0.0249	0.0321	0.0462	0.0622	0.0796
	3	0.0269	0.0310	0.0470	0.0624	0.0714
	Average	0.0262	0.0312	0.0461	0.0603	0.0771
Mass		0.2017	0.2124	0.2216	0.2327	0.2350
Gradient × $2m$ ($Nm^{-1}s$)		**0.0106**	**0.0133**	**0.0204**	**0.0281**	**0.0362**
Error (%)		7.3	7.4	4.1	4.2	4.9

This data produces the following graph of relationship between b and area:



unit for b?

The R^2 value here of 0.9993 implies a very strong correlation between the two, implying my model strongly reflects the reality of the situation.

Calculating Errors in *b* and area:
For the error in *b* I underwent the following procedure:
- I considered the maximum and minimum gradient allowed by the graph on pg 6 — detail?
- I used an algorithm in excel to do this in a repeatable, quick way detail?
- Subtracted this from actual gradient to give upper & lower bound error
- Repeated for other two repeats
- Averaged the three repeats for upper bound error and multiplied by factor $\frac{1}{\sqrt{3}}$ (takes into account reduction in error due to repeats) ok
- Multiplied by $2m$ to scale error accordingly

seems reasonable

- Repeated for the lower bound error
- This gave me the error bars you can see on the previous graph (pg 7)
- I repeated for all b values

(n.b. % error in table calculated using the average of error above and below)

For errors in area:

- I used vernier callipers to measure diameter – supposed my accuracy was $\pm 2mm$
- Calculated the area for maximum and minimum diameters using $2mm$ error
- Subtracted from actual area for the error
- Used this to plot error bars

Numerical relationship between b and area (A)

- I supposed that $b \propto A$, which was strongly supported by experiment
- i.e. as an actual equation, $b = \beta A$, where β is an arbitrary constant
- As I have plotted b vs A, my gradient is equal to the numerical value of β
- Reading off the gradient, $\frac{b}{A} = \beta = 1.03Nm^{-3}s \pm 0.14Nm^{-3}s$
- Error calculated by considering line of maximum and minimum gradient that would fit this graph
- Units result of the fact $\beta \times A \times v$ is a force

good

Predicting the shape of the oscillation:

- Now I have calculated experimentally a b value for the systems, I have all the data I need to predict the equation of one of the oscillators
- My prediction should be good for the first 20 seconds, and then become progressively less close to the real data
- To recap, the formula for x against t is:

$$x = e^{-\frac{b}{2m}t}(A\sin\Omega t + B\cos\Omega t), \text{ where } \Omega = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$

By measuring the parameters experimentally I have all the data I need to predict the oscillations, as long as I also have two results for x and t to use as starting conditions

Calculating A and B in a way that excel can repeat formulaically:

Suppose I have two sets of starting conditions, (x_1,t_1) and (x_2,t_2)
I substitute these into my equation, and gain the following:

$$x_1 = e^{-\frac{b}{2m}t_1}A\sin\Omega t_1 + e^{-\frac{b}{2m}t_1}B\cos\Omega t_1 = pA + qB$$
$$x_2 = e^{-\frac{b}{2m}t_2}A\sin\Omega t_2 + e^{-\frac{b}{2m}t_2}B\cos\Omega t_2 = rA + sB$$

A = **A**?

not sure this is clear

These are two simultaneous equations, which can be solved to give:

$$B = \frac{rx_1 - px_2}{qr - sp}, A = \frac{x_2 - sB}{r}$$

Which is a repeatable algorithm for calculating the starting conditions.

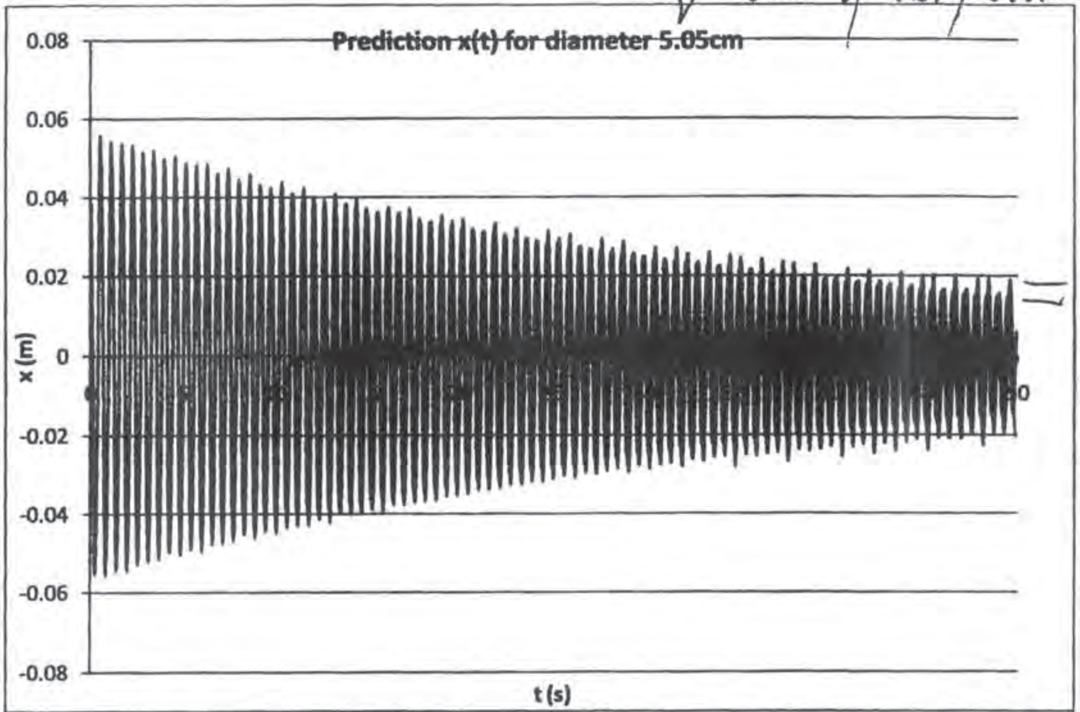
- I can now give excel starting conditions
- It calculates p, q, r, s
- It uses these to find the parameters A and B

assumes prior is correct

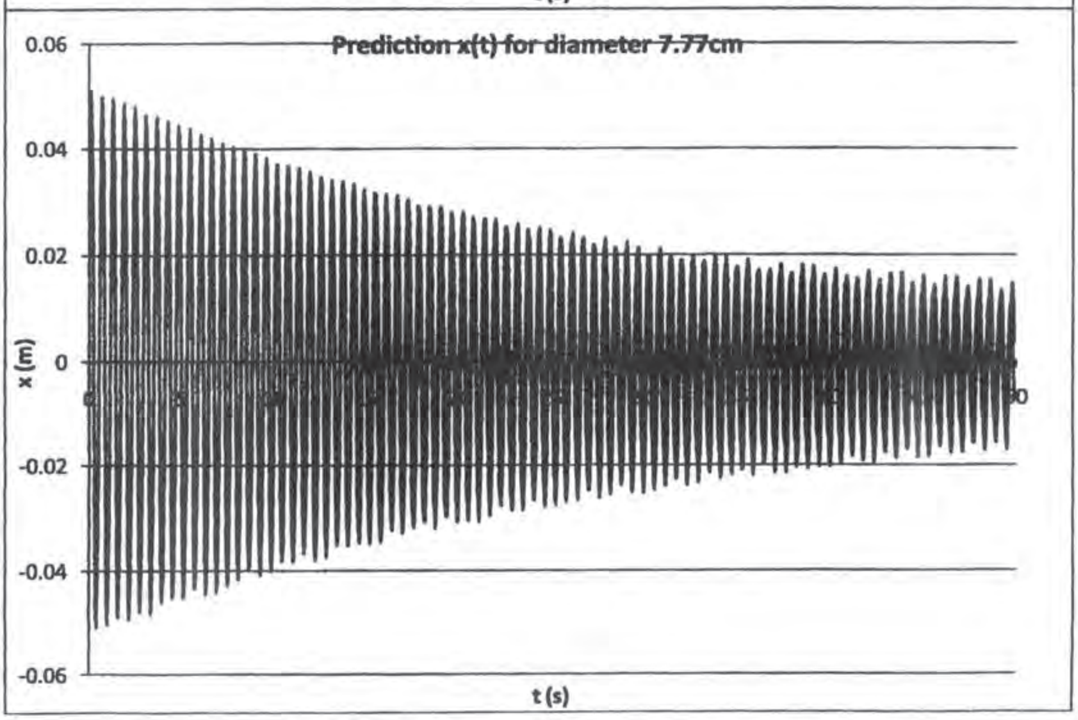
- It then combines this with the experimentally measured values b, m and k in the above formula, giving a formula predicted the equation for the oscillations

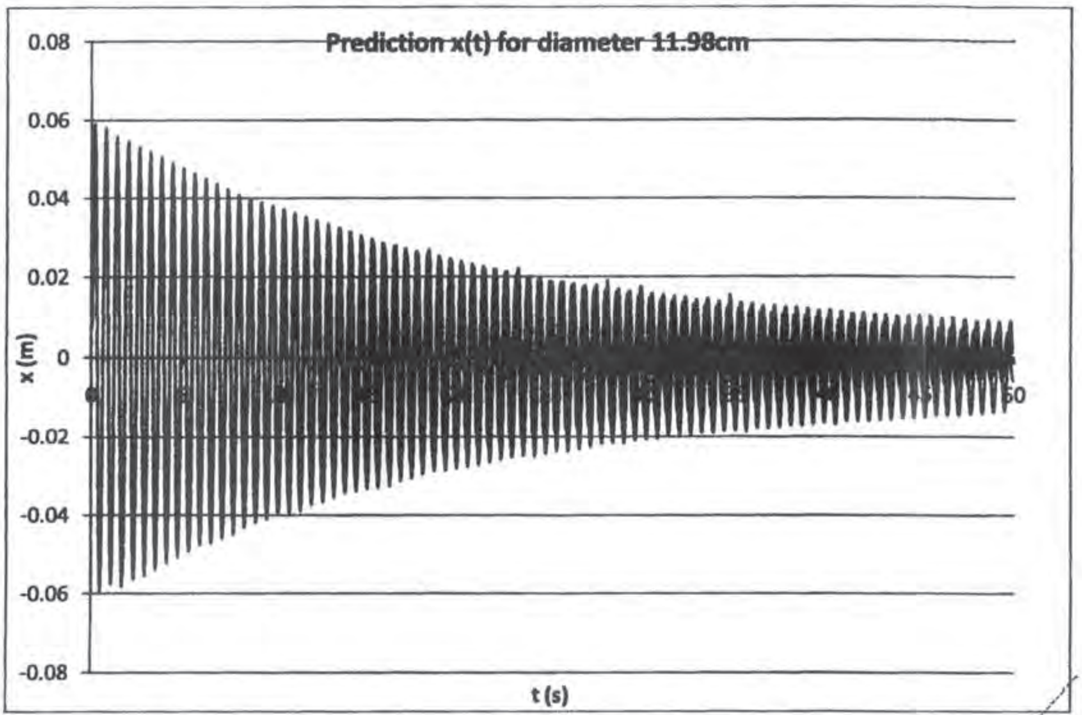
The following five graphs show how close my model fits the reality of the damped oscillating system for different areas of damper:
n.b. blue lines represent the model, red the actual data

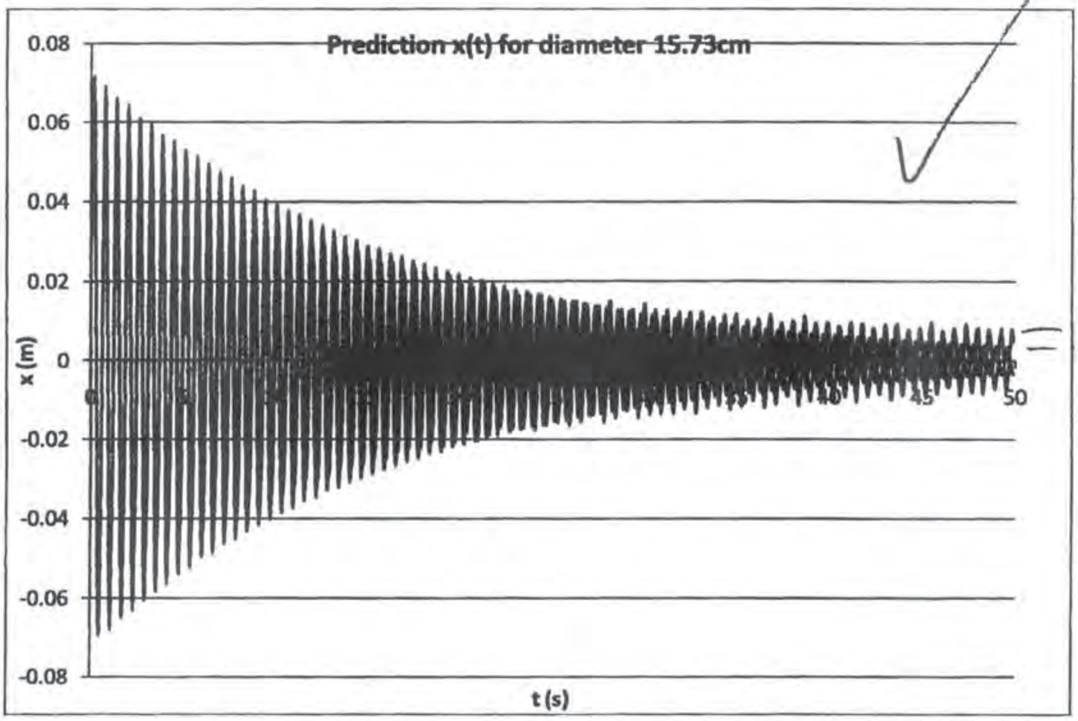
clearly very close



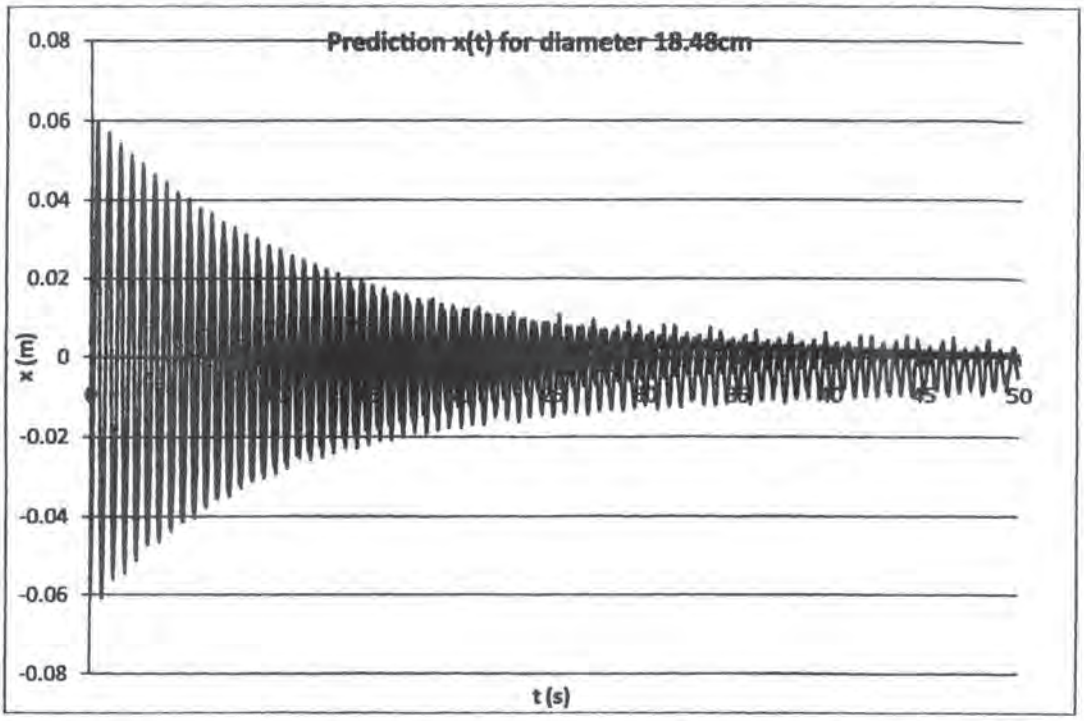
I this amplitude difference ought to be highlighted




Prediction x(t) for diameter 11.98cm
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
x (m)
50
t (s)


Prediction x(t) for diameter 15.73cm
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
x (m)
45
50
t (s)

= again



Interpretation?

- In general a good fit to the real data for the first 20 seconds, which was the period I felt the assumptions were valid for
- The model is also fairly accurate for the rest of the time, although there is a significant deviation for a large damper area (e.g. 18.48cm)
- The experimental and predicted time periods for each are very close – they deviate only half a time period for the 50 seconds even in the worst cases
- The fact that my model has a systematically small time period (compared to experiment) may be a result of the model of damping I have used

good

Damping Model?

- It appears the model has damping that is too small initially, and then becomes too large
- This seems logical, as it is more believable that damping should be proportional to v^2
- You can see this especially clearly in the graph for 18.48cm
- However, considering the difference in difficulty in the maths involved, considering the air resistance proportional to v yields impressive results

good

(quite right!)

Varying other parameters?

- In my plan I mentioned varying stiffness and mass
- However taking (and processing) the results above took longer than expected, and I felt my time was better spent looking at other things, like critical damping and resonance

Modelling damping proportional to v^2

- Air resistance can be more accurately modelled if I say that the damping force is proportional to the velocity squared, and in the opposite direction
- This would seem to lead to the following differential equation:
  $m\ddot{x} + b(\dot{x})^2 + kx = 0$
- However, as a number squared is always positive, this would make this force positive *regardless* of the direction the object is moving in – this would mean this was not a damping force, as a damping force should always be in the opposite direction to that of velocity
- I can solve this problem by introducing a modulus sign:
  $m\ddot{x} + b\dot{x}|\dot{x}| + kx = 0$
- This equation is very difficult to solve analytically
- Therefore decided it would be best to use excel to sole it numerically

good.

The Euler Method

- This method can be used to find a (fairly rough) numerical solution to a first order differential equation by repeating the same process for a small time δt and adding this to the previous value
- Firstly then I have to reduce my second order differential equation
- Suppose I define a variable y, where:
  $y = \dot{x}$, and therefore $\dot{y} = \frac{d\dot{x}}{dt} = \ddot{x}$
- Substituting this into my original equation:

$$m\dot{y} + by|y| + kx = 0$$

ok

$$\dot{y} = -\frac{1}{m}(by|y| + kx)$$

And from before: $\dot{x} = y$

- The Euler method is effectively an iteration for the approximate, numerical solution of as equation in the form $\frac{dy}{dx} = f(x, y)$, which says that:
  $x_{n+1} = x_n + h$
  $y_{n+1} = y_n + f(y_n)h$

  where *h* is a small period, which can be specified, and the smaller this is, the more accurate the iteration, and the increase in accuracy is O(*h*)

Applying the Euler Method:

- The iteration can be extended to coupled oscillators, and for this specific case it is as follows:
  $t_{n+1} = t_n + h$
  $y_{n+1} = -\frac{1}{m}(by_n|y_n| + kx_n)h$
  $x_{n+1} = y_n h$
- I used excel for this iteration

well beyond course level and not practical to score for coursework

13

- For large values of b (i.e. b>1) the iteration worked well with a large step size h
- However as I decreased *b* in order that it mirrored the data more closely the oscillations began undergoing strange behaviour, sometimes growing and usually settling on a constant amplitude rather than decaying
- I increased the step size to combat this, yet as I increased b further the number of iterations I had to perform began to near 100,000, and still the results were not that accurate to the data
- I decided that this method was insufficient to find numerical solutions to my equation

The Fourth Order Runge-Kutta Method:

- This method yields a far better numerical solution to a first order differential equation, which the accuracy scales up $O(h^5)$, i.e. if I decrease the step size by a tenth the approximation becomes 100,000 times more accurate
- The ideal numerical method would be to use a Taylor series expansion, however this method would be very labour intensive and unnecessary
- The Runge-Kutta methods effectively provide an iterative method which preserves the accuracy associated with a higher order method like a Taylor expansion
- I used the forth order method as it has the best ratio of effort required to accuracy of answer – it is the most commonly used method
- The method can be extended to coupled oscillators (i.e. two first order differential equations which are dependent on each other)
- The iteration takes the form:
  $t_{n+1} = t_n + h$
  $x_{n+1} = x_n + hG(t_n, x_n, y_n, h)$
  $y_{n+1} = y_n + hH(t_n, x_n, y_n, h)$
  where G and H are fairly complex functions, which manipulate the functions $f(t_n, x_n, y_n) = y_n$ and $g(t_n, x_n, y_n) = -\frac{1}{m}(by_n|y_n| + kx_n)$details of which can be found in ***appendix 2***

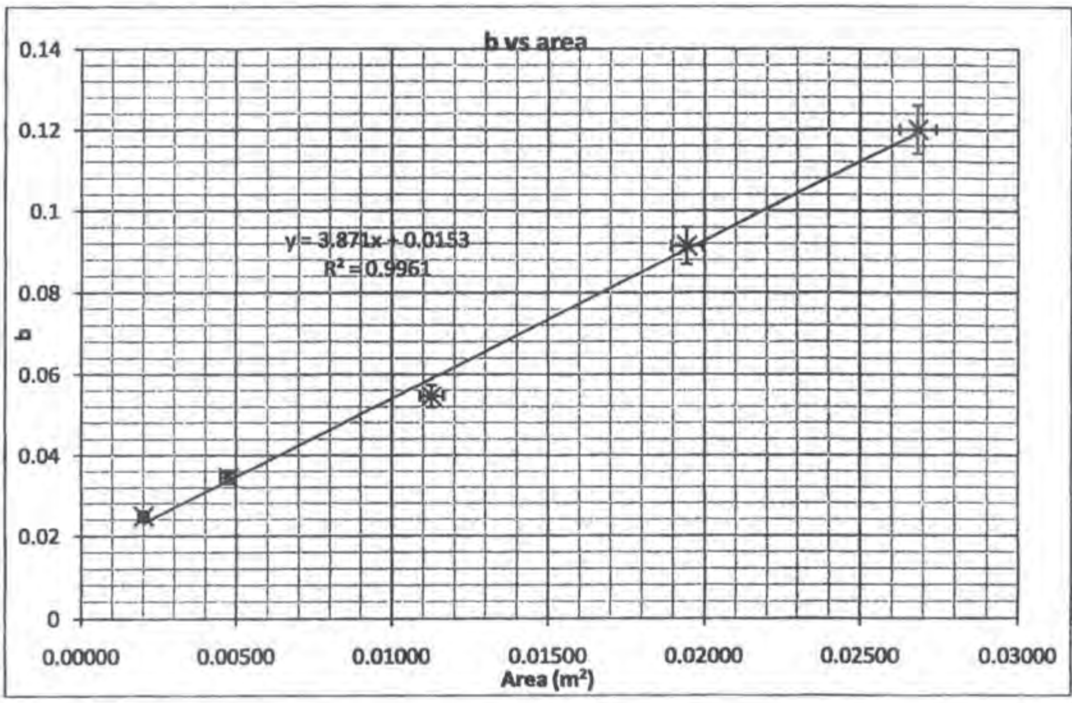
Extracting b values

- As I have no analytical solution to my equation, extracting a value for b would be problematic
- Initially I tried fiddling it until it looked like it fitted the data well – however this was a very qualitative, unsystematic method of analysis
- My solution was to do the following:
  - Set x_0 as the maximum displacement given by my data and y_0=0 (as v=0), and thus compare my model with data
  - Use excel to extract the values for maximum displacement for each consecutive oscillation for both my data and prediction, and to average these so that I had an average value for both my model and data
  - Find the difference, and through a method of trial and error, minimise this difference, until I had minimised this difference with a b value of 4sf
- The following table summarises the different b values I gained for the respective area of the damper (I ensured that different mass was also taken into account):

Area (3sf) unit	0.00200	0.00474	0.0113	0.0194	0.0268
b (4sf) $Nm^{-2}s^2$	0.02482	0.03451	0.05458	0.09149	0.12005 (5sf)

which very strongly suggests a linear relationship between the two, as I would have expected, as the greater the area, the more air to be displaced by the damper

- Graphically this relationship can be seen to be very strong:



Errors?

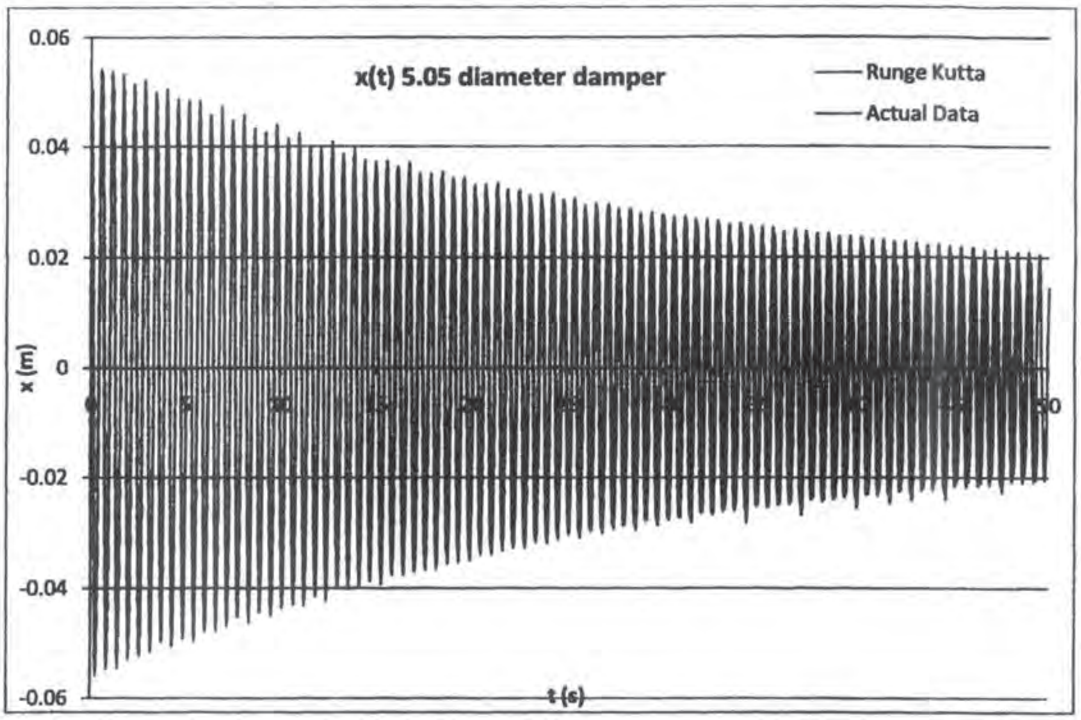
- Here errors in area are calculated in the same way as pg7-8
- Difficult to quantify the error in b, due to the trial and error method of obtaining it
- Therefore as on pg7-8, the error in b is roughly 5%, I use this for the vertical error bars

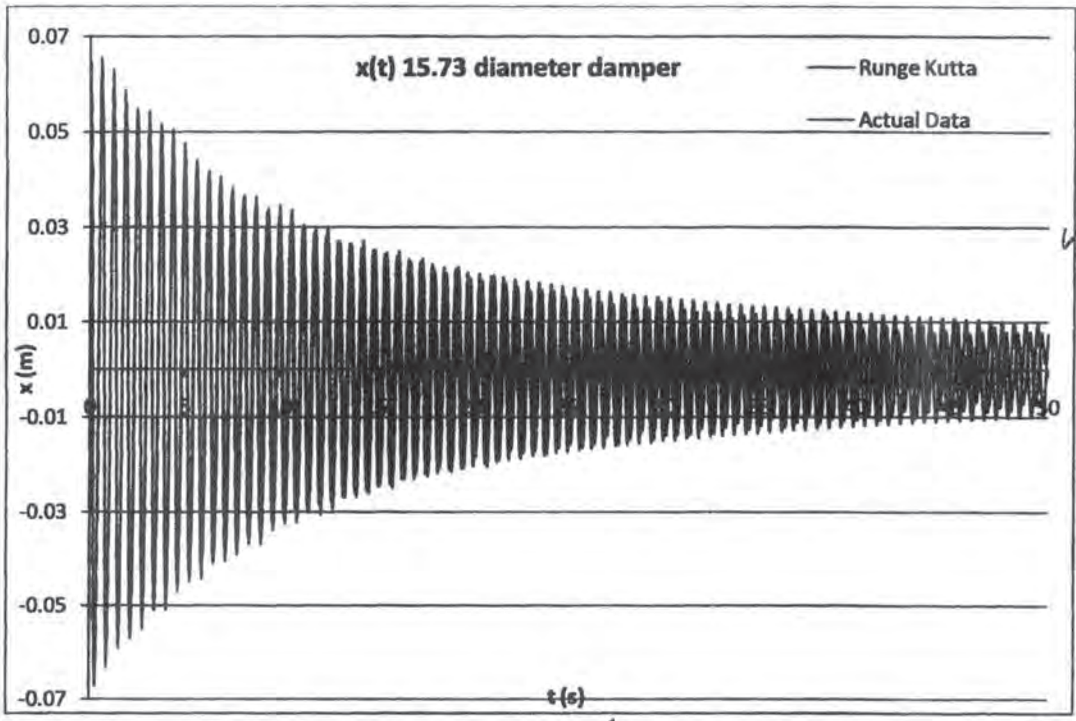
Relationship between b and area?

- Again my assumption that $b \propto A$ appears good, therefore I can say that $b = \gamma A$ (different constant this time)
- From the graph, $\frac{b}{A} = \gamma = 3.9Nm^{-4}s^2 \pm 0.43Nm^{-4}s^2$
- Error calculated by considering maximum and minimum gradient permitted error bar, as before
- The units due to the fact that $\gamma \times v \times |v| \times A$ is a force

How good is this model?

- Two examples attached compare the Runge-Kutta model and the analytic solution for damping proportional to velocity with actual data:





clearly a better model (though no new data)

- As for the other model the time period of the system is accurate to within half a period per 50 seconds, which is very accurate
- For a small amount of damping the Runge-Kutta is arguably better

- For large amounts of damping this method is far closer to the actual data, as you can see on the graph for damper diameter 15.73cm
- However it is still not perfect, as initially there is not quite enough damping and towards the end there is too much – opposite to the other model

Conclusion

- A better model for damping models the damping forces proportional to v^2
- A numerical approximation can be used with the Runge-Kutta method
- However consider the following:
  - When damping is proportional to v, the damping force is initially too small, and then too large
  - When damping is proportional to v^2, the damping force is initially too large, and then too small
- The implication is therefore that a compromise would yield the best model, i.e. modelling the damping force proportional to $\alpha v + \beta v^2$
- For the purposes of this investigation however I will stick to exclusively modelling damping either to v *or* v^2

(phew!)

Use of Measuring Instruments

Mark Scheme

Use of Measuring Instruments	
At least one experiment* is completed. There are some errors in using the apparatus, which make some of the readings unreliable. Some assistance in setting up or manipulating apparatus has been required.	0
At least one experiment* is completed where two measuring instruments are used to obtain results. Standard instruments are used effectively. In all experiments, apparatus has been set up and manipulated without assistance.	1
At least two experiments* are completed where at least two measuring instruments are used, at least one of which was zeroed or calibrated correctly to obtain accurate results. Standard instruments are used effectively. In all experiments, apparatus has been set up and manipulated without assistance.	2
More than two experiments* are performed with a range of different instruments, some of which require checking of zero, calibration or selection of different ranges. Some of the apparatus is either of a sophisticated nature (signal generator, cathode ray oscilloscope, two place digital balance, data logger, micrometer) or involves a creative or ingenious technique in its use. In all experiments, apparatus has been set up and manipulated without assistance.	3
Maximum mark 3	

General Comment

Candidates are expected to carry out two or more experiments with a range of different instruments which need calibration/range changes etc. Complicated instruments and/or creativity should be shown.

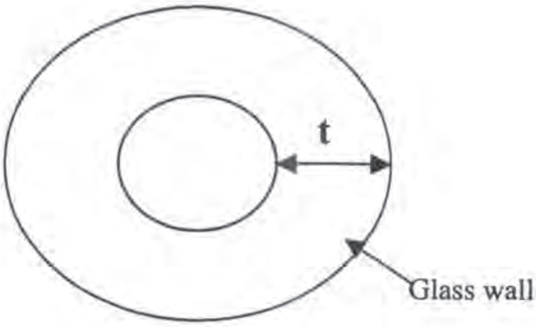
Example Candidate Response – Candidate A

A vibration generator and use of computers etc. from candidate A investigating resonance.

- **After constructing this new setup, my theory as to how the glass vibrates has changed a little;** Really tried to think through the underlying physics at every stage

Theory – 3

The vibration generator forces the glass to oscillate, it is a longitudinal vibration and oscillations will be between the 2 glass walls. This suggests the resonant frequency depends upon the thickness of the glass walls.



t = glass thickness

Direction of vibration = $\longleftrightarrow$

i.e transverse ?

- ***For resonance (i.e. standing waves);***

$$t = \frac{n\lambda}{2} \qquad \textit{and} \qquad f = \frac{v}{\lambda}$$

$$n\lambda = 2t$$

so

$$n\frac{v}{f} = 2t$$

$$f = \frac{nv}{2t}$$

This seems to be for longitudinal waves mostly radially. Another effect of the vib. generator would be to excite transverse waves around the circumference.

- ***This suggests as thickness of glass increases, resonant frequency decreases, following an inverse proportionality relationship;*** $f \propto \frac{1}{t}$
- ***It also suggests that radius has no effect on the resonant frequency. I think this will overrule any effect of extra mass or higher stiffness due to increased thickness.***

- I also thought of trying filming the glass with a high-speed camera and using a stroboscope to find the resonant frequency but the school does not stock stroboscopes of high enough frequencies; if I can get hold of one then I will try this method. Yes she does!

She tried many practical methods – including use of a stroboscope – but failed to detect the actual vibrations.

26/2/10

- I decided to go back to using "Audacity" to record the resonant frequency and its harmonics after tapping the glass with a metal rod so I could analyse the sound further.
- This time I firstly used my ear and the frequency generator to get an idea of what the fundamental frequency was so I would not be misled by the frequency spectrum displayed; this was the problem before – I took the frequency of highest amplitude to be the fundamental.
- This proved more successful; I obtained the frequency spectrum then exported it into excel at various sampling rates (to try and get the clearest possible picture of the trend in harmonics without too much background noise).
- The problem before was that I was recording the loudest harmonic as the fundamental which meant I was recording much higher frequencies than I should have (the fundamental is not always the loudest).
- For the empty wine glass I obtained a peak for fundamental frequency at 473Hz, which corresponded with the sound my ears were picking up.
- The notion that this is the glass resonating is supported by the fact that when I placed a large block of wood in the glass (displacing most of the air but not touching the sides of the glass), the frequency recorded remained the same.

Good.

- I then added various amounts of water to see its effect on both the fundamental frequency and how it affects which harmonics are present and their amplitudes.

Theory -5

- *I expect the resonant frequency to decrease as more water is added; the water damps the glass' vibration, absorbing energy so the energy of the waves decreases and vibrations become slower i.e. speed decreases so frequency decreases.*

Not sure this is the reason.

- *Also, as more water is added, there is more mass for the glass walls to displace, so the walls flex more slowly and frequency decreases;* more likely

- *Although I am not yet sure of the actual relationship between mass (or volume) of water added and frequency, I am sure it will not be straightforward as the glass resonance is so complex.*

- *Hitting the glass below the water level should give a sound of very low amplitude and should give rise to little (if any) resonance as the glass will be*

- I then compared the exported graphs of frequency vs. amplitude for different volumes of water, looking at the harmonics present.
- I noted the values of the peaks of significant amplitude to see if there was a trend in the harmonics.
- I thought that maybe some of the harmonics would show different trends being due to the air column resonance rather than that of the glass.

Results

Interesting way of displaying data.

Very poorly presented table.

Volume water/cm^3 Frequency of peaks as a multiple of fundamental

0.0	2.0	4.8	7.9	10.9		14.9	18.9	21.9	23
100.0	2.9	4.9	7.9	11.1		14.9	19.0	22.0	23
200.0	3.1	4.9	8.0	11.1	13.4	15.1	19.1		
300.0	2.9	4.9	7.9	11.0	13.1	15.0	19.3		
400.0	2.8	5.2	8.1	11.8	13.1	14.8	19.0		
500.0	2.9	5.3			13.0	16.2	18.9	20.9	
600.0	3.0					16.9		24.1	29
700.0	2.9					17.0			26

(see graphs - 3)

- There is a definite pattern in the harmonics present (although they were not exact multiples of the fundamental, this can be accounted for when considering the sample rate; different sample rates give slightly different frequencies);
- The 3rd, 5th, 8th, 11th, 15th and 19th harmonics seem to regularly occur – which explains why the peaks on the graphs shift to the left as volume of water added increases (as fundamental decreases). ← Not really clear on graph?.
- There are other harmonics which occur but less regularly, possibly due to background noise or even just my hitting the glass in a slightly different way (the harmonics that emerge may be very sensitive to conditions, especially for those higher up). ✓
- This is made more difficult to read due to some of the peaks being 'split' rather than 2 separate peaks, possibly due to imperfections in the glass.
- As more water is added, the number of harmonics of significant amplitude clearly decreases due to the effect of damping. ✓
- There is no very clear deviation from the general decrease in fundamental although for the 3 readings where most water is added, the 15th harmonic is not present but the 16th/17th is which shows an increase in frequency that could correspond to the decrease in length of the air column. However this could also be due to the other factors mentioned above.
- The loudest harmonic for each reading was the 15th harmonic (16th/17th for the larger volumes of water). I'm not sure of why this is, although if this one harmonic were due to the air column (which I am skeptical about) this would be an interesting occurrence.
- When I tapped the glass below the water level, the sound decayed very quickly, indicating critical damping occurs below the water level. ✓

Needs more structure – rather 'garbled' but does contain some good points.

critically damped, so the water absorbs most of the energy of the vibration and very little energy reaches the top of the glass (which is where the most obvious flexing should occur).

- *I believe the damping of the water will override*
  - *The effect of the decrease in the air column size, which would cause frequency to increase (as stated earlier).*
  - *The increase in volume of water restricting/impeding the flexion of the glass walls, effectively making them stiffer – which would also cause a frequency increase.*
- *Damping may also reduce vertical flexion of the glass walls.*

Results

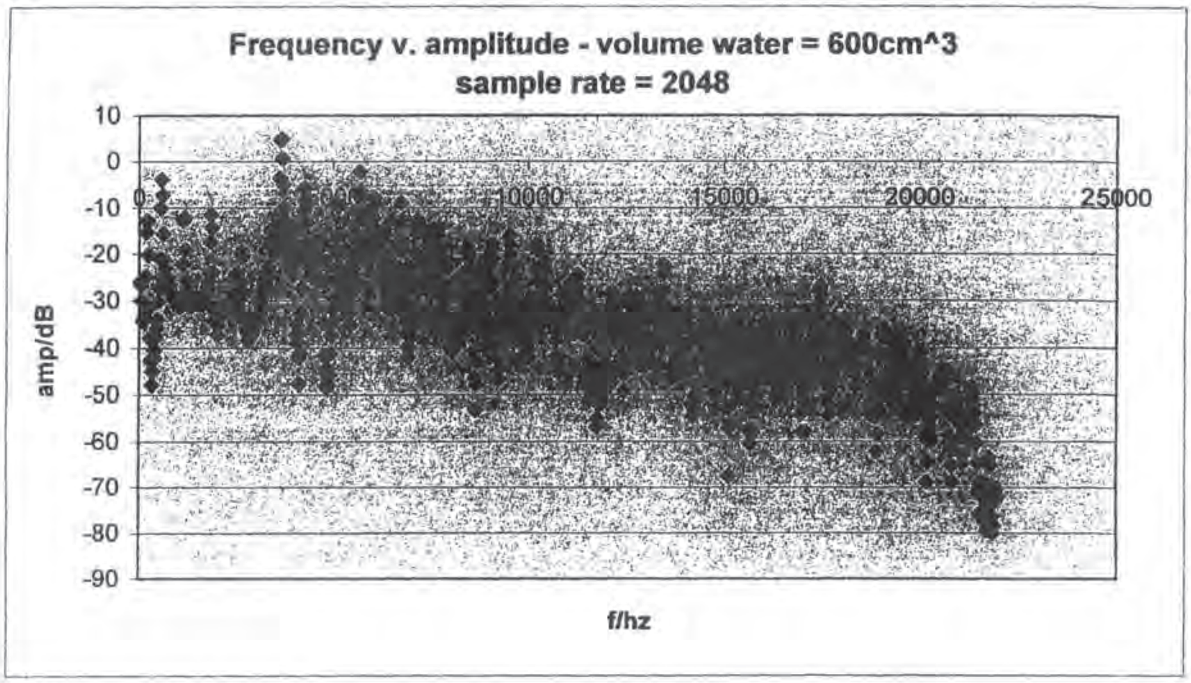
Poor presentation of data.

Volume water /cm^3	Water height /cm	Fundamental frequency /Hz
0.0	0.00	473
100.0	4.30	430
200.0	5.60	430
300.0	6.60	430
400.0	7.70	387
500.0	9.40	344
600.0	10.60	258
700.0	13.00	215
1.0	0.50	0.5Error

(see graphs 1&2)

- **This shows as volume/ height of water added increases, fundamental frequency decreases.**
- **The relationship followed is not very clear (especially as there are other factors which may be influencing the behaviour; the glass changed radius and curvature at different heights).**
- **As volume = mass/density, this therefore suggests as mass of water increases, frequency decreases.**
- **However, the graph is not a very close fit so further testing is required to ascertain the relationship.**
- **This supports my theory; the fundamental frequency decreases as more water is added due to the increased mass being forced to vibrate so vibrations are slower i.e. frequency decreases.**
- **It reinforces the suggestion that the glass resonance when I hit its side overrides the air column resonance.**
- **This result also suggests that the vertical and horizontal vibrations lower down in the glass are significant as even small volumes of water absorb enough energy to change the resonant frequency.**

Good evaluation.



Yes please!

- Now that I have a definite method of detecting the glass' resonance, I will begin the next lab session by trying to make the frequency analysis graphs more accurate (and easier to read) using the FFT filter and noise reduction on "Audacity."
- I then would like to try varying other parameters such as radius/height of the glass (using cylinders of the same dimension but different radius/height so there is not the complication of curvature etc. however, these may have to be ordered into school so I may not get them in time) and liquid type (now that I am more certain that significant liquid damping occurs; this would reinforce that conclusion).

- I began by using the "noise reduction" and the "FFT filter" on the "Audacity" software" to filter the sound recorded by the microphone so that I obtained less background noise. This was quite successful and made determining fundamental frequency and easier, quicker task.

Good refinement – getting used to sophisticated apparatus.

- I also found a different speaker to the one that I had previously been using that had a smaller "head" so the output sound didn't spread out as quickly.
- As a quick trial, I placed a few – very small - pieces of paper on the glass rim to see if any vibration could be detected at the resonant frequency.
- This was very successful; I set the frequency generator (connected to the speaker as shown in my original plan) to the fundamental frequency that had been recorded using "Audacity" and observed the glass' reaction.
- The glass showed strong resonance at this frequency – with both the rim and the entire glass vibrating.
- I then added more (about 20) pieces of paper and found that they were separated into 4 "clumps," i.e. where there were nodes.

Good simple method.

- This "paper" experiment/method therefore confirms that, with the frequency analyzer "Audacity," I am measuring the correct resonance (that of the glass flexing), which is something I hadn't actually shown before, just assumed, as it is what the results suggested.
- It also verifies my theory about the resonating modes of the glass; at the fundamental frequency, the glass resonates with 4 nodes.

Example Candidate Response – Candidate C

Some interesting work using ultrasound sensors and then a mechanical oscillator from candidate C who was investigating damping.

Another method placing the system in a tube:

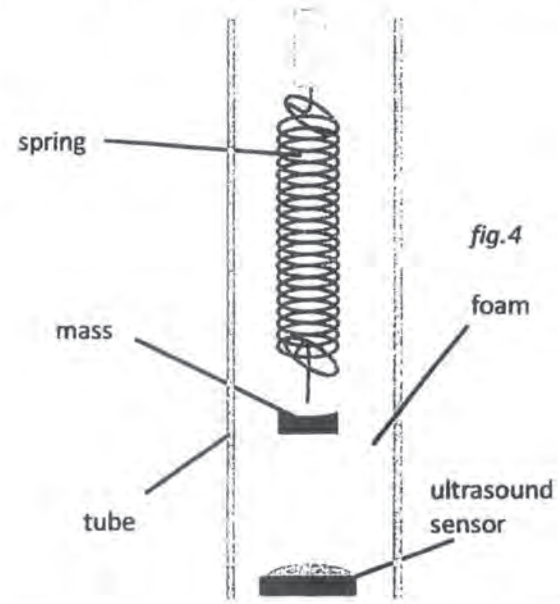
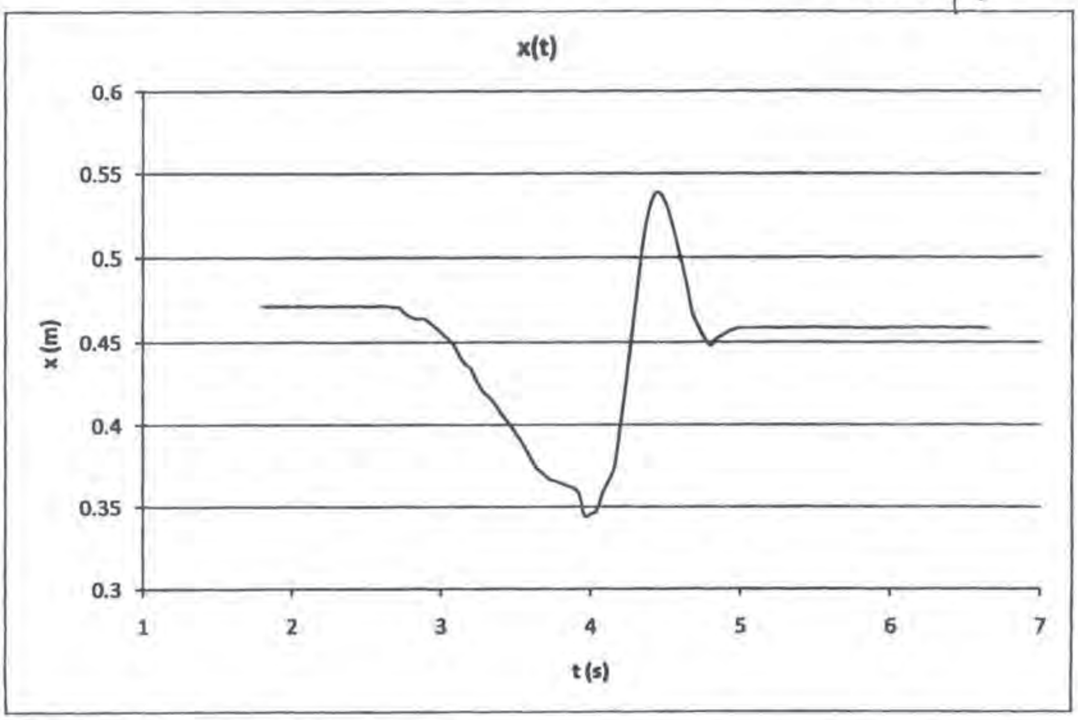


fig.4

- Placed the system in a plastic tube, with the ultrasound sensor at the bottom of the tube
- Place foam on mass which made it fit 'snugly' in the the tube, hopefully providing a large amount of damping from the air flowing around the edges of the foam
- This produced some results which could be considered to be over damping: Really?



There are some features of this graph (and other similar looking ones) which make me doubt this (nb initial movement from 2.5 to 4 seconds is while I displace the mass):

- The equilibrium position is not the same before and after, which implies there is a force not proportional to velocity resisting the spring's force which would otherwise bring it to equilibrium
- This is probably static friction, as the systm did rub on the inside of the tube
- Also the system has at least three maximums (including initial displacement), whereas over damping only allows for two until it asymptotes
- What is more likely is that there is some velocity dependent friction, but mainly I have a normal oscillation which is resisted by kinetic friction (which is constant when moving), and which is prevented from oscillating indefinitely into smaller oscillations by static friction

evidence

Best to use stick to the same kind of damping to have a continuity across experiments – therefore decided to return to using another fluid

Forced Oscillations

Creating an oscillator that outputs a known sinusoidal wave:

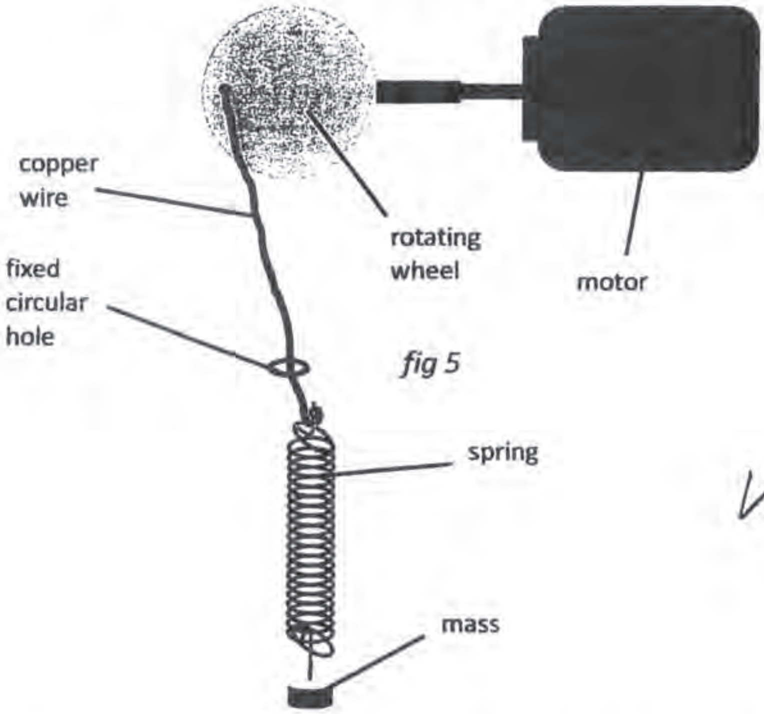


fig 5

✓ good

- Decided to use the vertical componenet of a rotating disk to be a forcing term that was sufficiently large and massive not to be noticeably affected by the spring's oscillations
- Drove the disk with a motor, which I could change the voltage to (had the ability to change strength of magnetic field *and* current passing through wire)
- Attached a copper wire to the wheel, fed this through a fixed circular hole and attached to the spring ✓

Result?
- Copper wire does produce largely vertical motion, however there is some sideways motion and it seems inevitable that this will be the case unless I make it far longer
- This sideways motion is far too significant making it impossible to take results ✓

Solution – a pivoting system which minimises sideways motion:
- The following diagram shows how introducing an extra pivot ensures the motion is only vertical: ✓

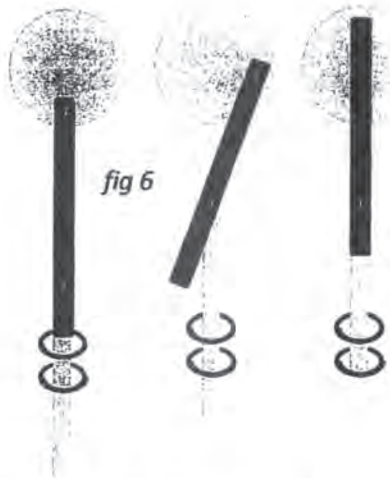
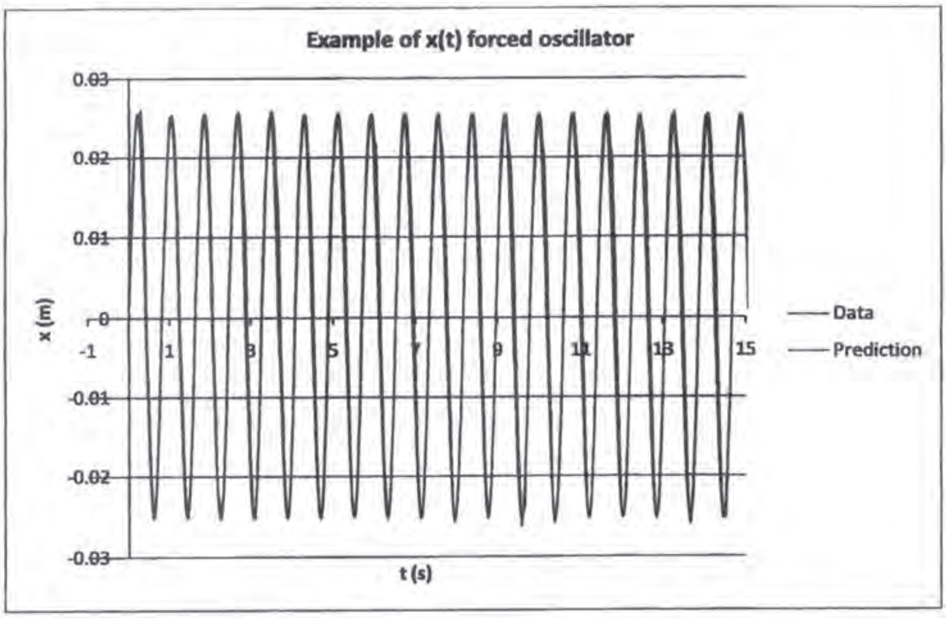


fig 6

✓ very good development

- Although the green rod has horizontal motion, the silver rod is guided by two rings which mean it can only move up and down
- This motion will be a very good approximation to sinusoidal motion (not exact as the green rod moves with a horizontal component)
- With this in mind I designed my experiment as in the diagram above
- However I wanted to check how closely the oscillation of the forcing term was to sinusoidal

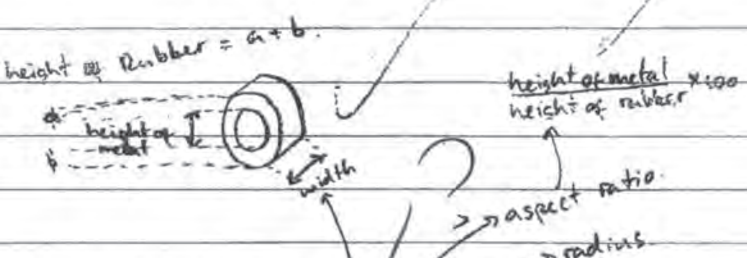
Experiment to evaluate how good a sinusodal approximation this is: ✓ important
- Run experiment with *no spring* to gain data for the displacement against time
- Measure the parameters *amplitude* and ω
- Plot a sine curve using this data, and compare to the actual data
- Below is an example:



- Prediction and data fit *very* closely
- The assumption that it is sinusoidal seems a valid assumption ✓ good.

Example Candidate response - Candidate B

Some creative use of everyday equipment (thinking "outside the box") from this candidate looking at the moment of inertia of a car wheel.



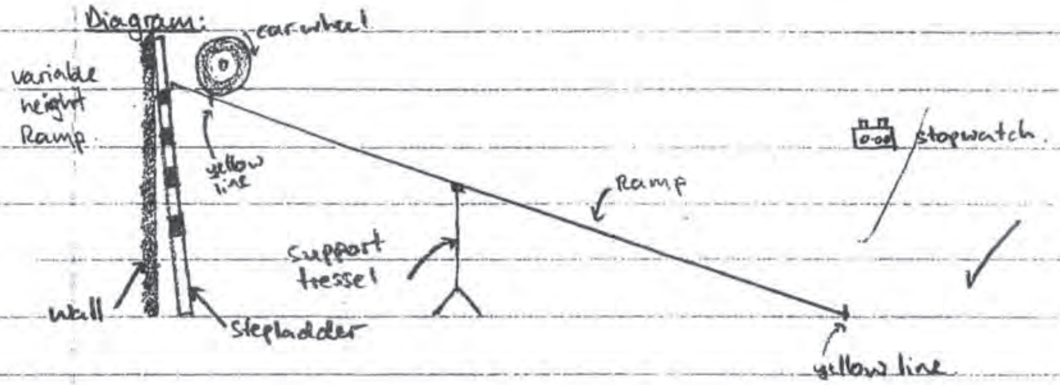
Sunday 27th December 2009:

I looked around my house which is still under construction for a suitable wheel. The wheel I found was a 155/70/13 which is slightly smaller than a modern car tyre and may well have been from a small trailer. It had good tread and didn't show any signs of uneven wear, therefore it should roll in a straight line. After ~~weighing~~ measuring the mass of the wheel, 10.0kg, I proceeded to look for a suitable slope. One possibility was the road outside my house which was on a uniform slope. Another option was several scaffold boards which were screwed together by a piece of baton. In the end I opted for a narrower plank of wood that was longer and by chance could be layed inside the handrails of a ladder. This was set up on a windowsill with a tressel to support it. After an ititial trial it was clear that it would need to be wider as the wheel fell off the edge. I found two wider pieces of floorboard and using a drill and screws attached these onto the original plank. This worked a lot better. In order to adjust the height, I placed a ladder beside the windowsill so it could be easily adjusted. The bottom of one of the pieces of wood was a bit crumbled/rotten so I stuck a bright yellow strip of electrical tape accross it. The same was repeated at the top 100mm away from the ladder. Using a helper to release the wheel from the top I recorded the time using a stopwatch. Standing at the bottom of the ramp allowed me to advise the helper on which way to aim/tilt the wheel which became more crucial the lower down the ~~ramp~~ ladder I got ie, when there was least amount of slope. I took 10 readings at each height so I could take an average. After this

Measuring the Moment of Inertia of a Car Wheel by rolling it down a slope

Aim: Measure the moment of Inertia of a car wheel.

Diagram:



method:

- Set up apparatus as shown on heighest rung of step ladder.
- ~~h~~hold wheel with bottom touching yellow mark on ramp.
- get assistant to help you align wheel to roll in a streight line.
- On the count of three, release the wheel and get assistant to Start stopwatch simultaneously. Stop stopwatch when wheel passes second yellow mark.
- Record time and repeat 9 more times.
- If wheel falls off ramp, ignore time and repeat.
- After 10 successful repetitions, lower ramp onto the next rung down. The tressel will probably have to be moved and or lowered.

Risk Assesment

Safety!

- From the heigher rungs of the ladder, the wheel is travelling quite fast at the bottom - be careful not to get hurt.
- The ramp is heavy - be careful lifting.

Raw Data: Rolling Wheel down Slope				
Length of Ramp (m)				4.45
Circumfrance of Wheel (Measured) (m)				1.78
Circumfrance of Wheel (Measured) (m)				1.78
	Height 3 (m)	Height 4 (m)	Height 5 (m)	Height 6 (m)
	0.92	1.21	1.52	1.80
Replication 1	2.73	2.25	2.19	2.01
Replication 2	2.71	2.3	1.92	1.81
Replication 3	2.70	2.19	2.14	1.94
Replication 4	2.58	2.30	2.17	2.11
Replication 5	2.56	2.32	2.0	2.03
Replication 6	2.73	2.21	2.08	2.08
Replication 7	2.64	2.28	2.08	2.26
Replication 8	2.72	2.37	2.15	1.94
Replication 9	2.44	2.22	2.08	1.98
Replication 10	2.71	2.28	2.01	1.97

Some inconsistency in precision.

Derived Data: Rolling Wheel down a Slope					
Average Time	s	2.65	2.27	2.08	2.01
Mass	kg	10.0	10.0	10.0	10.0
Gravitational Potential Energy	J	90	119	149	177
Average Velocity	m/s	1.68	1.96	2.14	2.21
Final Velocity	m/s	3.36	3.92	4.27	4.42
Final Velocity^2	$(m/s)^2$	11.26	15.34	18.27	19.55
Linear Kinetic Energy	J	56	77	91	98
Rotational Kinetic Energy	J	34	42	58	79
Angular Velocity w	radians/s	3.77	4.40	4.80	4.97
Angular Velocity^2 w^2	$(radians/s)^2$	14.22	19.37	23.07	24.68
Moment of Inertia	Kgm^2	1.19	1.08	1.25	1.60

GPE = mgh

$= \frac{\text{length of ramp}}{\text{time}}$ Good

$= 2 \times$ av. velocity ✓

$= \frac{1}{2}mv^2$ ✓

$= \frac{1}{2}I\omega^2$ ✓

Rotational KE $= \frac{1}{2}I\omega^2$

$\frac{1}{2}I = \frac{\text{Rotational KE}}{\omega^2}$

$I = 2\,\frac{\text{Rotational KE}}{\omega^2}$ ✓

Average $= \frac{1.19 + 1.08 + 1.25 + 1.60}{4}$

$= 1.28\,kgm^2$ ✓

Angular Velocity.

# of times wheel turns down slope $= \frac{4.45}{1.78} = 2.5$

∴ turned through 5 radians

Angular velocity at bottom $= 2 \times \frac{5}{2.65}$

$= 3.77$

? THIS TURNED OUT TO BE INCORRECT

Practical Techniques

Mark Scheme

Practical Techniques	
The number and range of measurements taken in some, but not all, experiments is adequate. There is no attention paid to anomalous measurements. There is some awareness of the need to consider precision and sensitivity, and some measurements are repeated.	0
The number and range of measurements taken in most experiments is adequate. Some measurements are identified as anomalous but there is little attention paid to them. There is some awareness of the need to consider precision and sensitivity, and measurements are usually repeated where appropriate.	1
The number and range of measurements taken in each experiment is adequate, with additional measurements taken close to any turning points. Anomalous measurements are correctly identified but in most cases they are not investigated further. There is awareness of the need to consider precision and sensitivity, and experiments are designed to maximise precision. Measurements are repeated where appropriate.	2
The number and range of measurements taken in each experiment is adequate, with additional measurements taken close to any turning points. Anomalous measurements are correctly identified and are investigated further. There is awareness of the need to consider precision and sensitivity, and experiments are designed to maximise precision. Measurements are repeated where appropriate. Where it is appropriate, more than one measuring technique is used to help corroborate readings or inventive methods are used to help improve or check readings.	3
Maximum mark 3	

General Comment

The examiner is looking for an adequate range and number of measurements, anomalies identified, repeats where appropriate, with a consideration of precision and a range of measuring techniques or innovation.

Example Candidate Response – Candidate D

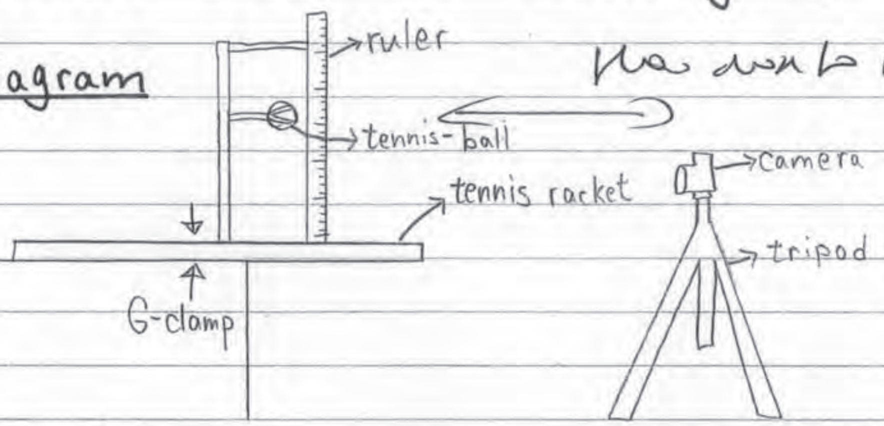
Candidate D's investigation into the sweet spot of a tennis racket shows repeats and the use of a camera (rather than judging by eye).

Aim

To find out where the sweet spot is on the racket face and to see how different positions affect the efficiency.

Diagram

Has done to avoid parallax error?



Method

- Use a G-clamp to clamp the racket firmly on the table

- Use a stand and clamp to secure the position of the ruler which should be placed right on top of the racket.

- use a clamp to secure to the position of the tennis ball

- make sure the ruler is put near to the tennis ball to have a more accurate result why? as it would ~~be~~ reduce the parrallax error

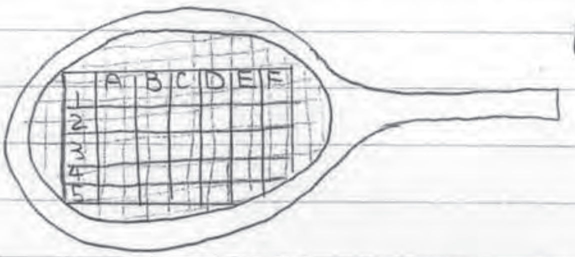
- also put the camera around 2 ~ 3m away from the set-up to reduce the error of parallax

- place the camera on the tripod to get a more stable recording

- adjust the height of the tripod to horrizontal level to the tennis ball to reduce the error due to parallax.

- divide the tennis racket face into different parts

- draw the grids on a piece of paper and stick it underneath the racket face.



Nice

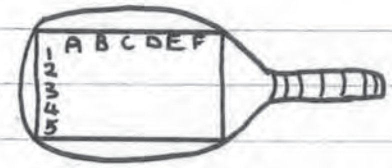
Ingenious way of gathering/recording data

- drop the tennis ball onto a grid. Drop it 2 - 3 times until you get a consistent result.

- do it to all the grids.

- plot a graph of bouncing height and position and find where the sweet spot is.

Results



Bounce height in cm?

(mm)	A	B	C	D	E	F
1	220	210	190	180	150	130
2	200	180	160	140	130	120
3	180	160	150	140	120	100
4	180	160	160	150	120	110
5	220	170	180	180	140	120

Analysis

In this experiment, there are some difficulties in observing the bounce height. First of all, as the time of the ball staying at the highest point after bounce is very short, it is extremely hard to observe an accurate result. Secondly, after bouncing the tenis ball sometimes bounced away from its vertical axis and therefore ~~has~~ I have to re-drop it until its vertical. Thirdly, when I use my camera to record the whole dropping and bouncing process, there is a problem of parallex. The camera would not be able to stay on the horrizontal position as the tennis ball and it would therefore affect the accuracy of the results.

From the graph, we can see that efficiency is the highest in position A1 and A5 and it gradually decreases chronologically to F. This is because there is more oscillation at the far end of the racket than the clamped point of the racket. This can be proved by using the camera to record the oscillation of the racket given the same drop height. There is a very obvious oscillilation when the ball is dropped on F whereas there is barely any oscillation on A. However, it is impossible to measure the frequency as the frequency is too high and the amplitude is too low.

In order to make my experiment more reliable I have done a few more tests to see if my set-up is accurate enough. I have dropped a tennis ball onto one of the grids 40 times and see how is the efficiency. At the end the result is 37/40. That means there are 37 times the ~~ball~~ dropped onto the grid ~~without touching the lines or dropping outside the grid~~. The efficiency is therefore 93%. Moreover, I have done a test on how well the ball is dropped. I have ~~to~~ used a clamp and stand to drop the tennis ball 40 times and have to observe whether the ball dropped without slipping or spinning. The result is 38/40 and the efficiency is 95%. Due to the difficulties and uncertainties in observing the results which I have mentioned in the first paragraph, I have

testing reliability of drop method

Repeat ✓

dropped the tennis ball for at least 3 times until I get a consistent result. The camera I used has a very high frame rate which makes my observation ~~more~~ easier and more accurate. why?

The difference in the drop height and the bounce height also implies there is energy transfered. As I have done two seperate experiments before about energy losts on tennis string and tennis ball, I can work out the energy lost when the ball is dropped onto the racket. The energy lost should be very close to the energy of tennis ball plus the energy lost of tennis string.

Lets take the ~~average~~ highest and smallest bounce height: ~~[illegible]~~ 220mm, 100mm

As there is height difference between the drop height and bounce height, there is energy lost. Therefore we can use the formula $mg(h_d - h_b)$ to calculate the energy lost.

But units are mm,

$mg\left((300-\cancel{250})\right)^{\times 10^{-3}}$ = energy lost
or 100

as we have measured the mass of the tennis ball ≃ 57g,

80mm ? 80×10^{-3}

✓ $0.057(9.8)(\cancel{[illegible]})$ = $\cancel{[illegible]}$ J
80×10^{-3} 0.04

$\times 10^{-3}$?

$0.057(9.8)(200)^{\times10^{-3}}$ = $\cancel{[illegible]}$ J
0.1

Example Candidate Response – Candidate C

An example of good data collection with a concentration around the turning point from the experiment on damping. This could also be considered as a good example of data collection for the next marking criteria.

The Resonance Experiment

- Now I was in a position to study the phenomenon of resonance
- I used the apparatus with the system submerged in water, as described above
- Firstly I placed a mass, equal to the mass of the mass-spring system, but with *no spring*, onto the forced oscillator
- Setting the voltage across the electromagnet in the motor at 12V, I began with the voltage across the coil as 3.5V, and measured x(t) for the forced oscillator
- Then, without changing anything else, I replaced this with the mass spring system, and switched the motor back on
- I allowed at least 20 seconds for the oscillating system to settle, and then measured $x(t)$ for 50 seconds
- I repeated this stage twice more, so that I had 3 results
- I then changed the coil voltage to 4V, and so on, repeating the procedure
- I continued this process until 9V, in 0.5V increments

Processing the results

- My aim was to see how the resultant amplitude of a steady state oscillation varied with the forcing ω (i.e. $\propto$ forcing frequency)
- Therefore I needed
  - ω for my forcing oscillations
  - Maximum displacement for the system including spring

The forcing frequency

- To minimise error, I measured for roughly 50 seconds, the time taken for n time periods to elapse (measuring from peak to peak) and divided by $n-1$ ($n-1$ as I divide by the number of spaces, which is one less than the number of peaks)

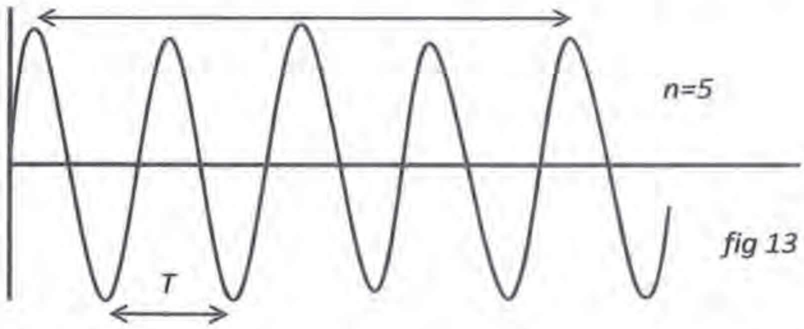


fig 13

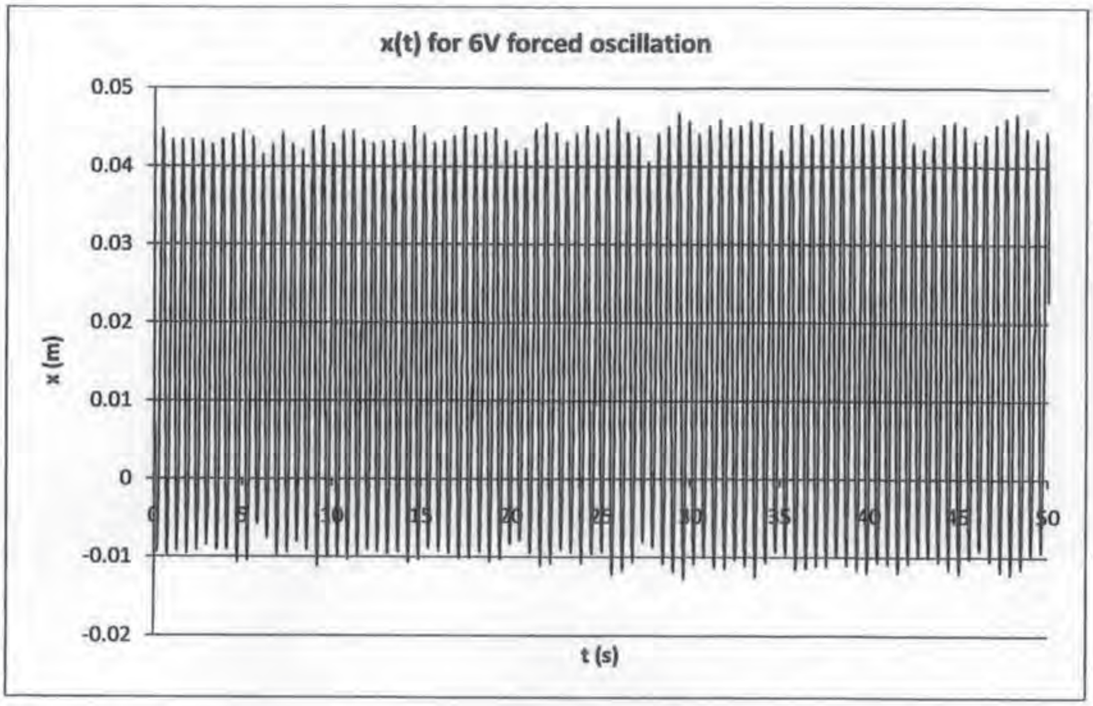
- e.g. here there are 5 peaks, therefore for the time period I divide the time elapsed for these 5 peaks by 4
- I can then find a value for ω, as $\omega = \frac{2\pi}{T}$

Error in forcing frequency

- I supposed that since the sensor only had a resolution of 0.04 seconds, and I used two results to calculate time, my measurement of time between the two peaks was about 0.2s
- I divided this value by $(n-1)$, for the error in the time period (ΔT)

- For the error in ω, I supposed: $\Delta\omega \approx \frac{2\pi}{T} - \frac{2\pi}{T+\Delta T}$ where Δ is 'the uncertainty in'
- I used excel to repeat this for all readings

The amplitude of the mass spring system
- The graph below is an example of $x(t)$:



- Some (minimal) beating, however amplitude remains fairly constant, fluctuating across much smaller values
- By averaging out these, I can extract a good estimate for the steady state amplitude

Extracting a value for amplitude
- I used excel, using methods described above, to extract and the values of maximum and minimum amplitude
- I then used it to average these out, subtract the average maximum and from the average minimum and divide by 2 to gain a value for the amplitude
- I repeated this for the other two readings, discarded anomalous results, and then averaged these out to again
- This gave me a very accurate and reliable value for the amplitude, as so many readings had been taken into account
- Once I had a good idea where the peak resonance would occur, I took more results around this particular forcing frequency to identify more accurately where the peak occurred ✓ good

Quantifying the error
- I needed to find a repeatable, algorithmic way to calculate errors due to the sheer volume of data I was processing
- My solution was the following process:

- I used excel to extract, from the list of maximum displacements, the maximum and minimum of these, and subtract one from the other to find the *range* of the maximum displacements
- I repeated for the minimum displacements
- By finding the mean of these, I had a good estimate for the error of any single measurement of amplitude I might have made ✓ good.
- I then took into account the fact I averaged many results by multiplying the error by $\frac{1}{\sqrt{n}}$, where n is the number of readings used to calculate that amplitude
- I then repeated for the other 2 results, averaged the error, and multiplied by $\frac{1}{\sqrt{3}}$ to take into account this averaging ✓
- This error value was unsurprisingly very small, considering the volume of data used to collect a single result
- I also ensured than any anomalous results were discarded

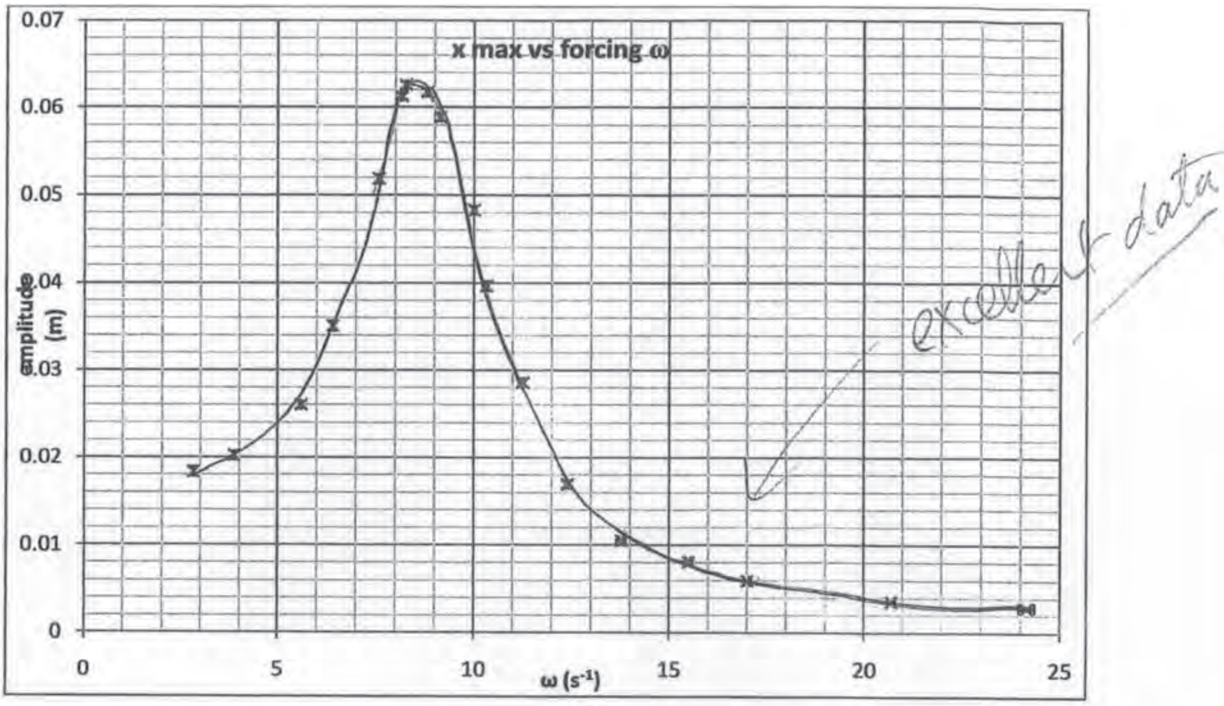
The Results

- After extensive processing, I produced the following table of results, and also the graph which follows:

forcing ω (s^{-1})	% error	amplitude (m)	% error
2.80	0.31	0.0183	3.2
3.86	0.43	0.0202	2.4
5.59	0.41	0.0260	1.5
6.41	0.41	0.0351	1.7
7.58	0.41	0.0518	1.0
8.16	0.41	0.0612	0.5
8.26	0.41	0.0626	0.6
8.80	0.41	0.0617	0.6
9.14	0.41	0.0589	0.7
10.00	0.41	0.0483	1.1
10.32	0.41	0.0396	1.4
11.25	0.41	0.0286	1.5
12.38	0.40	0.0169	2.1
13.77	0.41	0.0105	1.7
15.49	0.40	0.00806	2.8
16.99	0.41	0.00591	1.9
20.69	0.40	0.00354	4.5
24.15	0.82	0.00288	5.8

✓ good

an enormous effort on its own!



Interpretation:

- On the left of the graph it appears the graph will cut the y axis at a positive value
  - I would expect this, as the $\lim_{\omega \to 0} x_{max}$ should be the amplitude of the forcing term, as the spring will not extend, so it will just move up and down with the oscillator (although when $\omega = 0$ the system won't move at all) ✓ good
- The $\lim_{\omega \to \infty} x_{max}$ seems to = 0, which is quite an interesting effect
  - When actually watching the experiment, I could see that what happens here is that the forced oscillator moves up and down so quickly the mass doesn't have time to move, it has too much inertia ✓ good
  - The spring effectively continues to contract and expand, while the mass remains almost motionless, oscillating only a very small amount
- There is a definite peak at around $\omega = 8.5s^{-1}$, the position of maximum resonance
  - Here the oscillations of the forced oscillator reinforced the oscillations of the system, giving it more and more energy until effects of damping balanced this ✓
- In general, the data is very effective in demonstrating the effect of resonance, as due to the small errors the curve is very smooth and there are many data points ✓

06/03/10

The Theory of Resonance

Using theory to predict maximum amplitude:

- Previously I showed that, using the SHM model with damping $\propto v$, the steady state solution for forced oscillation is: $x = psin\omega t + qcos\omega t$, where:

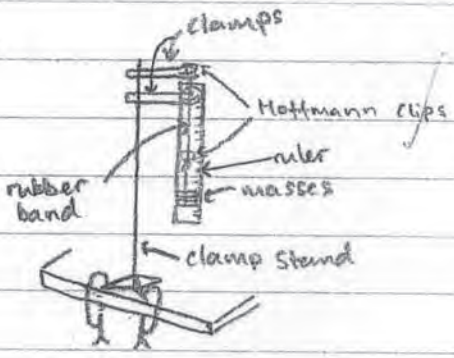
Example Candidate Response – Candidate B

Two excerpts have been included from this candidate. The first is a straightforward elongation of an elastic band. This should also be considered as an example for the Data Processing section of the mark scheme.

Measuring Hysteresis of Rubber by stretching a Rubber Band.

Aim: Determine what percentage of the work done on rubber is given out in the form of thermal energy. ✓

Diagram:



Method

- measure mass of rubber band.
- Set up Apparatus as shown.
- Place Hoffman clips on either end of rubber.
- Record length of rubber band that will be stretched - bottom of top hoffman clip to top of bottom clip.
- Add masses in 20g increments and record new length after each 20g has been added - allow 10seconds before recording length.
- Creep will be negligable after this time. ✓
- Once 600g has been added, remove masses 20g at a time and wait 10seconds before reading new length.
- ~~G clamp onto desk.~~
- Plot Force / Extension graph
- work out area between loading and unloading curves (count squares)
- work out area between loading curve and extension axis (count squares).
- work ~~this~~ out percentage of work done that is given off in the form of heat.

Saturday 9th January:

I used this ~~apparatus~~ lesson to set up the apparatus needed. This involved cutting a rubber band in half and clamping a stand onto the workbench. I then recorded the mass of the hoffmann clip (22g).

Sunday 10th January:

The hysteresis experiment was carried out upto 600g with increasing masses of 20g incriments up to 600g and then unloaded. I plotted a ~~force~~ extension/force graph. I realise that there will be a systematic offset from the 22g hoffmann clip although I needed this to stretch the band streight. Looking back the graph I plotted should have started from 200mm on the y-axis. By counting the number of squares in between the loading and unloading curves, I was able to estimate the thermal energy dissapated. (0.148J)

Monday 11th January:

I worked out the area between the loading curve and the y-axis by using rectangles as shown on my graph. This represents the Energy put into the system, which came to (1.44J). I then calculated the percentage of the energy put in that was lost as heat ~~due~~ (10.27%)

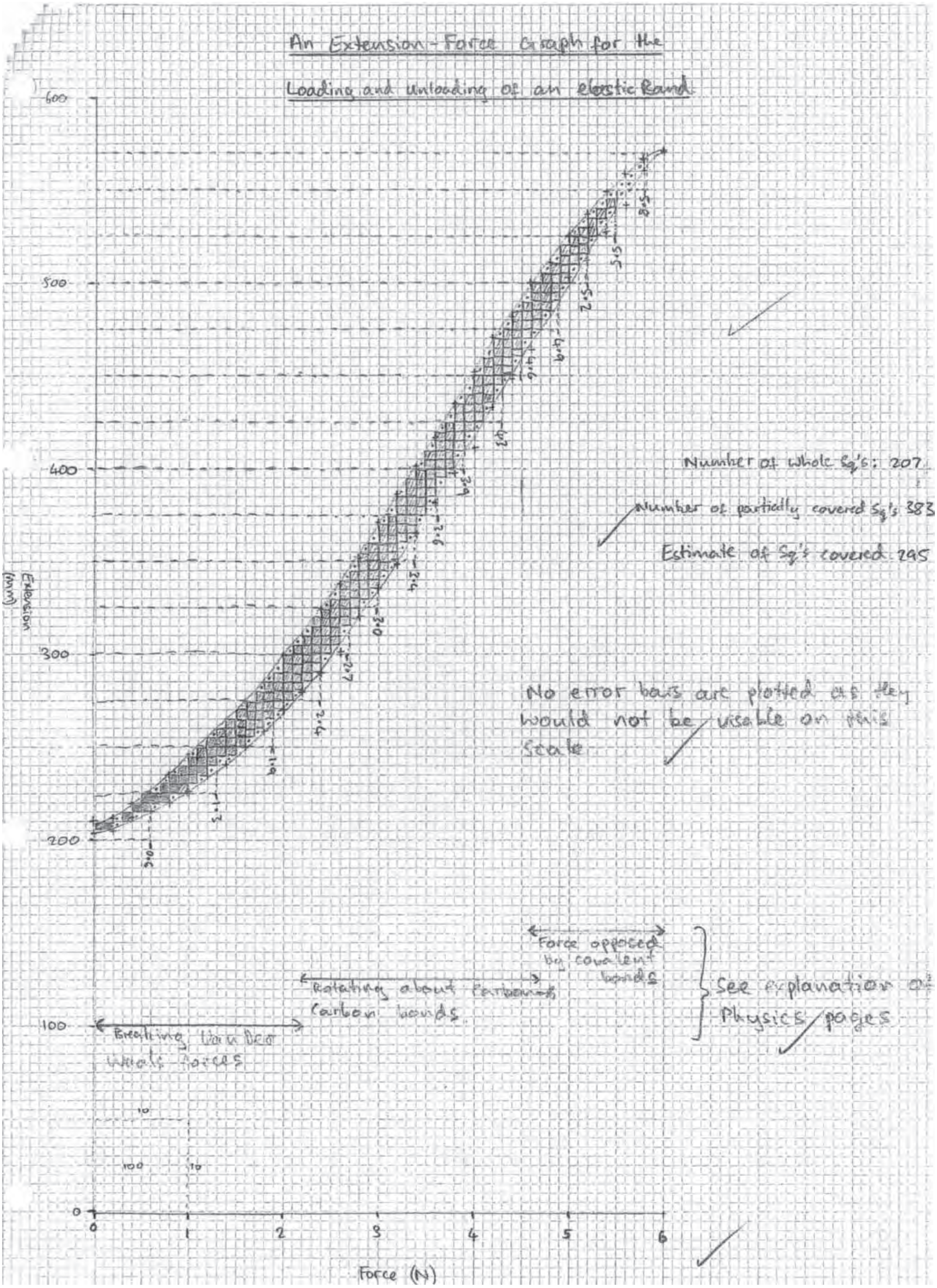
Tuesday 12th January:

I ~~had~~ made some of my data tables a little neater and added table lines to my excel spreadsheets and printed them off.

Raw Data: Stretching of Elastic Band

g = 10 N kg⁻¹ rather than 9.81 N kg⁻¹

Mass (g)	Force (N)	Loading (mm)	Unloading (mm)
0	0.0	203	210
20	0.2	205	212
40	0.4	211	220
60	0.6	215	225
80	0.8	220	235
100	1.0	226	246
120	1.2	235	255
140	1.4	242	265
160	1.6	250	275
180	1.8	258	285
200	2.0	269	300
220	2.2	278	310
240	2.4	290	325
260	2.6	302	338
280	2.8	319	352
300	3.0	335	372
320	3.2	348	386
340	3.4	365	401
360	3.6	382	417
380	3.8	397	435
400	4.0	412	452
420	4.2	433	470
440	4.4	447	482
460	4.6	464	500
480	4.8	485	512
500	5.0	502	525
520	5.2	512	537
540	5.4	527	549
560	5.6	542	558
580	5.8	560	566
600	6.0	572	572


An Extension-Force Graph for the
Loading and unloading of an elastic Band
Extension (mm)
Force (N)
Number of whole Sq's: 207
Number of partially covered Sq's: 383
Estimate of Sq's covered: 295
No error bars are plotted as they would not be visable on this Scale
Force opposed by covalent bonds
Rotating about Carbon Carbon bonds
Breaking Van Der Waals forces
See explanation of Physics pages

Analysis of Hysteresis Curve:

Thermal Energy Given out:

minimum: Number of whole Squares = 207

maximum: Number of whole and partially covered squares = 383. { Percentage Error: 383 − 295 = 88

Estimate: Number of squares over 50% covered = 295 { $\frac{88}{295} \times 100 = 30\%$

~~1 sq = 0.0000 Nm~~ 1 sq = 5×10^{-4} Nm. { ⇒ 30% is the absolutely max. error. Infact it is probably less than a $\frac{1}{3}$ of this ie 10%

Energy lost as heat:

$295 \times 5\times10^{-4} = 0.1475$ J. (± ≈10%)

Work Done on System – Area between loading curve and y-axis.

Correspond with graph

$(0.02\times5.8)+(0.025\times5.5)+(0.025\times5.2)+(0.025\times4.9)+(0.025\times4.6)+(0.025\times4.3)+(0.025\times3.9)+(0.025\times3.6)\ldots$

$+(0.025\times3.4)+(0.025\times3.0)+(0.025\times2.7)+(0.025\times2.4)+(0.025\times1.9)+(0.025\times1.3)+(0.025\times0.6) = 1.436$ J.

{ Percentage error deduced from looking at graph is (≈10%)

Percentage % of Energy lost as heat = $\frac{0.1475}{1.436} \times 100$

$= 10.27\%$ (± ≈20%)

length of rubber being stretched = 203 − rubber in hoffmann clips.

= 203 − (5+8) { percentage error = ±0.5mm at top

= 203 − 13 { ±0.5mm at bottom

= 190mm. { ∴ ±1mm = 0.5%

percentage of rubber being stretched = $\frac{190}{203} \times 100 = 93.6\%$ (± 0.5% × 2) = ± 1%

mass of rubber = 1.60g (±0.30%) / percentage of rubber being stretched = 1.60 × 0.936 (±1.3%)

= ~~1.4976g~~ = 1.50g.

Specific heat capacity of India rubber = 1.25 (at 273K) | reference?

Expected temperature rise of rubber.

$E = mc\Delta t$ { percentage error = 10% + 1.3%

$1.436 = 1.50 \times 1.25 \times \Delta t$ { = 11.3%

$\Delta t = 0.77$K (± 11.3%)

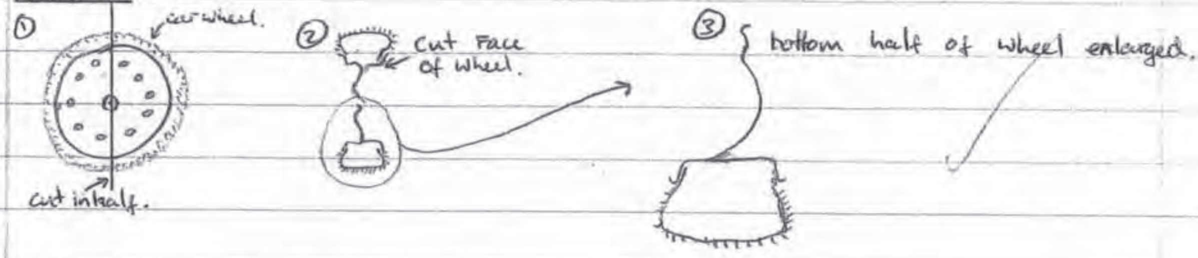
Example Candidate Response – Candidate B

A more unusual method of finding the moment of inertia of a car wheel.

Calculating the Moment of Inertia of a Car Wheel by Cutting it in Half.

Aim: Calculate the Moment of Inertia of a car wheel.

Diagram



Method.

- weight wheel (10.0kg)
- Cut wheel in half using angle grinder with thin metal cutting dish on.
- trace bottom half of the half. cut up as shown in ~~image~~ drawing ③ above. to start with only trace metal, not rubber, using a marker pen onto an A3 sheet of paper.
- measure thickness of two pieces of metal that make up wheel using vernier callipers.
- Plot this outline onto the computer using a spline function? on Autocad. After the thiness of the metal on the computer to the thickness measured using the vernier callipers.
- Split up the total volume of the wheel into 20mm divisions out from the radius of the wheel.
- work out the area of each of these divisions (using Autocad). Very ingenious
- Calculate the volume of each division about the whole wheel.
- Using the mass of the metal section of the wheel, which needs to measured, and the total volume of metal, work out the density of the metal.
- Compare this with the data book value for steel.
- work out the mass of each of the 20mm divisions in ~~the~~ the wheel.
- Calculate the moment of inertia for each division.

- Sum the moments of Inertia
- Repeat for the rubber tyre. ✓
- Add both of the sums for the wheel and tyre.
- This will give the moment of Inertia.

Risk Assesment.

- Take care using angle grinder - do not use cutting blade for grinding. ✓
- wear goggles.
- cut outdoors so rubber smell will dissipate.
- make sure new blade is firmly screwed on.
- Freshly cut face will be sharp around edges and hot - wear gloves
- wear protective clothing to stop not sparks damaging clothing.

Safety! Moderator NB done with supervision!

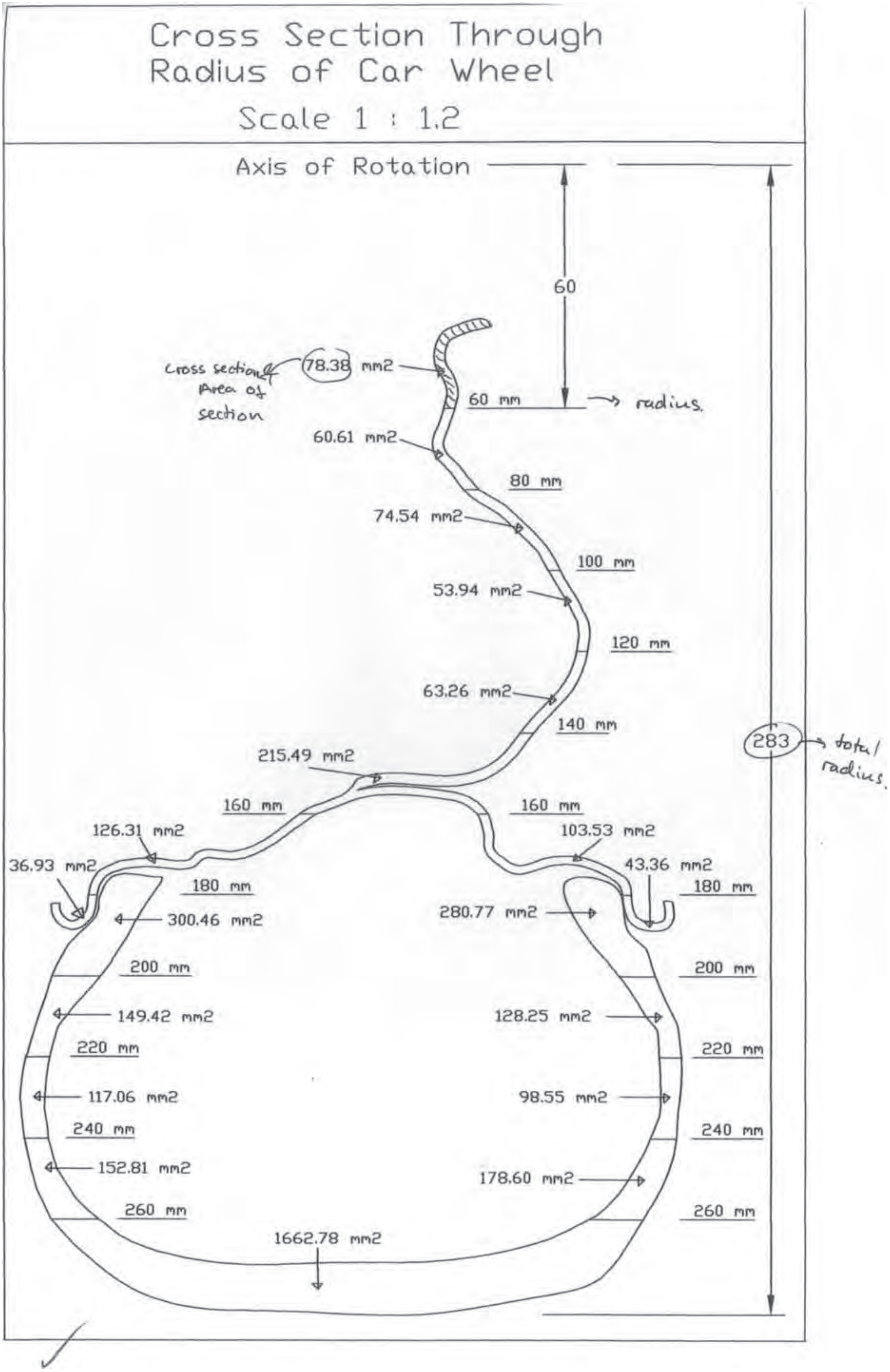

Cross Section Through
Radius of Car Wheel
Scale 1 : 1.2
Axis of Rotation
60
Cross section of Area of section
78.38 mm2
60 mm
radius.
60.61 mm2
80 mm
74.54 mm2
100 mm
53.94 mm2
120 mm
63.26 mm2
140 mm
283
total radius.
215.49 mm2
160 mm
160 mm
126.31 mm2
103.53 mm2
36.93 mm2
43.36 mm2
180 mm
180 mm
300.46 mm2
280.77 mm2
200 mm
200 mm
149.42 mm2
128.25 mm2
220 mm
220 mm
117.06 mm2
98.55 mm2
240 mm
240 mm
152.81 mm2
178.60 mm2
260 mm
260 mm
1662.78 mm2

Table: Mass and MOI

Steel Wheel					
Radius	**Circumference**	**Cross Section**	**Volume**	**Mass**	**M O I**
	$2\pi r$		C.S*Circum	(Vol/Tot Vol)*Tot mass	Mr^2
(mm)	(mm)	(mm^2)	(mm^3)	(Kg)	(Kgm^2)
50	314	78	24624	0.18	0.0005
70	440	61	26658	0.20	0.0010
90	565	75	42151	0.31	0.0025
110	691	54	37281	0.28	0.0034
130	817	63	51672	0.38	0.0065
150	942	215	203095	1.51	0.0340
170	1068	230	245502	1.82	0.0527
190	1194	80	95851	0.71	0.0257
			726832	5.4	0.1262
	Scale weight (Kg)	5.4			
Calculated Density (Kg/m^3)		7430			
Quoted Density (Kg/m^3)		7,750 - 8,000			
Rubber Tyre					
Radius	**Circumfence**	**Cross Section**	**Volume**	**Mass**	**M O I**
(mm)	(mm)	(mm^2)	(mm^3)	(Kg)	(Kgm^2)
190	1194	581	693875	0.68	0.0244
210	1319	278	366377	0.36	0.0157
230	1445	216	311585	0.30	0.0160
250	1571	331	520578	0.51	0.0317
270	1696	1671	2834276	2.76	0.2011
			4726691	4.6	0.2889
	Scale weight (Kg)	4.6			
Calculated Density (Kg/m^3)		973			
Quoted Density (Kg/m^3)		1000 - 1200			
				10	0.415

kgm²

$= 0.4\,kgm^2$

Moment of Inertia.

$= \Sigma\, MOI$

$= \Sigma\, mr^2$

Data Processing

Mark Scheme

Data Processing	
Most data is tabulated correctly and graphs are mostly plotted correctly, with only a few minor errors. However, calculations contain some major errors and conclusions are not well supported by the results.	0
Data is tabulated correctly and graphs are plotted correctly. Calculations contain some errors but these are not major. Some conclusions are not well supported by the results.	2
Data is tabulated correctly and graphs are plotted correctly. Calculations are correctly completed and linear relationships are successfully analysed. Error bars are shown, although not on all graphs and not always correctly, and there is some treatment of uncertainties. Conclusions are well supported by the results.	4
Data is tabulated correctly and graphs are plotted correctly. Calculations are correctly completed and relationships are successfully analysed. Some of the work is sophisticated and requires for example the plotting of logarithmic graphs to test for power laws or exponential trends. Error bars are shown wherever appropriate, and uncertainties are routinely calculated for derived quantities. Conclusions are well supported by the results.	6
Maximum mark 6	

General Comment

Here we are looking for well-presented tables with correctly plotted graphs with error bars. Excellent calculations should be the norm, with a good sophisticated analysis, including logarithmic graphs where appropriate. Uncertainties should be considered as a routine task. The previous examples are also a good indication of the standard required for the highest marks.

Example Candidate Response – Candidate E

A good piece of work on uncertainties at the end of some work on magnetic fields from candidate E.

Same as "Experiment 7", test whether "B" is proportional to "N" for a coil with 1 A passing through $3.15\text{x}10^{-5}$ m diameter copper enamelled wire with a plastic air core.

L = 0.032

This was achieved by spreading the loop out over the first layer then started winding the second layer and the third layer over the same length.

Apparatus

- 1 Plastic air core
- 1 Amp meter
- 1 Power supply
- Enamelled copper wire
- Magnetic flux density unit
- Power drill

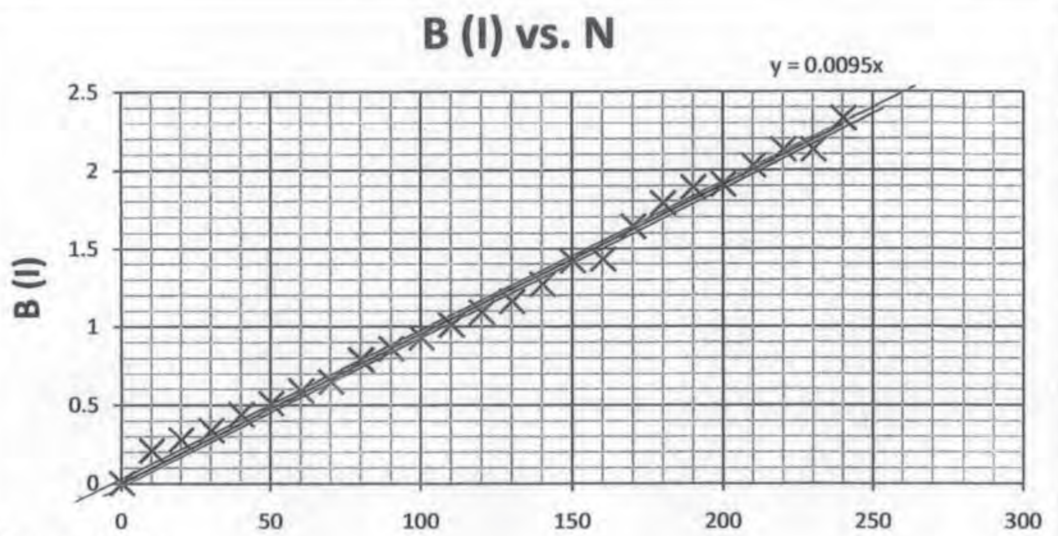
Diagram

See diagrams under "Experiment 4"

Result

N	L (m)	I (A)	B (I)
240	0.032	1.0	2.33
230	0.032	1.0	2.13
220	0.032	1.0	2.13
210	0.032	1.0	2.03
200	0.032	1.0	1.91
190	0.032	1.0	1.89
180	0.032	1.0	1.79
170	0.032	1.0	1.64
160	0.032	1.0	1.43
150	0.032	1.0	1.42
140	0.032	1.0	1.27
130	0.032	1.0	1.16
120	0.032	1.0	1.09
110	0.032	1.0	1.01
100	0.032	1.0	0.93
90	0.032	1.0	0.86
80	0.032	1.0	0.79
70	0.032	1.0	0.65
60	0.032	1.0	0.59
50	0.032	1.0	0.51
40	0.032	1.0	0.44
30	0.032	1.0	0.34

20	0.032	1.0	0.28
10	0.032	1.0	0.21
0	0.032	1.0	0.00



Error bars:
largest error in y direction, ± 0.01 for all values

The graph confirms that "B" is linearly proportional to "N" for a coil with an air core.

$$\mu = \frac{LB}{NI}$$

Since $\frac{L}{I} = \frac{0.032}{1} = 0.032\ \text{mA}^{-1}$

Therefore $\mu_{\text{air core}} = 0.009 \times 0.032 = 2.88\text{x}10^{-4}\ \text{TmA}^{-1}$

<u>Uncertainties</u>

"N" is the number of turns. I counted them more than once to make sure that N±0

"L" was also measured by a ruler with the smallest division of 1 mm. L±10^{-3}

"B" was measured using a magnetic flux density unit. In this experiment, B±~~0.02~~ 0.01

"I" was measured by an amp meter. I±0.01

Using the method used in "Experiment 3"

$\mu_{\text{air core}} = 3.03\text{x}10^{-4}, 3.19\text{x}10^{-4} = 3.11\text{x}10^{-4} \pm 7.94\text{x}10^{-6}\ \text{TmA}^{-1}$

% uncertainty = 2.55 %

This is very low and because there may be other uncontrolled variables or other uncertainties; such as the magnetic density flux unit may be a lot more inaccurate because there were many other magnetic objects around the probe at the time of use. The % uncertainty may be as high as 10 % in reality.

Conclusion

The equation $B = \mu\frac{NI}{L}$ is valid for all cases of solenoid with an air core. As supported by experiment 3, 5 and 8, $B \propto I$, $B \propto N/L$ and $B \propto N$, respectively.

Generally $B = \mu\frac{NI}{L}$ is valid for most cases of a solenoid with a magnetic coil. As supported by experiment 4 and 7, $B \propto I$ and $B \propto N$, respectively. However $B = \mu\frac{NI}{L}$ does not always hold for a solenoid with a magnetic core. Such as in "experiment 6", "B", was not proportional to "N/L". This was suspected to be due to hysteresis of the magnetic core[12]. ← More likely due to small values of L.

$\mu_{air\ core}$ and $\mu_{soft\ iron\ core}$ were also expected to be constant when the same solenoid core material was used as they represent the permeability of the electromagnet core material.

- For air core:

In "experiment 3", $\mu_{air\ core} = 6.32\text{x}10^{-4}, 6.46\text{x}10^{-4} = 6.39\text{x}10^{-4} \pm 6.84\text{x}10^{-6}\ \text{TmA}^{-1}$

Good evaluation

% uncertainty = 1.07 %

In "experiment 5", $\mu_{air\ core} = 1.16\text{x}10^{-5}, 2.19\text{x}10^{-5} = 1.68\text{x}10^{-5} \pm 5.16\text{x}10^{-6}\ \text{TmA}^{-1}$

% uncertainty = 30.7 %

In "experiment 8", $\mu_{air\ core} = 3.03\text{x}10^{-4}, 3.19\text{x}10^{-4} = 3.11\text{x}10^{-4} \pm 7.94\text{x}10^{-6}\ \text{TmA}^{-1}$

% uncertainty = 2.55 %

or the wrong model was used.

The $\mu_{air\ core}$ values from experiment 3 and 8 are comparable, they are in the same order of magnitude. The value from "experiment 3" is about twice the value from "experiment 8". This confirms that the % uncertainties must be a lot higher, given that $\mu_{air\ core}$ = constant is assumed to be true. There must be other uncontrolled variables or other uncertainties[13].

The $\mu_{air\ core}$ value from "experiment 5" is not even comparable to the values from experiment 3 and 8, suggesting that the % uncertainty is a lot higher than 30.7 %.

- For soft iron core:

In "experiment 4", $\mu_{soft\ iron\ core} = 7.83\text{x}10^{-3}, 7.99\text{x}10^{-3} = 7.91\text{x}10^{-3} \pm 8.17\text{x}10^{-5}\ \text{TmA}^{-1}$

% uncertainty = 1.03 %

[12] Explained in more detail under "Research 2" section
[13] Such as the magnetic density flux unit may be a lot more inaccurate because there were many other magnetic objects around the probe at the time of use

In "experiment 7", $\mu_{soft\ iron\ core}$ = 3.63x10^{-3}, 3.81x10^{-3} = 3.72x10^{-3}±9.24x10^{-5} TmA^{-1}

% uncertainty = 2.48 %

Again, the $\mu_{soft\ iron\ core}$ values from experiment 4 and 7 are comparable; they are in the same order of magnitude. The value from "experiment 4" is about twice the value from "experiment 7". This confirms that the % uncertainties must be a lot higher, given that $\mu_{soft\ iron\ core}$ = constant is assumed to be true. There must be other uncontrolled variables or other uncertainties[14].

Change from the Initial Plan

There are many changes to the initial plan. The main change is the way I measure the field strength. The initial plan was to be done by sketching[15] and comparing the field lines of a permanent magnet and a solenoid with a certain setup. However in "experiment 2", this was proven to be impractical and so failed to measure the magnetic field strength accurately. From "experiment 3" onwards, a magnetic flux density unit was used instead to measure the magnetic field strength. ✓

The aim itself remains largely the same throughout the investigation which is to "investigate the different factors which could potentially affect the strength of an electromagnet". Although after I did the research to find out what the factors are and how they are related to the strength of an electromagnet, I then went on to investigate if the relationship $B = \mu\frac{NI}{L}$ holds for all conditions. And if not then which conditions does it not hold.

The way I manufactured the different solenoid with different configurations also changed from the initial ideas. Initially, I intended to manufacture the coils by winding wires around a soft iron core or a plastic air core by hand. However, this proved to be impractical as it is very time consuming to make a solenoid in which each turn of wire is equally spaced out.

C So in order to minimise the inaccuracies in the field strength generated caused by the non-uniform turns per unit length density, I decided to use a power drill. The drill acts as lathe turning the core at a constant speed. I used my hand to feed in the wire just like an automatic feed in a real lathe. ✓

This was a good practical innovation

[14] Such as the magnetic density flux unit may be a lot more inaccurate because there were many other magnetic objects around the probe at the time of use
[15] Using the method described in "Pilot Experiment 1"

Example Candidate Response – Candidate D

Candidate D does some work on exponential decay: a little lacking in depth, but showing the use of logarithmic graphs.

Aim: Motivation?

To find out whether the dampening of the ruler is exponential. ✓

Method:

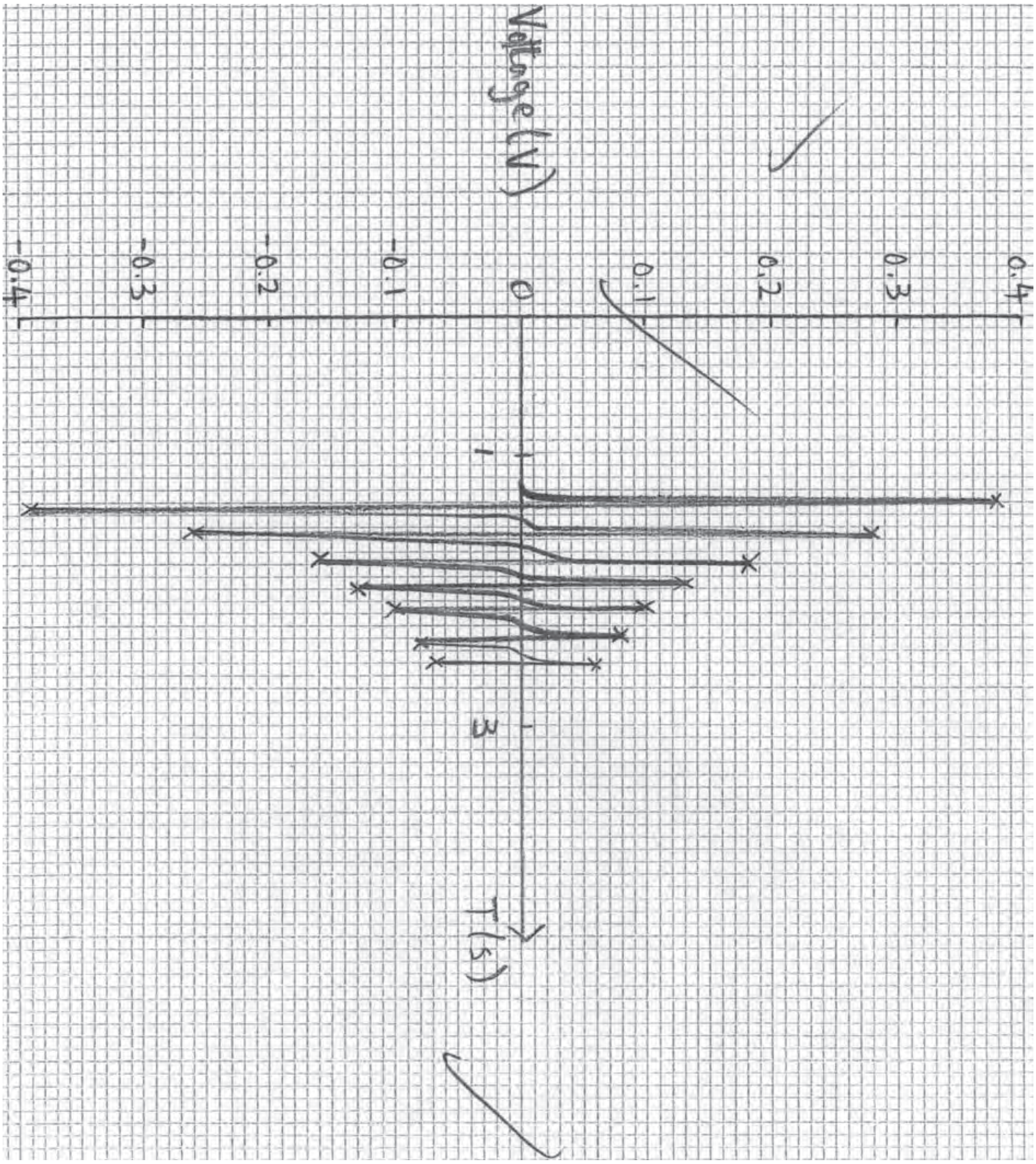
I will use one of the graph that was plotted in the computer using the voltage sensor to ~~plot~~ get the values of T and V and plot a log-linear graph to see if it is a straight line. If it is exponential, $V = V_0 e^{-kt}$ and $\ln V = \ln V_0 - kt$. If the curve of the graph lnV against t is straight line, $\ln V = \ln V_0$ it suggest that the damping of the ruler is exponential.

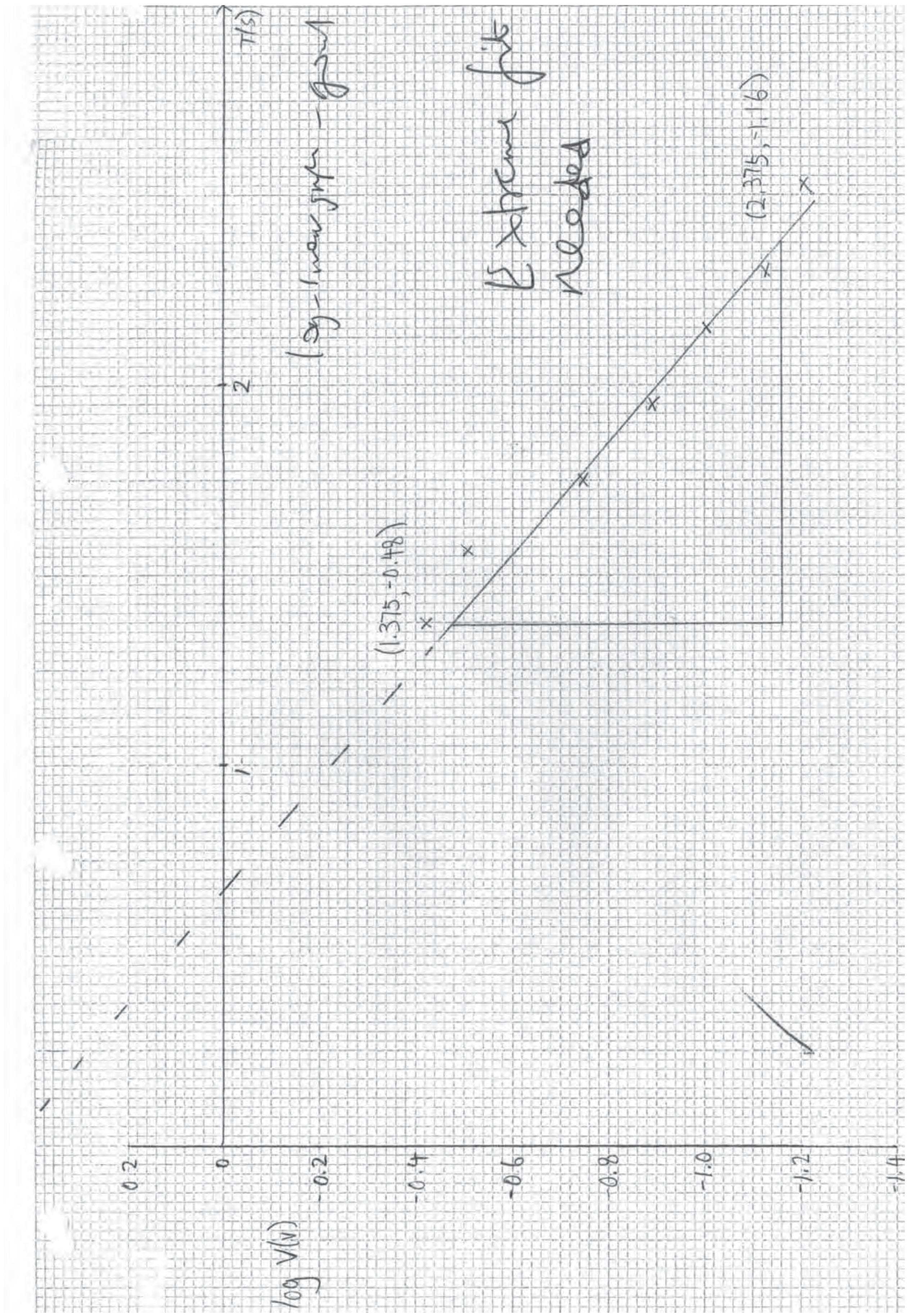
Results

✓

T(s)	V(v)
1.37	0.38
1.41	-0.39
1.57	0.28
1.60	-0.26
1.75	0.18
1.79	-0.18
1.95	0.13
1.99	-0.13
2.14	0.09
2.18	-0.09

T(s)	log V
1.37	-0.42
1.57	-0.55
1.75	-0.745
1.95	-0.89
2.14	-1.045
2.33	-1.131
2.53	-1.21


Voltage (V)
T(s)
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
1
3


log V(V)
T/s
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
1
2
(1.375, -0.48)
(2.375, -1.16)
Extreme fit needed

Analysis

The first graph I plotted is the graph of voltage against time. As the original graph is plotted in the computer and for some reason it is not possible to print it out, I drew it out. The shape of the curve looks very exponential and therefore I plotted the graph of log V againt t. As $V = V_0 e^{-kt}$,

$\log V = \log V_0 - kt$ and therefore $-k$ which is the attenuation with respect to time would be the gradient of the graph ~~the~~ and y-intercept would be $\log V_0$.

Since $V = V_0 e^{-kt}$
$\log V = \log V_0 - kt$
$y = mx + c$
$\therefore y = \log V$, $-k = m$ and $t = x$

$$\text{Gradient} = \frac{-0.48 + 1.16}{1.375 - 2.375}$$

$$= -0.68$$

$$\therefore k = 0.68 s^{-1}$$

t ? units ? s^{-1}

As the value for time and voltage is given by the computer, therefore there are at leat 2 decimal places. For time there are 0.005s error and for voltage there are 0.005V error. The errors for both factor are too small that I couldn't draw appropriate error bar according to that.

The straight line in the log graph suggests ~~that~~ the oscillation of the ruler is exponential.

It would have been nice to have quoted the eqn $V = V_0 e^{-kt}$

Example Candidate Response – Candidate D

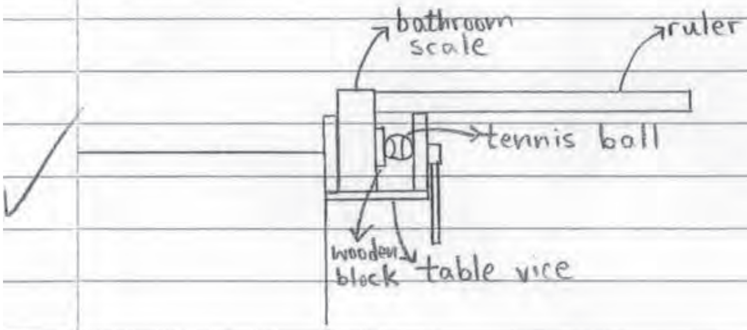
This candidate also looked at energy losses on compressing a ball.

Energy loss of a tennis ball

Aim: To find out the energy lost of a tennis ball by plotting a hysteresis graph by applying a force to compress the ball.

Apparatus: 1 × tennis ball
1 × wooden plate
1 × 150cm ruler
1 × bathroom scale (0-200N)
1 × table vice
1 × stool

Diagram:



Ingenious method.
Planning 4

Method:

- adjust the bathroom scale so that the arrow is pointing exactly to zero newton
- place the bathroom scale, wooden plate and a tennis ball in the table vice.
- place the ruler horrizontally on the vice to measure the compression

- wind the handle on the vice to increase the force
- the amount of force can be seen on the scale.
- record the change in diameter when the ball is compressed
- record the change in diameter when the ~~ball~~ force is removed gradually.
- plot a graph of extension against time for the two sets of data and work out the energy loss by findingout ~~the~~ the area between two curves.

This should be zero!

Results

Force (N)	Compression (winding) (mm) ±0.5	Compression (unwinding) (mm) ±0.5
0	65.0	58.0
25	60.0	55.0
50	57.0	52.0
75	55.0	50.0
100	52.0	47.0
125	49.0	46.0
150	46.0	45.0
175	44.0	43.0
200	42.0	42.0

This is quite poorly explained

Force(N)	Compression(winding)(mm) ±0.5	Compression(unwinding)(mm) ±0.5
0	65.0	65.0
25	61.0	59.0
50	57.0	53.0
75	54.0	49.0
100	51.0	48.0
125	48.0	46.0
150	46.0	45.0
175	44.0	42.0
200	42.0	42.0

? Not sure what this means.

Analysis

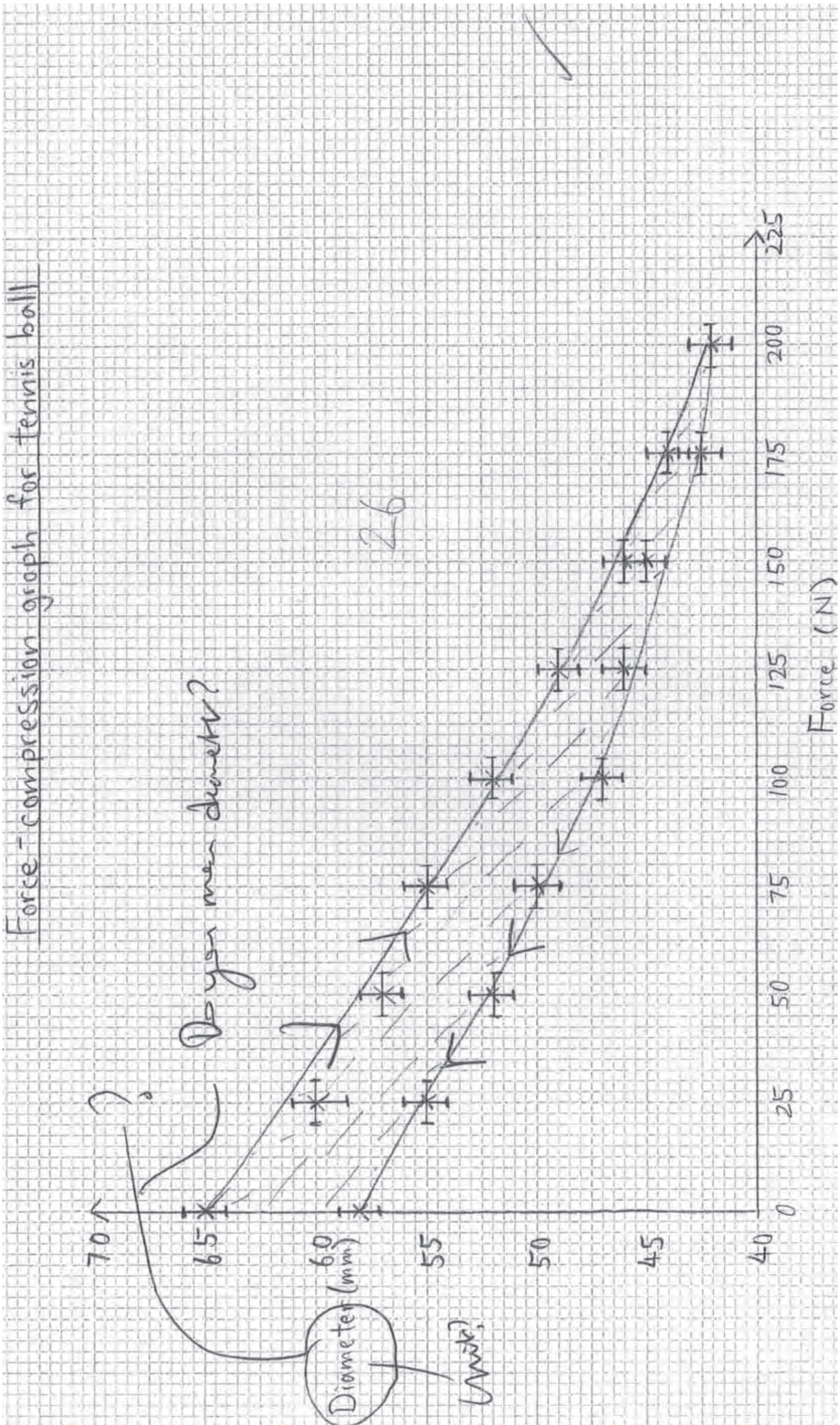
In this experiment, I have chosen to use ruler to measure the change in diameter. Ruler can give up to 0.~~5~~1cm precision. Although this may not seem precise enough, consider there is gap between the ruler and the tennis ball, 0.1cm precision is more than enough. For the force applied, I have chosen to use the bathroom scale to measure. Before I used it, I did a test to see if its accurate. I put 2 × 5kg masses onto the scale and found out the scale had shown a correct reading which is 98N.

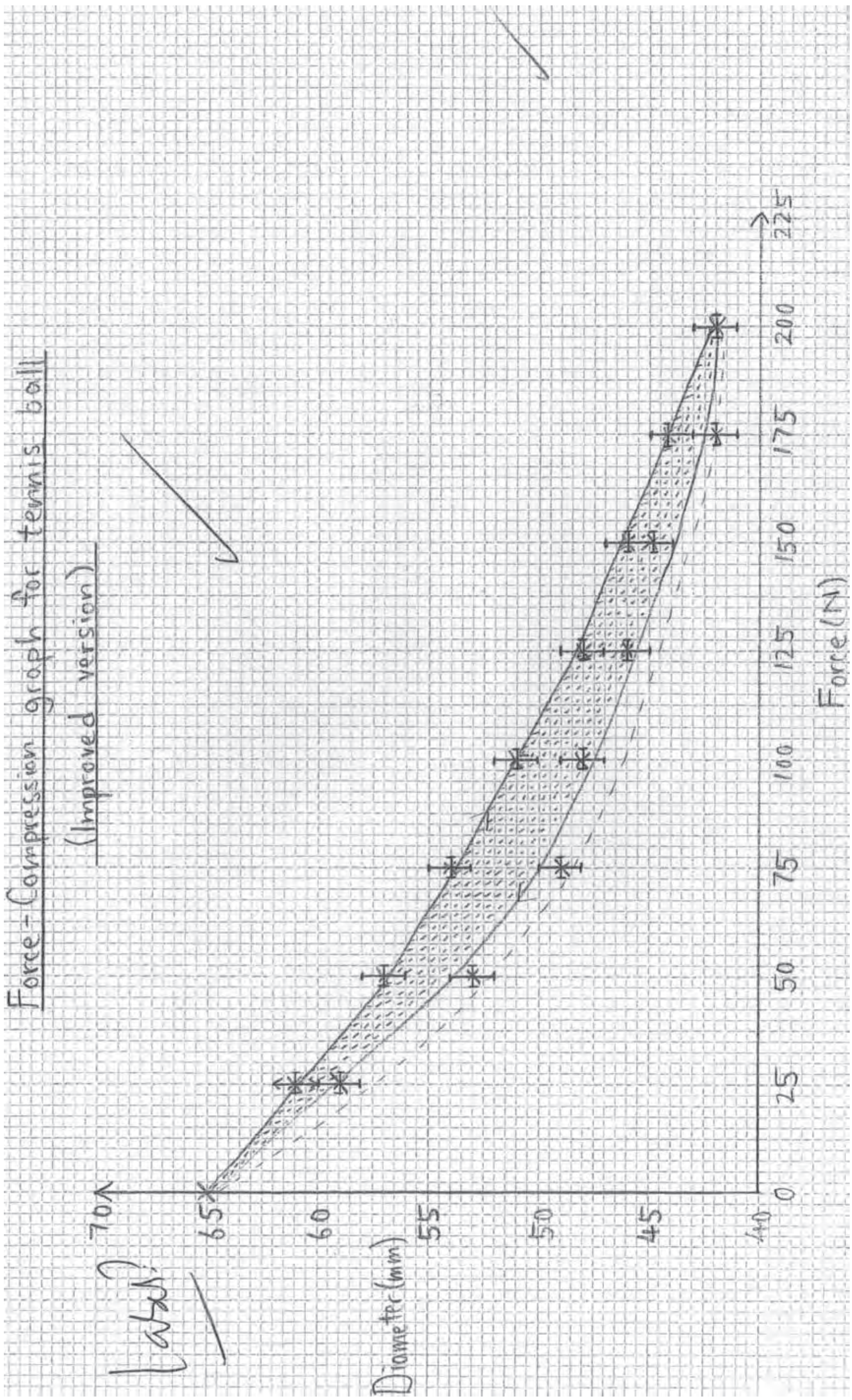
Before doing this experiment, I have planned how I set up the apparatus. However, when I started setting up, I realized my initial plan didn't work. I immediately altered my set-up and changed it the one I think its best. — What is...? Explain

I have done the experiment twice as when after the ball was compressed, the diameter of the ball should stay more or less the same as before. However, there was a 8mm difference. Also, I have added a wooden block between the ~~two~~ tennis ball in order to spread the force across the wooden block. After I have done the second time, the area between the two curves has decreased and it went back to the original diameter after compression.

Improved expt. design

In order to find out the energy lost I have to count the number of boxes


Force - compression graph for tennis ball
Do you mean diameter?
26
Diameter (mm)
(unit?)
Force (N)
70
65
60
55
50
45
40
0
25
50
75
100
125
150
175
200
225


Force-Compression graph for tennis ball
(Improved version)
Force (N)
Diameter (mm)
0
25
50
75
100
125
150
175
200
225
40
45
50
55
60
65
70

Since energy = ~~work~~ force × distance moved in the direction of force

1 box $= 2.5 \times (0.5 \times 10^{-3})$

$= \frac{1}{80}$ J

For experiment 1:

There are totally 632 boxes in the shaded area. Therefore energy lost:

$632 \times \frac{1}{80}$

$= 8$ [illegible] J

Too many sig figs

Since error bars are drawn, I can work out the largest value. There are totally 672 boxe for the largest possible value. Therefore

energy $= \cancel{6}72 \times \frac{1}{80}$

$= 8.4$ J

∴ the percentage error is $\frac{8.4 - 8.125}{8.125} \times 100$

$=$ [illegible] %
15.7

16%

'Error' analysis Ok.
Minor errors – sig. fig. appropriateness.

∴ Since the error is ±16%
the energy lost of tennis ball is
8J ± 1J

$\therefore \approx 8 \pm 1$ J

For the improved version:

There are totally 376 boxes

$\therefore$ energy $= 376 \times \frac{1}{80}$

$= 4.7\,J$

✓

For maximum and minimum value it is around 376 ± 62 boxes

$\therefore$ the percentage error : $\frac{438-376}{376} \times 100\%$

$4.7 \pm 0.8\,J$

$= 16.5\%$

$\therefore$ energy $= 4.7 \pm 0.8\,J$

As I have already found out the value of energy lost for both tennis ball and tennis string, I will be testing the energy lost of the ball bounce on the tennis racquet by using the drop and bounce method. Also, I can find out where the sweet spot is on the racquet face.

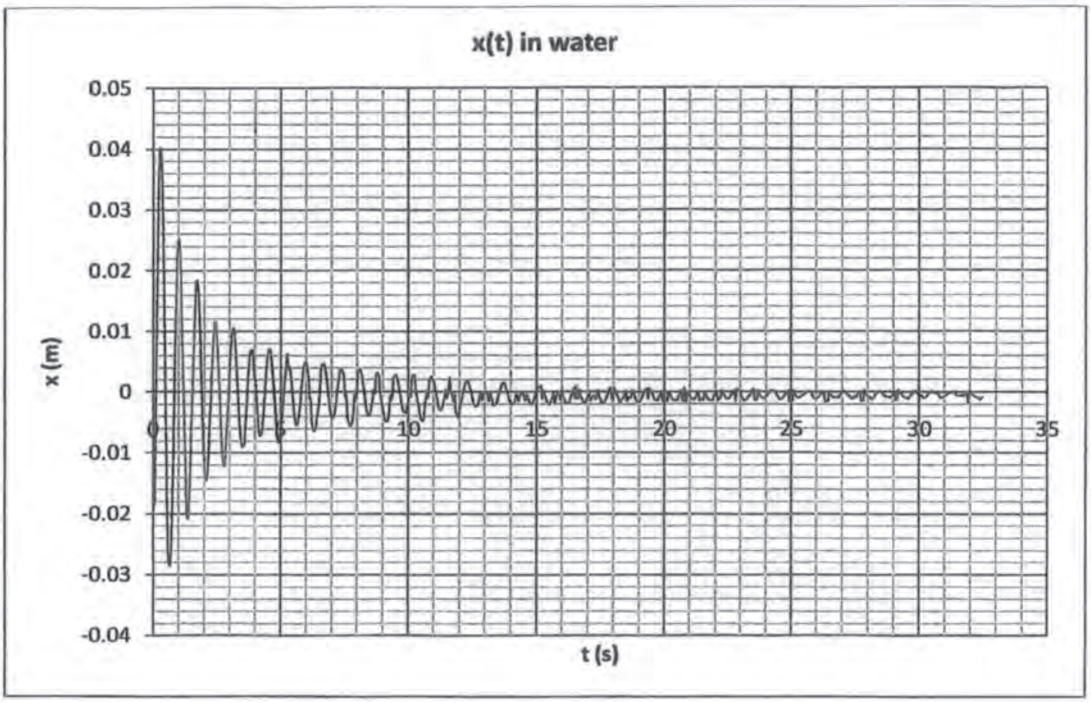
✓

Example Candidate Response – Candidate C

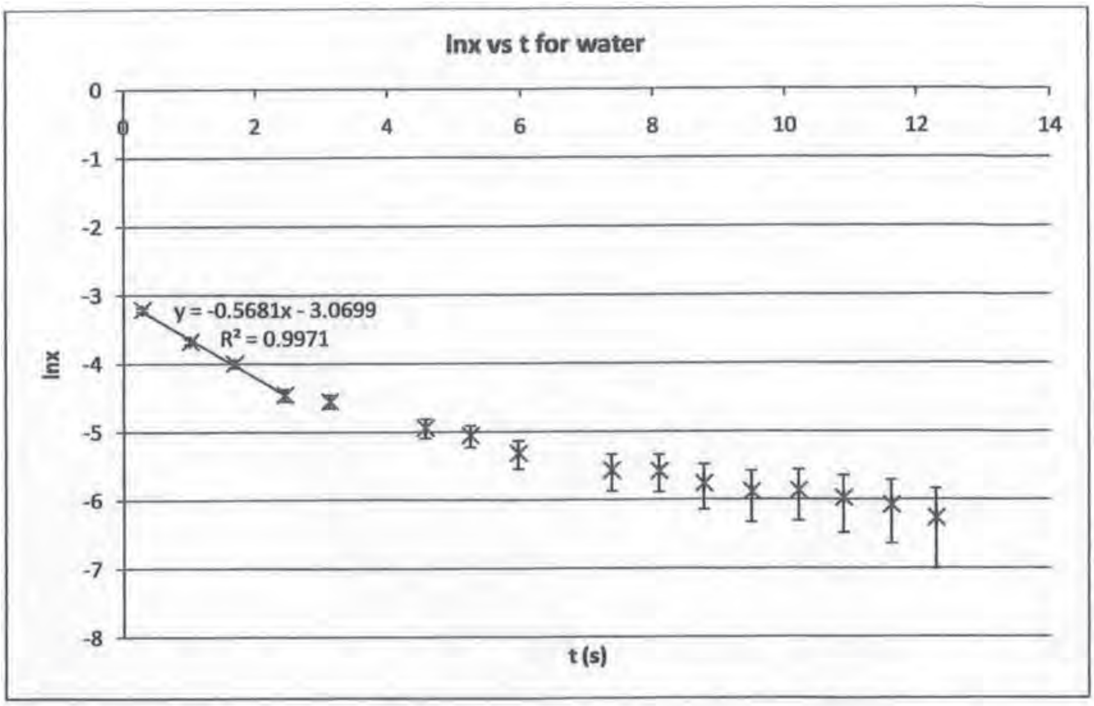
Good error bars (although not subsequently used) and a logarithmic graph.

The Natural Frequency and Damping in Water

- As before when I studied damping, I need to experimentally measure the damping due to the water
- To this I allow the system to oscillate naturally in the water and measure displacement against time
- The following graph shows an example of this:



- I can quickly see that damping is far greater in water
- Also I can see that natural oscillations become effectively negligible after about 15 seconds, therefore this is how long I must wait before taking any results when including a forcing frequency
- To calculate b I need to extract the values for maximum displacement, and then plot the natural log of this against time
- Below is an example of this:



- Errors in lnx are calculated by assuming the sensor is accurate to $\pm 1mm$, using excel to calculate the maximum and minimum ln(x) this would give for each separate data point, then use this as the value for max and min error bars
- Error in t assumed to be 0.01s (i.e. effectively negligible)

Measuring a gradient?

- This line is clearly not straight – this is not unexpected, as above I showed the model was not completely valid for air
- However, the previous graph shows that about only the first 4 oscillations have an amplitude greater than about 0.01m, and since I am unlikely to be working at amplitudes less than this, I will use the first four data points to plot my line and find the gradient

good

My value for the gradient:

- Using excel to measure the gradient of this graph (ignoring minus sign), and using the gradients of the maximum and minimum lines allowed by my error bars, I calculated a value of the gradient as 0.57 ± 0.05
- Repeating for twice more, and finding the mean of the results, my value for the gradient is 0.565 ± 0.03
- I calculated the reduction in error by saying that, if I take n results and then average these, the reduction in error is by a factor $\frac{1}{\sqrt{n}}$

My value for b:

- By multiplying the gradient by $2m$ (as before during experiments on damping), where $m = 250.2g$, I get a value of $b = 0.285Nm^{-1}s \pm 0.015Nm^{-1}s$
- The error was calculated by scaling the previous error 0.03 by factor $2m$
- I ignored the error in mass as this was negligible compared

Communication

Mark Scheme

Communication	
A report is produced but there are omissions in the account and a poor structure so that the report is not straightforward to follow. References are included but these do not make the source clear (for example, page numbers are missing).	0
A report is produced. There is some attempt at organisation and layout so that the report provides a clear outline of the course of the project. Some of the aims and conclusions are stated fairly clearly for some of the practical work. References are included but these do not make the source clear (for example, page numbers are usually missing).	2
The report summarises most of the main findings clearly. It is easy to read and follow. Sub-headings are used. Spelling and grammar are largely correct. Technical terms are usually used correctly but there are occasional errors. Aims and conclusions are generally stated clearly. References identify sources clearly (for example by providing page numbers).	4
The report is well organised with a clear structure which details all the main findings clearly. Material is presented in a logical order and is easy to read and follow. Aims and conclusions are stated clearly for each practical and for any mathematical analysis. Ideas are linked together and clearly show development and feedback between experiment and analysis. There is a clear account of any changes from the original plan. Spelling and grammar are correct. Technical terms are used correctly and there is a glossary of all new technical words encountered and used in the project. There are references to books, journals and websites clearly showing the source of the information.	6
Maximum mark 6	

General Comment

The Examiner is looking for a well organised, logical report, showing ideas linked together with development and feedback. Technical terms, spelling and grammar should be correct with a glossary of new technical terms and clear references.

The complete report must be used to judge these areas. Two example extracts, from candidates D and C, are given of the final pages of the scripts.

Example Candidate Response – Candidate D

Candidate D gives a clear glossary and references with details of page numbers etc.

Glossary

Sweet Spot

G or 1

Oscillation of the racket after collision with the tennis ball on the sweet spot is minimum and it is also the node on the standing wave.

Standing Wave

It is extended oscillation that stores energy and is formed when waves of the same amplitude and frequency moving in opposite direction superpose.

Coefficient of Restitution

It is the ratio of velocities after and before the impact

Simple Harmonic Motion (SHM)

SHM is a kind of oscillation which is isochronous (ie. Time period independent of amplitude) and the force is always directed towards the centre of oscillation.

Exponential

When a constant change in the independent variable gives the same proportional change in the dependent variable

Magnetic flux

It is equal to the average component of magnetic field at 90° to area A X Area A.
Φ (flux)=AxB

Electromagnetic Induction

Electromagnetic induction is the production of voltage across a conductor situated in a changing magnetic field or a conductor moving through a stationary magnetic field.

Centre of Percussion

It is also known as centre of oscillation. It is the place on a racket where it may be struck without causing reaction or vibration. When a ball is hit at this spot, the contact feels good and the ball seems to spring away with its greatest speed and therefore this is often referred to as the sweet spot.

Bibliography

- The physics of Sports, by Angelo Armenti,Jr, published by Springer- Verlag 1992, p.139-166 ✓
- Introduction to Racket Science, http://www.racquetresearch.com/sevencri.htm
- Advanced Physics, by Steve Adams and Jonathan Allday, published by Oxford University Press 2000, p.112,264-268,452 ✓
- Salters Horners Advanced Physics for Edexcel A2 Physics, Pearson Edexcel, London 2009, p.397-407 ✓

Page numbers, etc

✓ G o.1

Example Candidate Response – Candidate C

Glossary, references and a final conclusion with thoughts for further work.

Overall Conclusion

Damping:

In general, I looked at damping that was the result of the oscillator moving through a fluid, i.e. I studied air, water, golden syrup

When there is no critical damping

- The motion produced appears sinusoidal, with a damping 'envelope', which reduces the amplitude (but has no effect on time period)
- Modelling damping as $\propto v$ s is a fairly good assumption
- However it breaks down though for small amplitudes, and when there is a large damping force, and in general
    - At large amplitudes it is too small
    - At small amplitudes it is too large
- Modelling damping as $\propto v^2$ is a better assumption
- This is mathematically much tougher to solve
- This is still not perfect
    - At large amplitudes it is too large
    - At small amplitudes it is too small
- In either case there was strong evidence to suggest the amount of damping was $\propto$ area of the damper, and I extracted a value that would allow me to predict the amount of damping for dampers of other areas
- Overall I came to the conclusion that damping is best modelled as $\propto \alpha v + \beta v^2$, i.e. a combination of the two

good

When there is critical damping

- This produces a motion that is not an extreme version, but rather a fundamentally different version of damping
- There are no oscillations, rather the amplitude simply approaches zero
- Modelling damping as $\propto v$ appears in this case a good assumption

Forced Oscillations and Resonance:

I studied the effect of a rod (driven by a motor), moving vertically with a sinusoidal $x(t)$, on the displacement of a mass spring oscillator, placed in water to increase damping

The Resonance Experiment

- When I plotted $x_{max}(\omega)$, I found a very clear curve, with very small errors, which showed the following important effects:
    - The $\lim_{\omega \to \infty} x_{max} = 0$ (or so it appeared)
    - $\lim_{\omega \to 0} x_{max}$ = amplitude of the forcing term (again it only appeared so)
    - There was a definite peak, where maximum resonance occurred

  and I made attempts earlier to explain these
- Using my model of damping $\propto v$, I attempted to mathematically derive a relationship for $x(t)$ for a forced oscillation described by my oscillator, and ultimately for $x_{max}(\omega)$

- The theory produced a graph of similar form to the experimental values, however it differed significantly quantitatively and the assumption broke down in the limiting cases of $\omega \to 0$, $\omega \to \infty$

Direction of Further Research

Damping:

- Consider the damper as an object moving through a fluid, in order to predict the damping force rather than obtaining it from experiment
- Starting initially with a spherical damper, predict the damping force using Stoke's Law
- Extend to more complex shapes, using numerical solutions to the Navier-Stoke equations to estimate damping

Forced Oscillations and Resonance:

- Come up with a theory that takes into account tension in the rod *or*
- Devise an experiment where there is *only* a sinusoidal forcing term and no tension, and see how closely this matches up to the theory
- Experiment with non-sinusoidal forcing terms
- See how parameters like k, b, affect the height and value for ω where the peak occurs

Glossary

Sinusoidal	A curve, motion, graph which has the form of a sine wave
R^2 value	A measure of how well correlated a set of data is to a straight line - $R^2 = 1$ implies perfect correlation - $R^2 = 0$ implies no correlation
Limit of proportionality	If there is too much force on a spring, Hooke's Law no longer applies – this is the point at which this breakdown occurs
Imaginary	The solution contains a component multiplied by i, i.e. $\sqrt{-1}$
$\dot{x}$	Shorthand for $\frac{dx}{dt}$, i.e. the rate of change of displacement which is velocity
$\ddot{x}$	Shorthand for $\frac{d^2x}{dt^2}$, i.e. the acceleration
Kinetic friction	A constant frictional force due to surface interactions between two objects moving past each other while rubbing against each other
Beating	A phenomenon caused when two oscillating quantities with different frequencies are superposed. The amplitude of the combination oscillates with a continually changing amplitude, and this is calling 'beating'.
$O(h), O(h^5)$	The 'O' is shorthand for 'order' – this means (e.g. in the first case) that the error is reduced by order h, i.e. decreasing step size by factor 10 decreases error by factor 10

References

Differential Equations for Engineers and Applied Scientists *by* W D Morris – information on the Runge Kutta Method

http://en.wikipedia.org/wiki/Q_factor – Wikipedia article giving information on the 'Q factor'

http://www.thestudentroom.co.uk/showthread.php?t=674554 – a thread on the Student Room website which discussing the density of golden syrup, on which someone stated this value, (I corroborated this elsewhere)

http://www.simetric.co.uk/si_water.htm - accurate value for density of water

Example Candidate Response – Candidate F

The final example is a complete Pass grade script for comparison purposes. The original mark was 10, perhaps closer to 9 (with only 1 mark awarded for Practical Techniques). The comments made by the teacher are all valid and where the script could be improved is self evident. There is a very clear indication of what marks are awarded; some page references would have helped the moderating Examiner further.

10 Agreed

Cambridge Pre-U Syllabus

Criteria for Component 4 Personal Project	Marks
Initial Planning	
The plan contains a title, a statement of the aim and an outline of initial experiment(s). There is little or no elaboration.	0
The plan contains a clear title and aim, with at least one research question. There is an outline of initial experiment(s) with some background physics that helps to interpret or develop the practical scenario. There is a sensible risk assessment (where relevant). At least one pilot experiment has been performed. Largely appropriate apparatus has been requested. There is a brief summary of how the investigation might develop.	2
The plan contains a clear title, aim and a number of clearly worded research questions. There is an outline of initial experiment(s) in a sensible sequence with substantial background physics that helps to interpret or develop the practical scenario. Some of the background physics has been researched and is novel to the candidate. There is a sensible risk assessment and written guidelines for maintaining safety (where relevant). Pilot experiment(s) are used to help develop the plan, for example in improving accuracy or precision or in checking a prediction. The plan contains experimental details and describes what will be measured and controlled, and uses clear diagrams. The apparatus chosen is suitable for every task. Some ingenuity has been shown, for example apparatus has been modified or new apparatus devised. There is a summary of how the practical work might develop, related to the research questions.	4
Maximum mark 4	0

no evidence submitted.

Organisation during the two weeks of practical work	
The work is written up only once a week or when the candidate is prompted. Notes of practical methods lack detail, records are generally incomplete, and the record of the work is poorly organised and difficult to follow. There is little evidence that the results of each experiment have been analysed and interpreted before work on the next experiment begins.	0
The work is written up more than once a week. Records are largely complete so that it is possible to follow what was done each day. There is evidence that some analysis and interpretation of each experiment has taken place before work on the next experiment begins, but there is little evidence of further research to help interpret the results.	1
The work is written up at least every two days. Practical methods are described clearly. Records are clear, well-organised and complete, making clear what work was completed each day and how the ideas evolved. The analysis of each experiment is completed (e.g. graphs are plotted and the mathematical relationships and uncertainties discussed) and results are interpreted (with the help of further research where necessary) before work on the next experiment begins. Where appropriate, the plans for later experiments are adapted in response to the results of earlier experiments.	2
Maximum mark 2	1

Quality of Physics	
The physics used is mainly descriptive. Most of it is copied and is of limited relevance to the research topic. Some calculations are performed successfully but there are also many errors and the misuse of units is common.	0
There is some use of Physics but there are omissions in its application to the interpretation of results. Some of it is copied and the references given, but it is put together with little coherence or direct reference to the research topic. Some calculations are performed successfully but there are some errors.	2
In most cases where it is appropriate, physics principles have been used to interpret results, perform calculations or make predictions. The physics is usually explained, draws on the content of the taught course, and is related to the project. Understanding is demonstrated and the physics has not just been copied verbatim from a text or website. There are some errors in calculations and in explanations.	4
Wherever appropriate, physics principles have been used to interpret results, perform calculations or make predictions. The physics is explained and goes beyond the requirements of the taught course. It includes some relevant quantitative arguments and is related to the project. Sound understanding is demonstrated and the physics has not just been copied verbatim from a text or website. There are no errors in calculations or in explanations.	6
Maximum mark 6	2

Use of Measuring Instruments	
At least one experiment* is completed. There are some errors in using the apparatus, which make some of the readings unreliable. Some assistance in setting up or manipulating apparatus has been required.	0
At least one experiment* is completed where two measuring instruments are used to obtain results. Standard instruments are used effectively. In all experiments, apparatus has been set up and manipulated without assistance.	1
At least two experiments* are completed where at least two measuring instruments are used, at least one of which was zeroed or calibrated correctly to obtain accurate results. Standard instruments are used effectively. In all experiments, apparatus has been set up and manipulated without assistance.	2
More than two experiments* are performed with a range of different instruments, some of which require checking of zero, calibration or selection of different ranges. Some of the apparatus is either of a sophisticated nature (signal generator, cathode ray oscilloscope, two place digital balance, data logger, micrometer) or involves a creative or ingenious technique in its use. In all experiments, apparatus has been set up and manipulated without assistance.	3
Maximum mark 3	2

* For the purposes of these criteria, an experiment involves changing an independent variable in order to observe or measure the effect on a dependent variable. Two experiments may be considered to be different if one or both of the variables are different.

Practical Techniques	
The number and range of measurements taken in some, but not all, experiments is adequate. There is no attention paid to anomalous measurements. There is some awareness of the need to consider precision and sensitivity, and some measurements are repeated. ✓	0
The number and range of measurements taken in most experiments is adequate. Some measurements are identified as anomalous but there is little attention paid to them. There is some awareness of the need to consider precision and sensitivity, and measurements are usually repeated where appropriate. ✓	1
The number and range of measurements taken in each experiment is adequate, with additional measurements taken close to any turning points. ✗ Anomalous measurements are correctly identified but in most cases they are not investigated further. There is awareness of the need to consider precision and sensitivity, ✗ and experiments are designed to maximise precision. Measurements are repeated where appropriate. ✓ Quite a lot of data, many repeats but discarded not averaged	2
The number and range of measurements taken in each experiment is adequate, with additional measurements taken close to any turning points. Anomalous measurements are correctly identified and are investigated further. There is awareness of the need to consider precision and sensitivity, and experiments are designed to maximise precision. Measurements are repeated where appropriate. Where it is appropriate, more than one measuring technique is used to help corroborate readings or inventive methods are used to help improve or check readings.	3
Maximum mark 3	2

Data Processing	
Most data is tabulated correctly ✗ and graphs are mostly plotted correctly, with only a few minor errors. However, calculations contain some major errors and conclusions are not well supported by the results.	0
Data is tabulated correctly ✗ and graphs are plotted correctly. ✗ Calculations contain some errors but these are not major. Some conclusions are not well supported by the results.	1 2
Data is tabulated correctly and graphs are plotted correctly. Calculations are correctly completed and linear relationships are successfully analysed. Error bars are shown, ✗ although not on all graphs and not always correctly, and there is some treatment of uncertainties. Conclusions are well supported by the results.	4
Data is tabulated correctly and graphs are plotted correctly. Calculations are correctly completed and relationships are successfully analysed. Some of the work is sophisticated and requires for example the plotting of logarithmic graphs to test for power laws or exponential trends. Error bars are shown wherever appropriate, and uncertainties are routinely calculated for derived quantities. Conclusions are well supported by the results.	6
Maximum mark 6	1

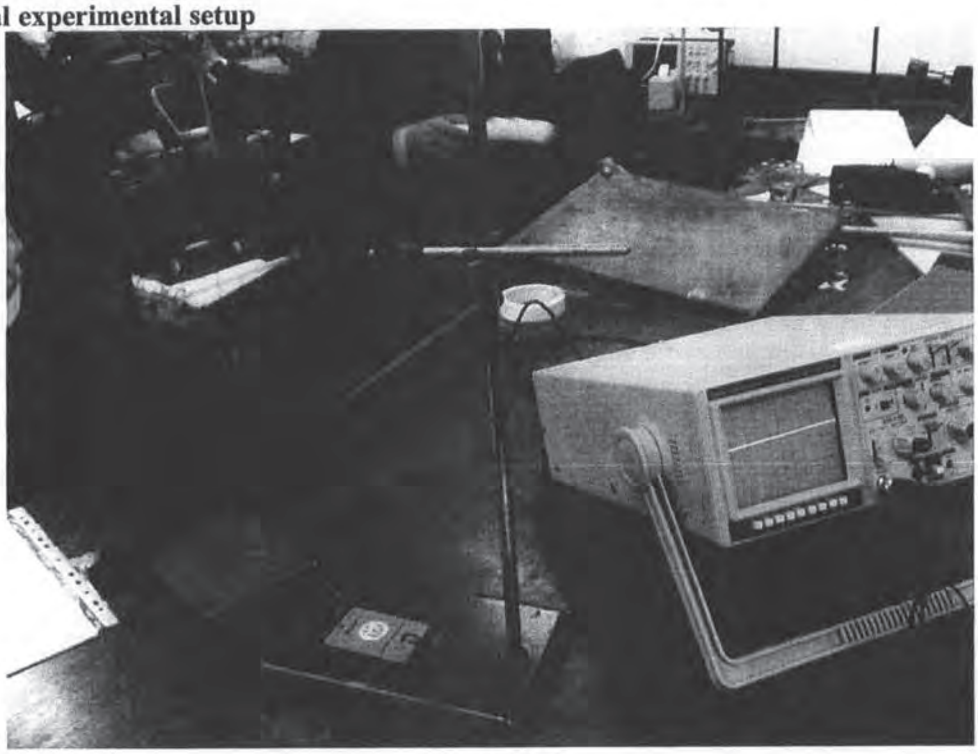
1

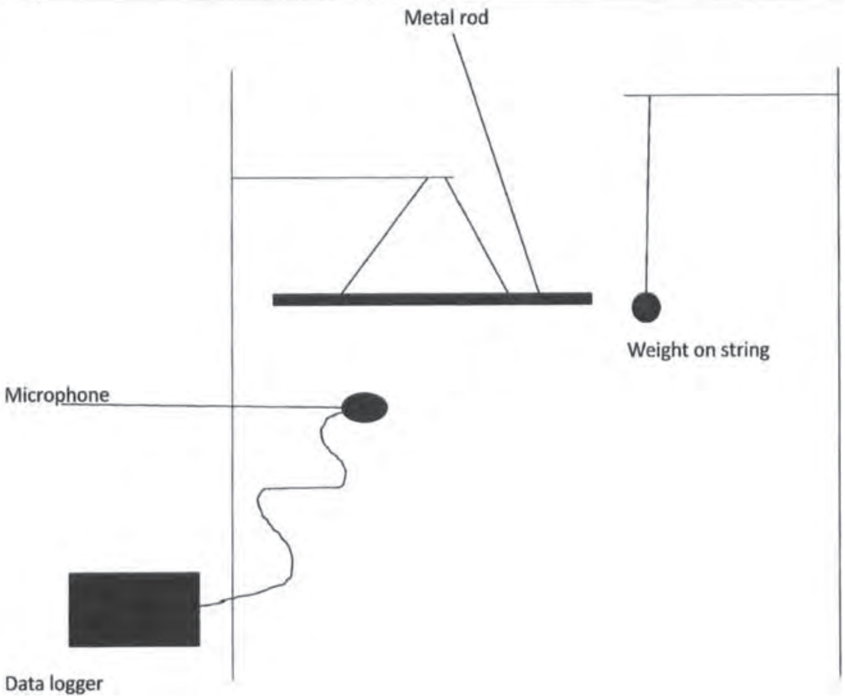
Communication	
A report is produced but there are omissions in the account and a poor structure so that the report is not straightforward to follow. References are included but these do not make the source clear (for example, page numbers are missing).	0
A report is produced. There is some attempt at organisation and layout so that the report provides a clear outline of the course of the project. Some of the aims and conclusions are stated fairly clearly for some of the practical work. References are included but these do not make the source clear (for example, page numbers are usually missing).	2
The report summarises most of the main findings clearly. It is easy to read and follow. Sub-headings are used. Spelling and grammar are largely correct. Technical terms are usually used correctly but there are occasional errors. Aims and conclusions are generally stated clearly. References identify sources clearly (for example by providing page numbers).	4
The report is well organised with a clear structure which details all the main findings clearly. Material is presented in a logical order and is easy to read and follow. Aims and conclusions are stated clearly for each practical and for any mathematical analysis. Ideas are linked together and clearly show development and feedback between experiment and analysis. There is a clear account of any changes from the original plan. Spelling and grammar are correct. Technical terms are used correctly and there is a glossary of all new technical words encountered and used in the project. There are references to books, journals and websites clearly showing the source of the information.	6
Maximum mark 6	2

How do the acoustic properties of a rod depend upon its physical properties?

Aim: To investigate the effect of changing the dimensions and physical properties of metal rods on the sound given off when hit by a constant force.

Initial experimental setup





✓ fair

evidence?

sophisticated equipment.

Pilot Experiments and changes from initial plan

My first experiment was to set up a storage oscilloscope to record the sound made by a steel rod, to record the sound given off in a manner that could be quantified. I had heard by hitting the rod in various places before using the oscilloscope that the pitch which rang for longest varied when the rod was hit on the flat end as opposed to along the length. ✓
Unfortunately, the complexity of the sound waves produced made it difficult to show how the sound varied with where the rod was struck, from the data available on the oscilloscope, so I instead used a laptop and an audio editing program (Audacity 1.3) to record the sounds produced in later experiments. ✓

I also tried to find how the various properties of a material effect its acoustic properties. Since in rods of similar dimensions, the only factor which could affect frequency would be the speed of sound due to the equation $v=f \times \lambda$, λ is fixed by the length of the rod, so whatever underlies the difference in speeds, the factor which should ultimately decide the difference should be the different speeds of sound in the materials.
Finding the frequency spectra of materials other than metals proved impossible, since wood and plastic rods did not resonate sufficiently long to form a frequency spectrum after noise had subsided.

Instead of changing the environment of the rods, it proved easier to change the shape of the rods and use copper tubing to see if the change in shape would effect the shape of frequency spectra. ✓

Experiment 1 – Comparing the major frequencies produced by hitting an aluminium rod along its length and on its end

Experiment setup – as shown in previous diagram but microphone is connected to laptop

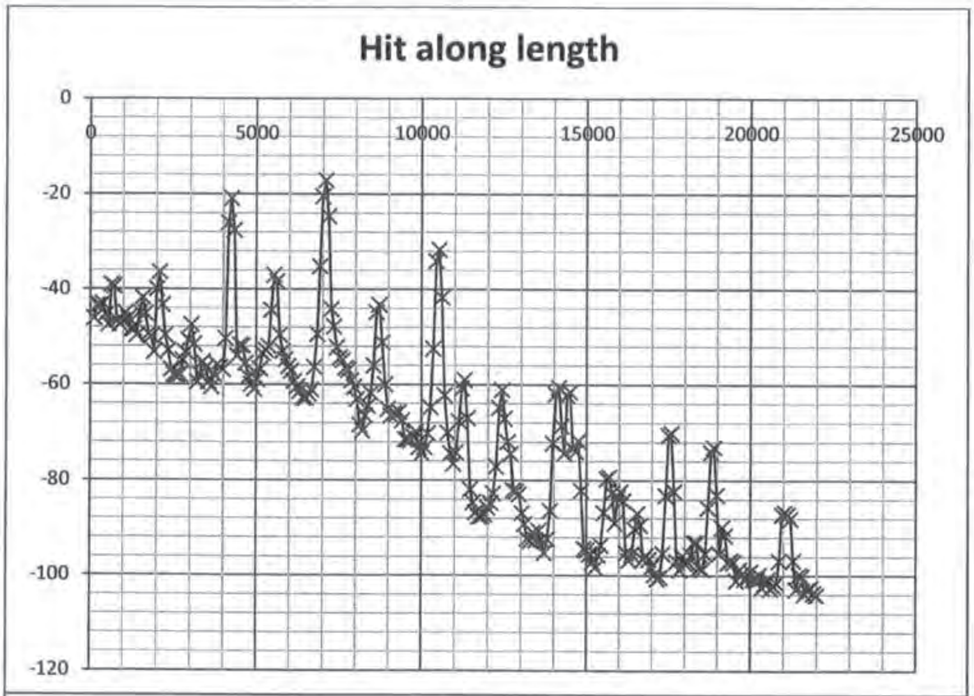
(Microphone mounted on foam to dampen noise)

Using audacity, I found the Fourier transforms of the sounds produced (cutting off the first moments to cut out the noise of the collision when non-resonant frequencies are present) when the weight was dropped from the same height as directly as possible onto the rod, to ✓ good.

Not necessarily – depends on stopping time.

produce the same force, so that the results of the repeats could be averaged, and the results of the two experiments compared. The results of the two experiments are below.

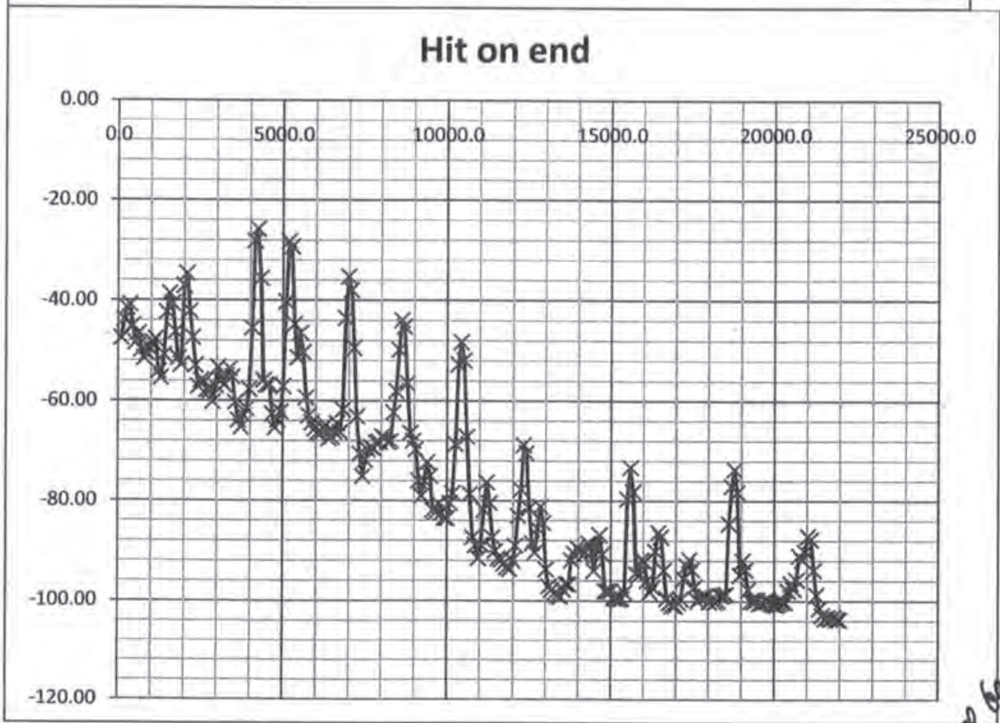
y-axis ?
scale ?
dB ?



x-axis ?
f/Hz ?

poor graphs.

ditto



Might have been better on a single graph offset for comparison

Stronger higher frequencies are produced by vibrations caused by hitting the rod on the end than along its length, the highest frequency peak when hit in the end being 0.3 times the height of its highest peak, compared to 0.2 when hit along the length, (-25 and -85 dB on the end, -87 and -17 dB when hit in the centre) fair
Lower frequencies are also slightly stronger when the rod is hit along its length. A slight error may be caused by the fact that it is easier to create a more inelastic collision, where a greater proportion of energy is transferred from the weight to the metal rod, when hitting along the length of the rod, however, the overall trend is clear, and use of repeats and attempts to minimise this effect mean that the trend remains valid.

Sensible physical mechanism explained

There are two main types of wave possible in a solid – longitudinal (compression) waves and transverse (shear) waves. Longitudinal waves travel faster, and occur in the same direction as energy transfer, whereas transverse waves are slower, and are perpendicular to the direction of energy transfer. Since longitudinal waves are faster, you would expect them to have a higher frequency, and hitting the rod on the end, which is more favourable to this type of wave produces higher frequencies at greater volumes than hitting the rod along its length, which would seem to be more conducive to transverse waves, and produces more lower frequencies relative to higher frequencies. ✓ ok

Experiment 2 – Comparing frequencies produced by materials with different physical properties
The exact compositions of the rods I used was not known, and so I tried several methods to pin down the speeds of sound in the respective materials, firstly by finding the density of the steel rod I used to better compare it to data books, and also by using two transducers which could be connected to the aluminium rod used, which converted kinetic energy transferred to them to an electrical signal picked up by a storage oscilloscope, the difference in timing between the two signals giving the time taken to travel the length of the rod.

Set up to measure speed of sound in aluminium

The value I found for the speed of sound in aluminium was around 6100 m/s, though repeats varied wildly, though it close to the value given by a data book (Kaye and Laby). evidence?

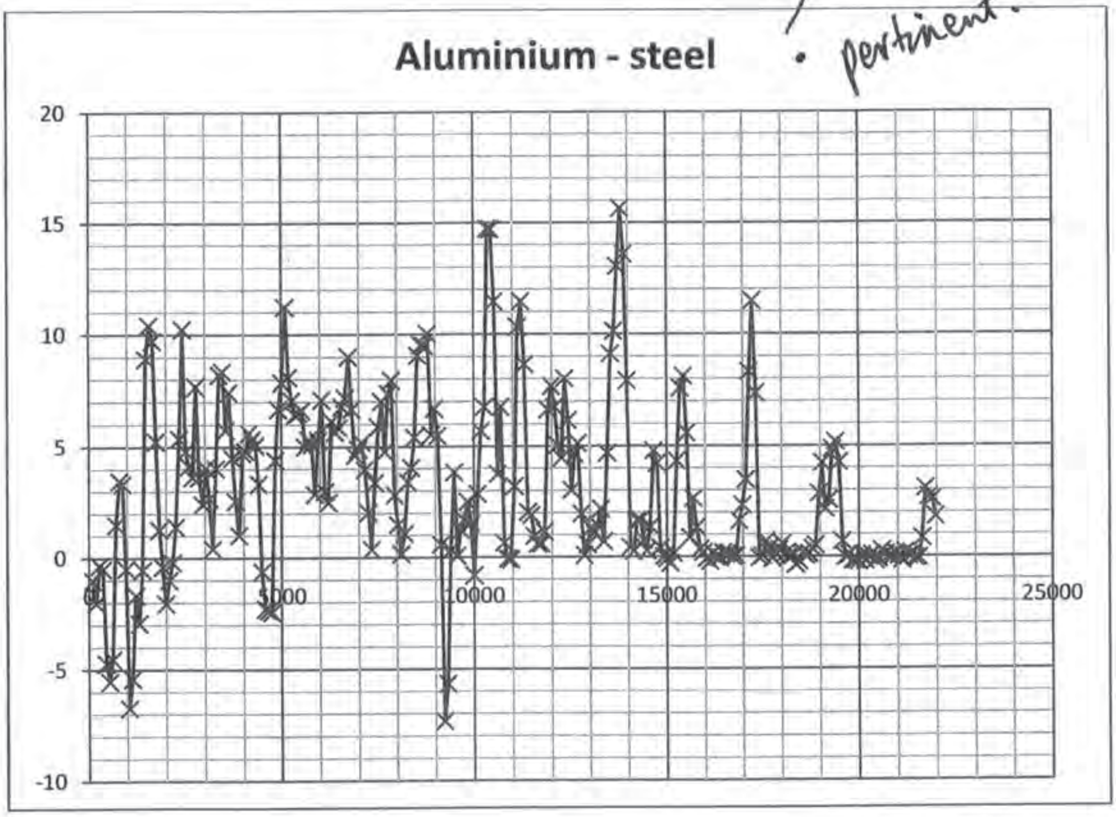
experimental data?
uncertainties?

Unfortunately, the density of the steel could not be narrowed down to differentiate between different types of steel, but since the values of the more common steels differed by only 20 m/s, I decided to use the values given by Kaye and Laby in both cases, as the differences in slightly different alloys of the same metal are negligible compared to the 400 m/s difference between steel and aluminium. ✓ true. ✓ ok.

To compare the two sets of results, I subtracted the average values of steel from aluminium. Larger negative values in the Fourier transform are lower sound levels at a given frequency, so a positive value in the graph shows that aluminium is stronger at a particular frequency and vice versa.

Aluminium: speed of sound – 6374 m/s
Steel: speed of sound – 5960 m/s

? pertinent?



I cannot understand the significance of this plot.

? Steel gives greater values for some lower frequencies, however the graph is positive at most high frequency peaks, showing that the speed of sound in a solid is a major factor in the frequencies it gives off when struck.

The speed of sound in a medium is given by $c = \sqrt{\frac{C}{\rho}}$, where C is the elastic modulus[1] and ρ is density; in two rods of similar dimensions, it may be possible to find the relationship between these two values, working back from their fundamental frequencies. ✓ seems realistic

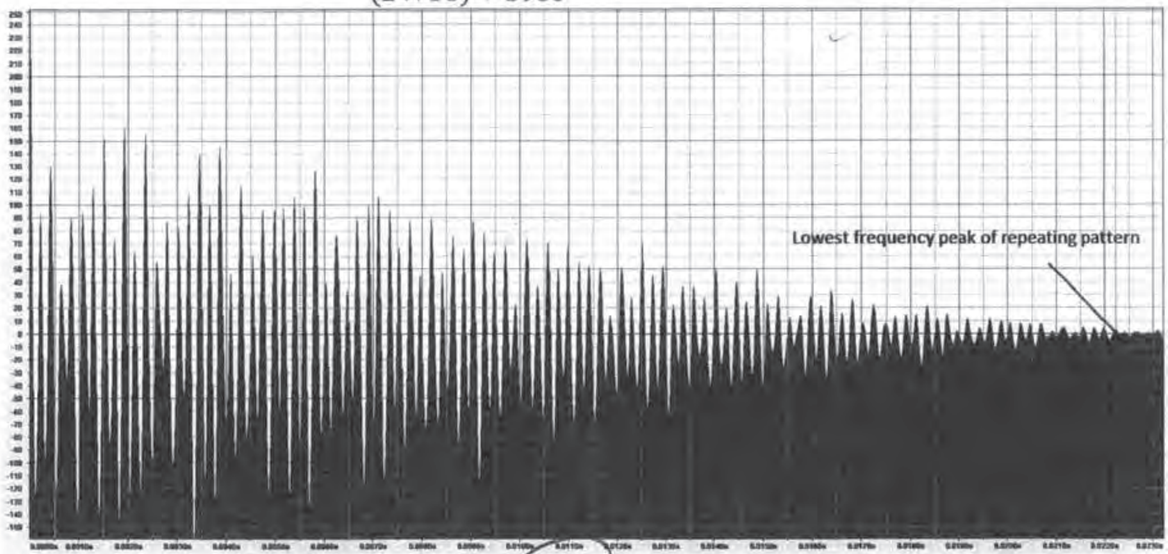
[1] in the case of longitudinal waves, the value which is relevant is the Young modulus

defined?

Autocorrelation of sounds produced by the two rods gives the lowest frequency peak of the steel to be 45 Hz, only 8 from a predicted 53 Hz assuming the speed of sound in the steel is exactly 5960 m/s,

$$\frac{1}{(2 \times length) \div speed\ of\ sound} = lowest\ fundamental\ frequency$$

$$\frac{1}{(2 \times 56) \div 5960} = 53\ Hz$$



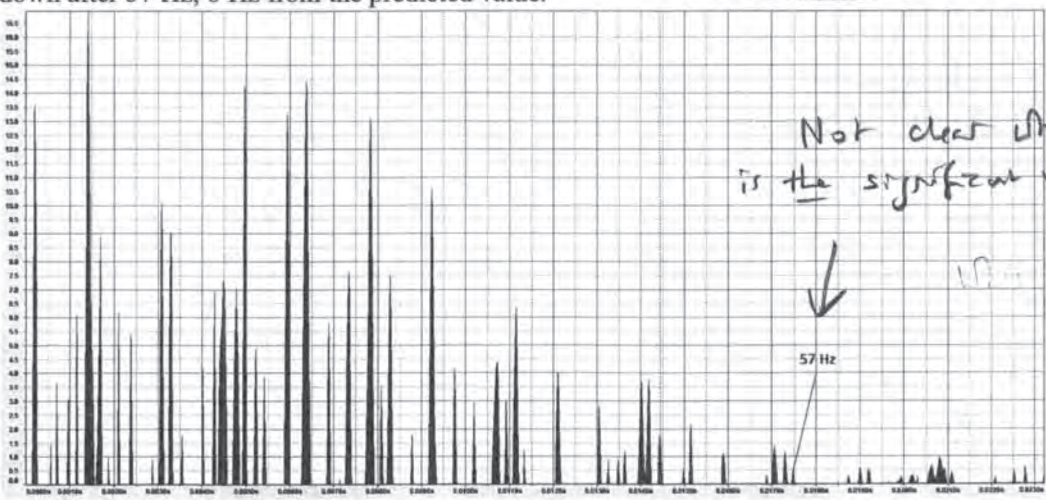
Autocorrelation of steel soundwave

For steel:

$$\frac{1}{(2 \times 50) \div 6374} = 63.74\ Hz$$

'Pattern' needs clarifying here.

It is less clear in the standard autocorrelation of the aluminium's soundwaves, so using enhanced autocorrelation which picks out peaks in the wave, the repeating pattern breaks down after 57 Hz, 6 Hz from the predicted value.



Not clear why this is the significant value.

Axes unlabelled + unreadable.

Aluminium?

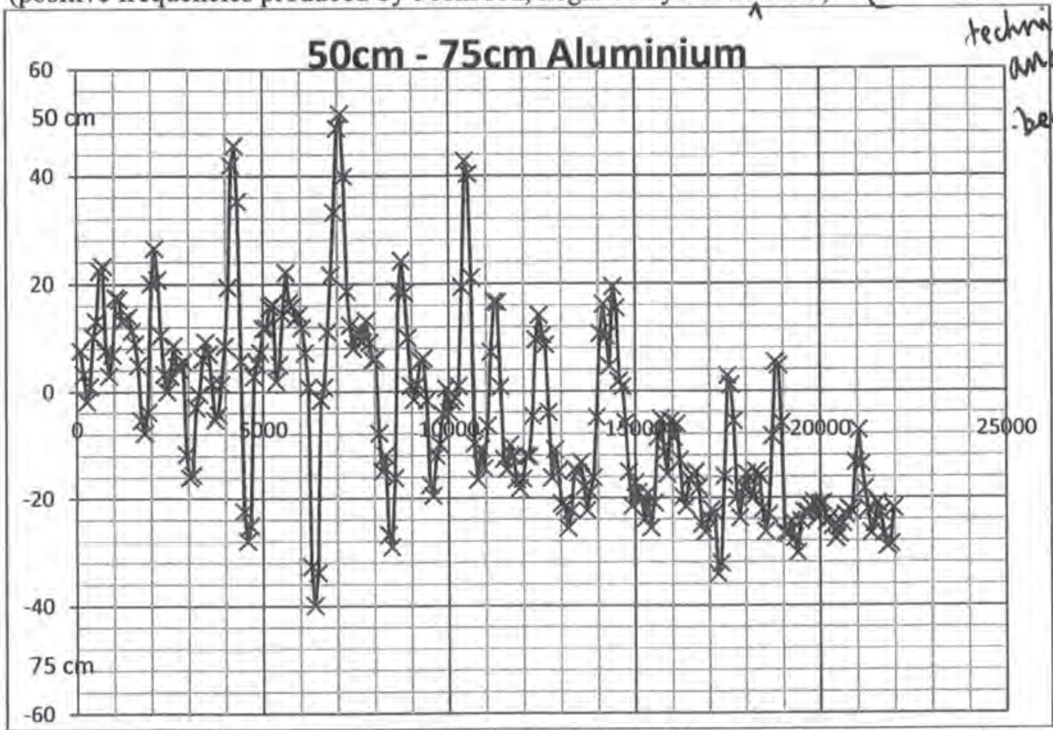
sig fig

! Where from?

This shows that the fundamental frequencies of a material can be used to approximate the speed of sound, from which the relationship between the coefficient of stiffness and density of a material can be found.
In aluminium, this relationship would be 40627876 C: 1 ρ. The actual values are 69 GPa and 2700kg/m^3, 25555555 Pa : 1 g/cm^3. This value is far from perfect, the predicted value being only 0.62 times the real value, but is of the right order of magnitude, showing that the relationships I am assuming are not entirely unfounded in reality.

Experiment 3 – Comparing frequencies of different lengths of aluminium

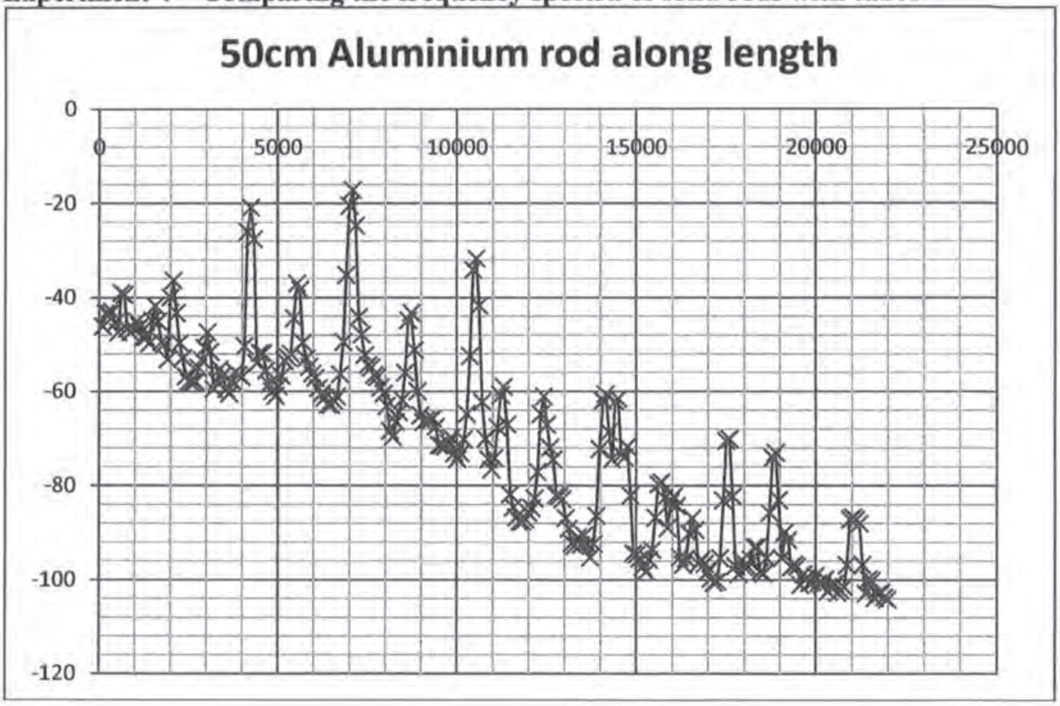
Using a similar method of comparison for 50 cm and 75cm lengths of aluminium to that used to compare aluminium and steel gave the following graph:
(positive frequencies produced by 50cm rod, negative by the 75m rod) ← not sure this technique of analysis has been well explained

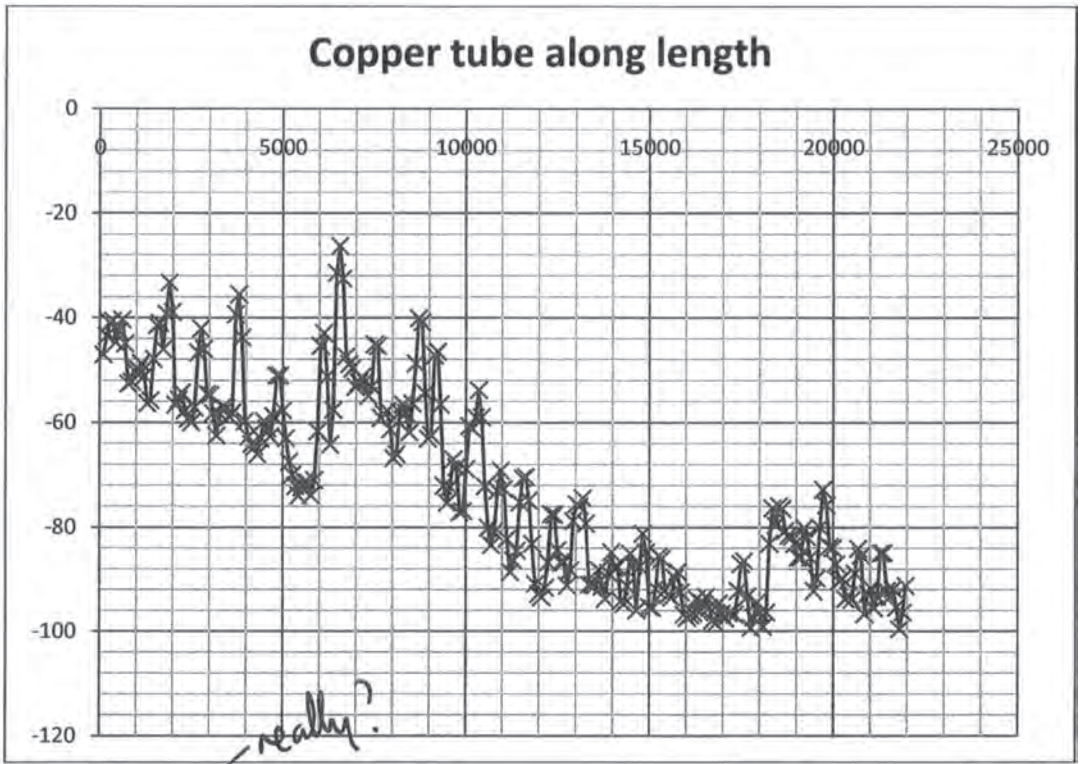


Whilst many low frequencies are more prominent in the 50cm rod, higher frequencies tend to be more prominent in the 75cm rod. I believe this is because the wavelengths of higher frequencies are higher, and so if a rod is longer, more nodes for this particular resonance will fit inside the rod, but for longer wavelengths, this effect is less pronounced, and even outweighed by the extra energy required to resonate a longer rod. not clear

? If v = fλ and v is the same then λ should be lower for higher frequencies.

Experiment 4 – Comparing the frequency spectra of solid rods with tubes

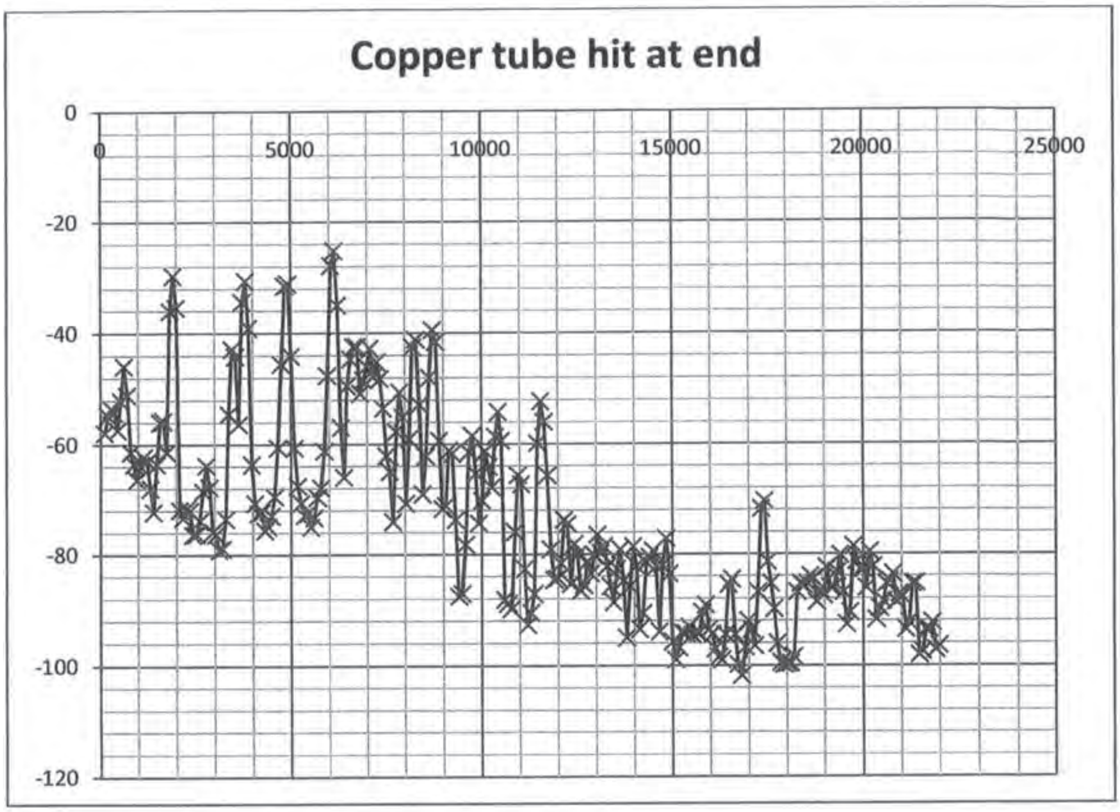


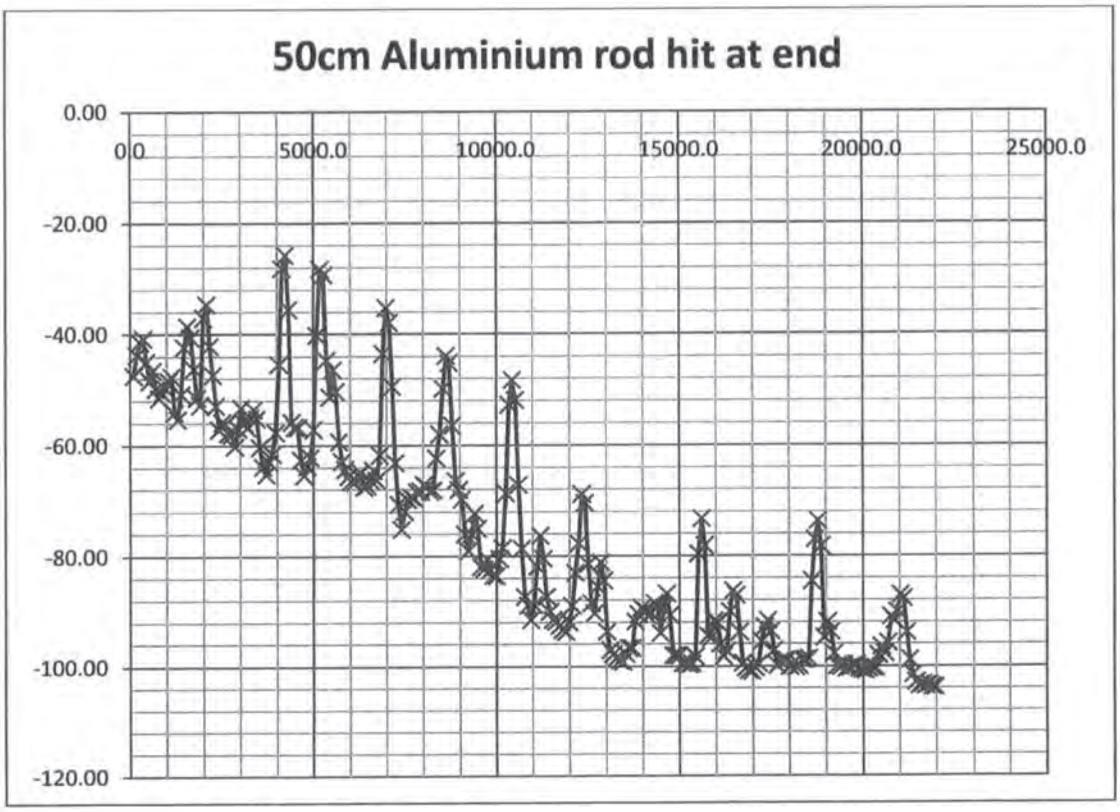


really?

There is no obvious difference between the two spectra, aside from a slight increase at the highest frequencies in a copper tube.

hardly a meaningful comparison.

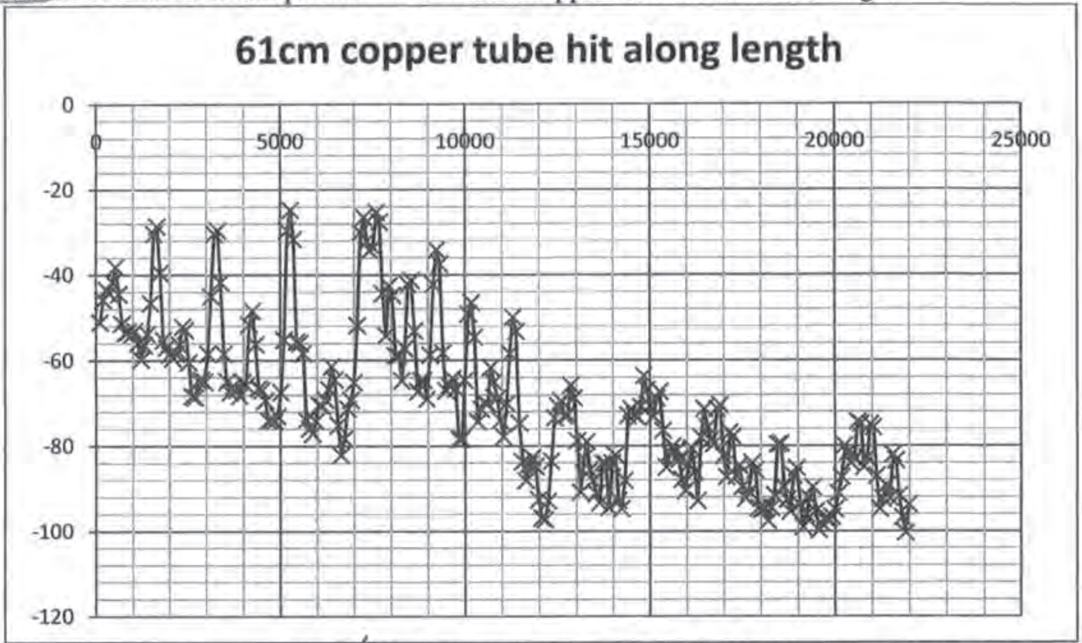

Copper tube hit at end
0
-20
-40
-60
-80
-100
-120
0
5000
10000
15000
20000
25000


50cm Aluminium rod hit at end
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
0.0
5000.0
10000.0
15000.0
20000.0
25000.0

7

What effect?

This effect is more pronounced when the tube is hit at the end, encouraging more longitudinal waves. The effect is still present in a different copper tube of a different length



This effect may be caused by whole in the tube. The speed of sound in air is quite low, so you would expect it to have less of an effect on high frequencies, however, a longitudinal wave which also rotated around the tube as it travelled would have a different speed along the tube, but is fast enough to explain the extra resonance at higher frequencies. This would have less of an effect in solid rods, since these waves would be masked by the non-rotational longitudinal waves travelling through the centre of the rod, however, in a tube, these masking waves would not be present, and the effect of waves travelling around the tube would be greater proportional to other types of wave, giving rise to an effect which is negligible in solid rods. In aluminium, the rotating wave travels at 5102 m/s, compared to 6374 m/s for longitudinal waves. In copper, the difference is only 900 m/s (4759 and 3813 m/s). The difference between the two speeds of the waves could effect the degree of this type of resonance, so certain metals would resonate more as tubes than others.

?

Where do these values come from?

Conclusion

The frequencies a metal rod creates when struck depend upon the speed of sound of the material and its length more than any imperfections in the material.

true

There seems to be a definite relationship between the speed of sound in a material and the frequencies it produces – waves which travel faster produce higher frequencies, and in metals with greater speeds of sound, more higher frequencies are produced.

If a rod is longer, more wavelengths will fit into it, so lower frequencies may be achieved, and higher frequencies sustained, as there are many more nodes.

In a solid, there are two main causes of sound wave, longitudinal and transverse waves. Longitudinal waves are responsible for higher frequencies, and transverse for lower frequencies, due to their different speeds, but in a tube, there may be a third type of wave, which causes more resonance effects at high frequencies.

Not much evidence presented to support this conclusion.

Glossary

Resonance – The tendency for a system to oscillate at certain frequencies at a greater amplitude than others

Fundamental frequency – the longest wavelength which occurs in a material [which in the rods used, is twice their length].

Fourier transform – a process which breaks a function into basic pieces, typically used to break down a wave into its constituent frequencies. ✓

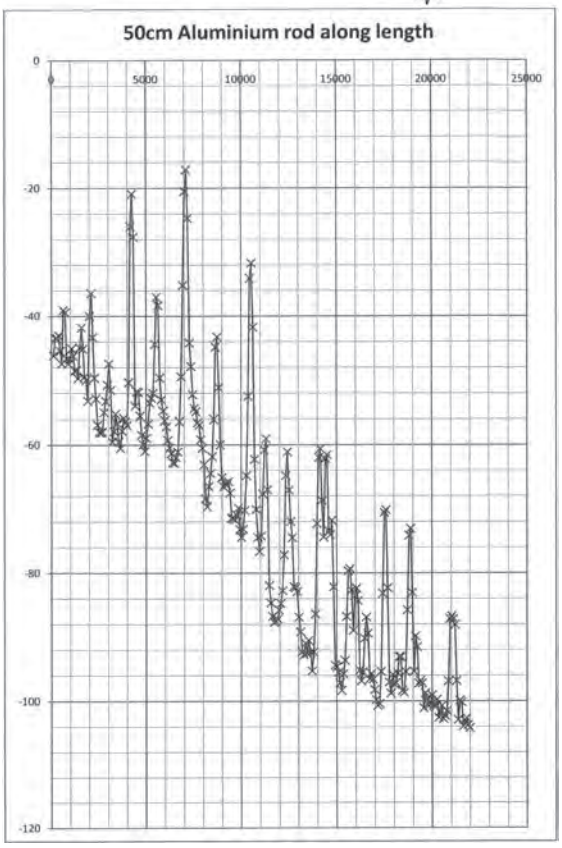
Autocorrelation – Correlation of a signal with itself; a mathematical tool for finding repeating patterns. ✓ eg?

References

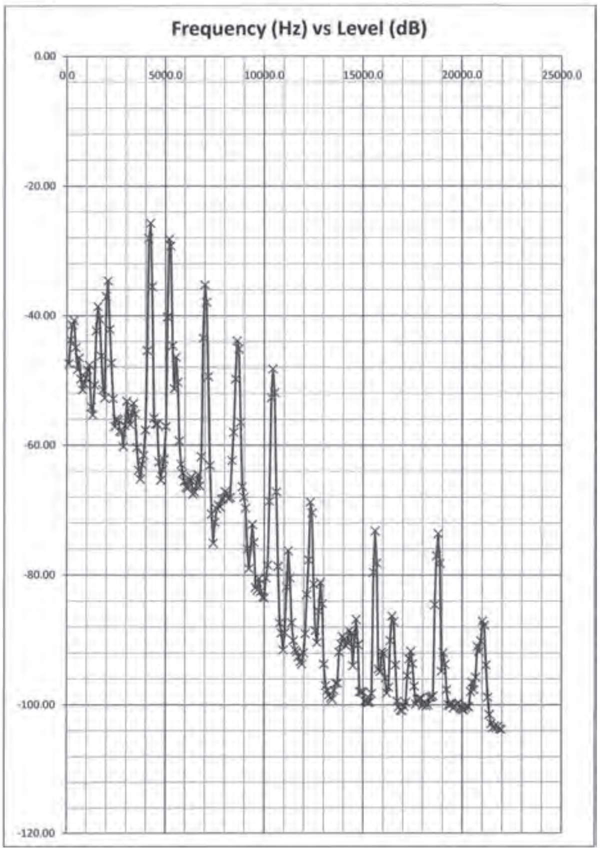
Materials' speeds of sound: http://www.kayelaby.npl.co.uk/ -online version of Kaye and Laby 16th edition (published 1995) ✓

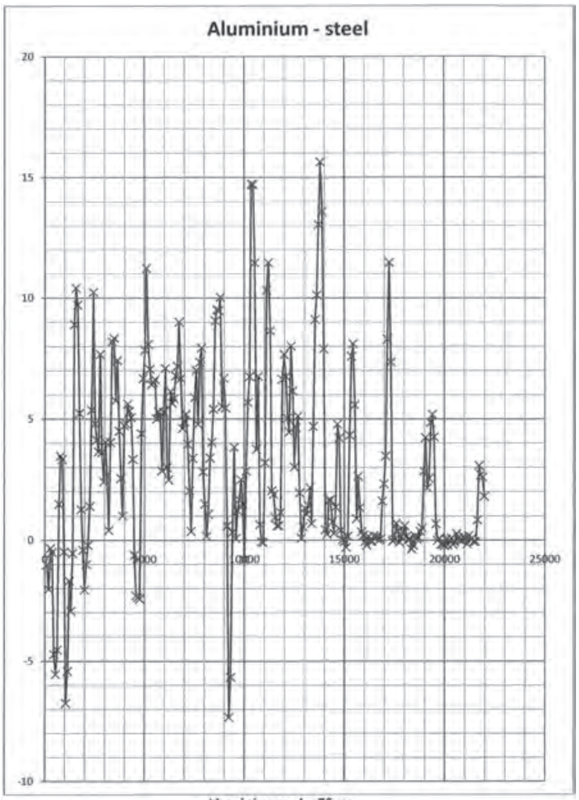
$c = \sqrt{\frac{C}{\rho}}$ - http://en.wikipedia.org/wiki/Speed_of_sound#Basic_formula (no citation)

Definitions – en.wikipedia.org (not cited from other sources) referred to?

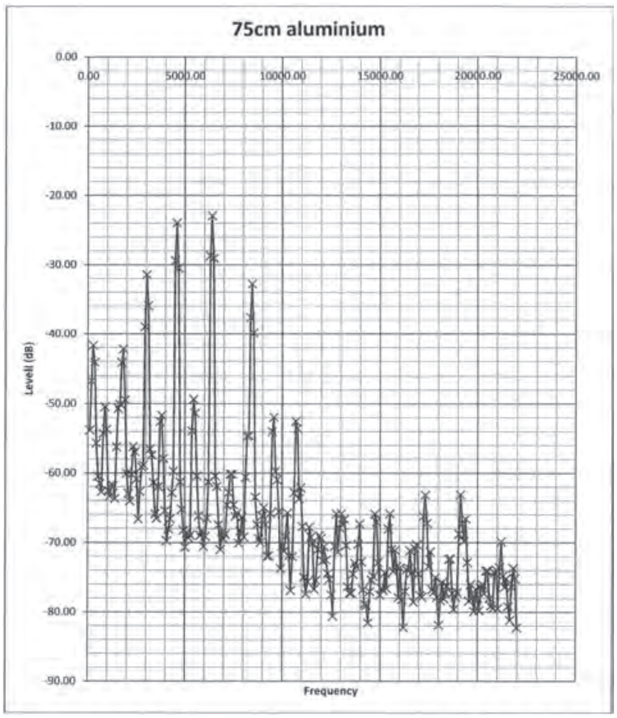


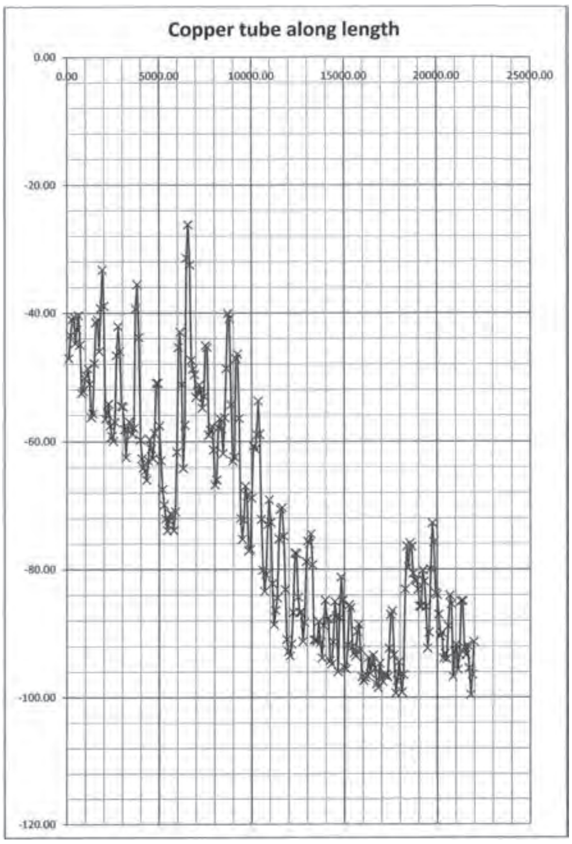
relevance?

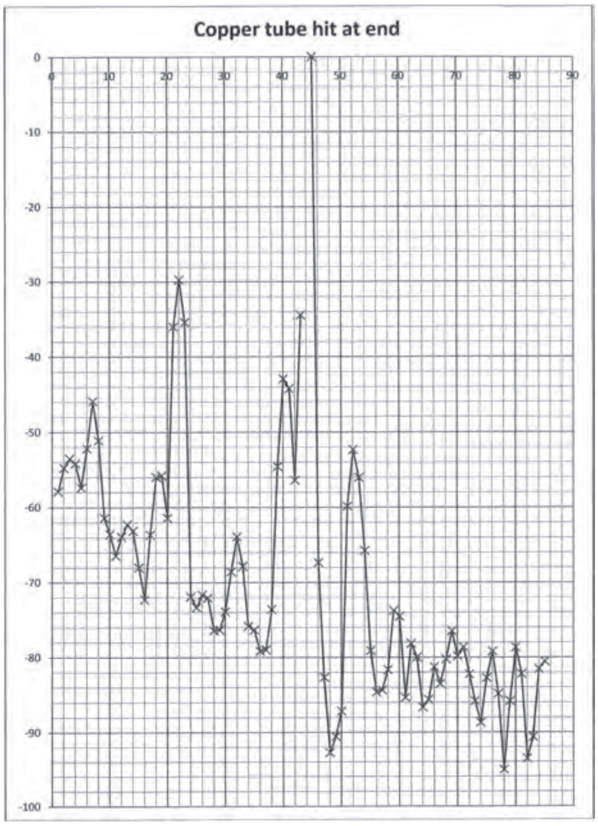


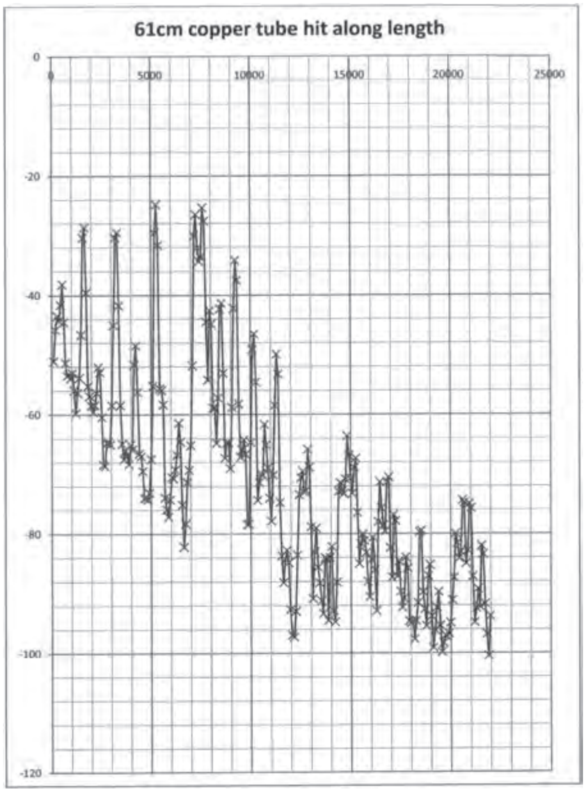


Aluminium rod – 75cm




Copper tube along length
0.00
5000.00
10000.00
15000.00
20000.00
25000.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00


Copper tube hit at end
0
10
20
30
40
50
60
70
80
90
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100


61cm copper tube hit along length
0
5000
10000
15000
20000
25000
-20
-40
-60
-80
-100
-120

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