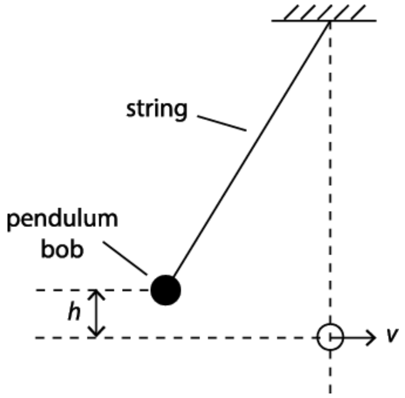
1(a). A group of students are conducting an experiment in the laboratory to determine the acceleration of free *g* using a simple pendulum as shown below.



The pendulum bob is released from **rest** from a height *h.* The speed of the pendulum bob as it passes through the vertical position is *v.* The speed *v* is measured using a light-gate and a computer.
The results from the students are shown in a table.

h / m	v / m s^{-1}	v^2 / m^2 s^{-2}
0.052	1.0 ± 0.1	1.0 ± 0.2
0.100	1.4 ± 0.1	2.0 ± 0.3
0.151	1.7 ± 0.1	2.9 ± 0.3
0.204	1.9 ± 0.1	
0.250	2.2 ± 0.1	4.8 ± 0.4
0.302	2.4 ± 0.1	5.8 ± 0.5

Complete the missing value of v^2 in the table.

[1]

(b). Fig. 24 shows the graph of v^2 against *h.*

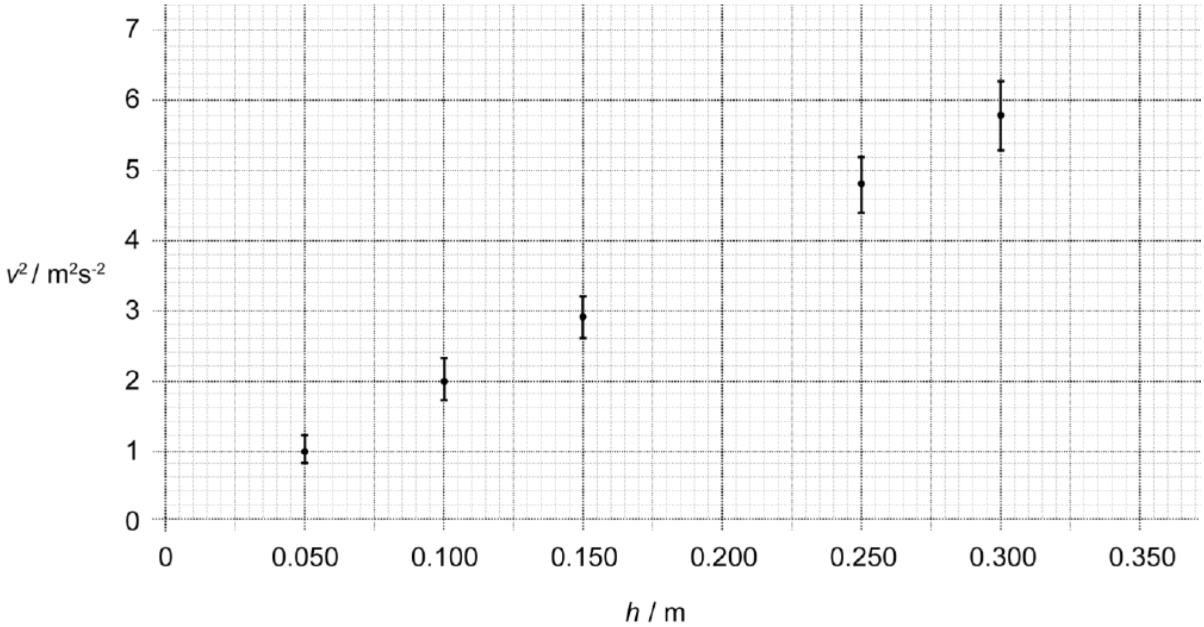


Fig. 24

i. Plot the missing data point and error bar on Fig. 24.

[1]

ii. * Explain how Fig. 24 can be used to determine the acceleration of free fall *g.*
Find the value of *g* and include the uncertainty in your answer.

[6]

2. This question is about a simple pendulum made from a length of string attached to a mass (bob). For oscillations of small amplitude, the acceleration *a* of the pendulum bob is related to its displacement *x* by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where *g* is the acceleration of free fall and *L* is the length of the pendulum.
The pendulum bob oscillates with simple harmonic motion.

Describe with the aid of a labelled diagram how an experiment can be conducted and how the data can be analysed to test the validity of the equation

$$T^2 = \frac{4\pi^2}{g}L$$

for oscillations of small amplitude.

[6]

3. A stabilising mechanism for electrical equipment on board a high-speed train is modelled using a 5.0 g mass and two springs, as shown in **Fig. 21.1**. For testing purposes, the springs are horizontal and attached to two fixed supports in a laboratory.

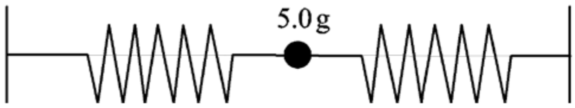


Fig. 21.1

Plan how you can obtain experimentally the displacement against time graph for the oscillating mass in the laboratory. Include any steps taken to ensure the graph is an accurate representation of the motion.

[4]

4(a). Fig. 5.1 shows a horizontal copper wire placed between the opposite poles of a permanent magnet. The wire is held in tension *T* by the clamps at each end. The length of the wire in the magnetic field of flux density 0.032 tesla is 6.0 cm.

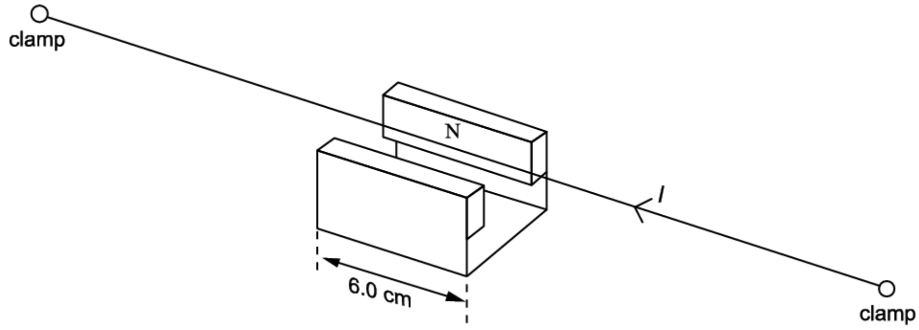


Fig. 5.1

The direct current is changed to an alternating current of constant amplitude and variable frequency, causing the wire to oscillate. The frequency of the current is increased until the fundamental natural frequency of the wire is found as shown in Fig. 5.2. This is 70 Hz.

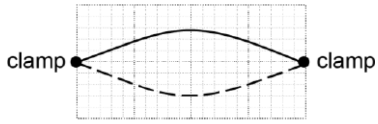


Fig. 5.2

i. In the situation shown in Fig. 5.2 the amplitude of the oscillation of the centre point of the wire is 4.0 mm. Calculate the maximum acceleration of the wire at this point.

maximum acceleration = ... m s^{-2} **[2]**

ii. The frequency is increased until another stationary wave pattern occurs. The amplitude of this stationary wave is much smaller.

1. Sketch this pattern on Fig. 5.3 and state the frequency

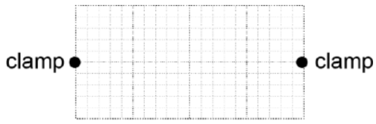


Fig. 5.3

frequency = ... Hz **[1]**

2. Explain why the amplitude is so small. Suggest how the experiment can be modified to increase the amplitude.

[3]

(b). The speed v of a transverse wave along the wire is given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension and μ is the mass per unit length of the wire.

i. Assume that both the length and mass per unit length remain constant when the tension in the wire is halved.

Calculate the frequency of the new fundamental mode of vibration of the wire.

frequency = ... Hz **[1]**

ii. In practice the mass per unit length changes because the wire contracts when the tension is reduced. For the situation in which the tension is halved the strain reduction is found to be 0.4%.

1. Calculate the percentage change in μ. State both the size and sign of the change.

percentage change in μ = ... % **[1]**

2. Write down the percentage error this causes in your answer to **(i)**. State, giving your reasoning, whether the actual frequency would be higher or lower than your value.

[2]

5. A mass is hung from the bottom end of a flexible spring.

Describe and explain how the mass can be made to show resonance.

[2]

6. A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

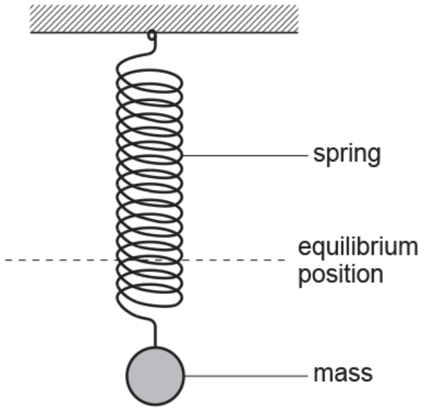


Fig. 18.1

At time $t = 6.5$ s the magnitude of the acceleration a of the mass is 3.6 m s^{-2} and its displacement x is 4.6×10^{-2} m.

The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

[4]

7. In order to investigate the behaviour of an oscillating mass and spring system, the spring is suspended vertically below a vibration generator. A mass is added to the bottom of the spring. The arrangement is suspended above an ultrasound distance sensor as shown in Fig. 2.2.

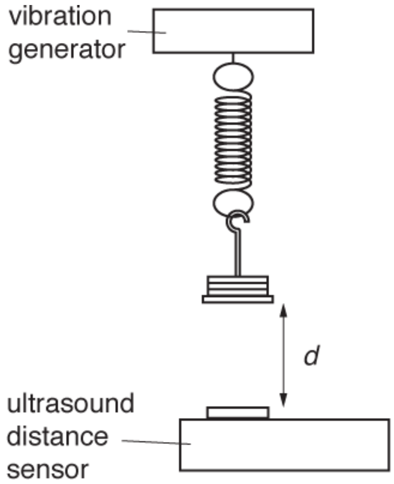


Fig. 2.2

By connecting the vibration generator to a signal generator it is possible to use this apparatus to investigate forced oscillations of the mass and spring system. Describe in as much detail as possible how you would carry out the investigation, the data that you would record and what you would expect the results to show.

[6]

8. This question is about determining the acceleration due to gravity *g* using a simple pendulum.

The pendulum bob has mass *m* and the length of the pendulum string is *L*.

A student measures the time taken for 10 oscillations of the pendulum bob to determine the period *T*.

She repeats this for 4 different pendulum lengths.

The results are shown in the table below.

Length of pendulum, *L*/m	**Time taken for 10 oscillations, t/s**	**Period, T/s**	T^2/s^2
0.300	11.33	1.133	1.284
0.400	12.70	1.270	
0.500	14.44	1.444	
0.600	15.41	1.541	

(a)

i. State and explain the advantage of determining the period *T* by measuring the time for 10 oscillations.

[2]

ii. Complete the table by calculating the three missing values of T^2/s^2.

[1]

iii. On Fig. 2.2, plot a graph of T^2 (on the y-axis) against L (on the x-axis) and draw a straight line of best fit through the data points.

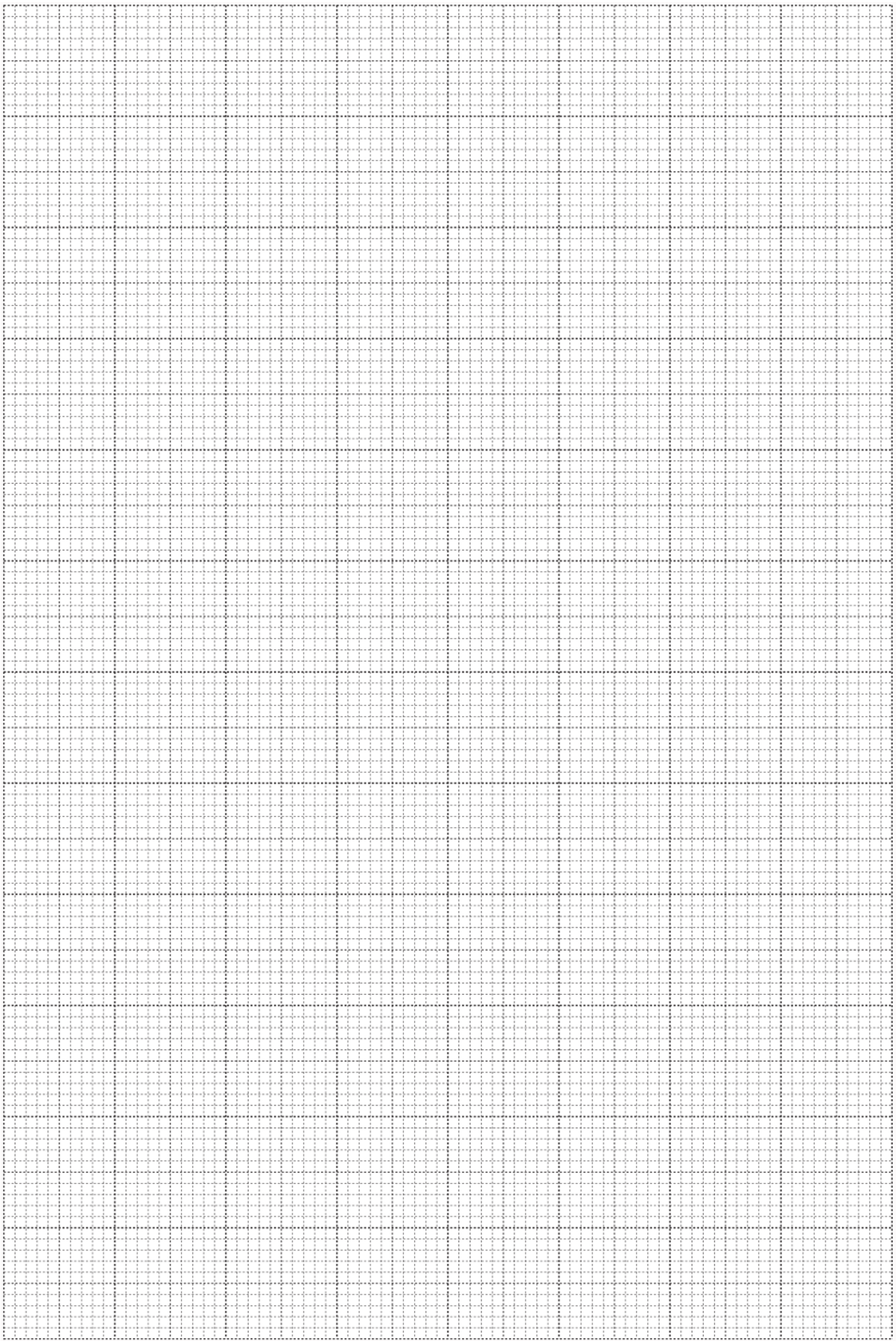


Fig. 2.2

[4]

iv. Use the graph to determine a value for the acceleration due to gravity *g*.

Show your working.

g = ... m s^{-2} **[2]**

(b). The student is considering the uncertainty in her value for *g*.

She thinks that data collected for the shorter pendulums have greater percentage uncertainty than those for the longer ones.

Explain her reasoning.

---

[2]

9. *A student missed the lesson when the topic of **resonance of simple harmonic oscillators** was introduced. You are asked to make notes and labeled diagrams to help explain these ideas and enable the student to catch up.

In your answer include a description of an experiment that illustrates and explains the resonance of a simple harmonic oscillator, including the effect of damping.

---

[6]

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		3.6 ± 0.4 ($m^2\ s^{-2}$)	B1	
	b	i	Data point and error bar correctly plotted	B1	**Allow** ecf from previous part.
		ii	* **Level 3 (5–6 marks)** Detailed analysis of the graph clearly linked to the principle of conservation of energy, including determination of the value of *g* and the related uncertainty in the answer. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Analysis of the graph linked to kinetic energy and / or potential energy, with an attempt to find the value of *g*. Mention of where one would find uncertainties in the answer but without analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Line of best fit drawn and gradient attempted. Mention of energy and / or where uncertainties may occur. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Explanation** 1. Principle of conservation of energy used to derive relationship. 2. $mgh = ½\ mv^2$ or $v^2 = 2gh$ 3. A graph of v^2 against *h* will be a straight line (through the origin). 4. Gradient of line = 2*g*. **Determination** 1. Line of best fit drawn through all data points. 2. Gradient in the range 17 to 21 ($m^2\ s^{-2}$). 3. *g* determined correctly from the gradient. **Uncertainty** 1. Worst line of fit drawn. 2. Correct attempt to determine the uncertainty.

3			**Total**	**8**	
2			**Level 3 (5–6 marks)** Clear description including steps to obtain high quality data **and** analysis *There is a well-developed line of reasoning which is clear and logically structured.* *The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description **and** some analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **and** analysis **Or** limited description *The information is basic and communicated in an unstructured way.* *The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	**B1 × 6**	**Indicative scientific points may include:** **Experiment** **Description** • Pendulum string clamped / fixed (can be shown on diagram) • Use a stopwatch to determine time period T • Time multiple oscillations to determine T • Use a ruler to measure L • Vary length L and determine T **Quality of Data** • Method used to ensure small oscillations • Small angles i.e. <10 degrees • Idea of fiducial mark • Start / stop timing at the centre of the oscillation • Measure from the fixed point to the centre of the bob **Analysis** • Correct plotting of graph, e.g. T^2 against L or T against $\sqrt{L}$ or lg T against lgL • Analysis of data table showing T^2/L = constant

					• Expect a straight line through the <u>origin</u> • Correct gradient of the line e.g. $4\pi^2/g$
			Total	**6**	
3			**Accept any sensible and successful method.** **Stroboscope:** Any two from • Use of stroboscope of known frequency or period • Photograph to capture several positions on one picture • Measure displacement from centre using a scale put behind the mass. **or** **Motion sensor:** Any two from • Motion sensor connected to data logger which sends information on displacement and time to computer. • Sensor placed close to moving mass to eliminate reflections from other objects. • Small reflector attached to mass.	B1 × 2	Video camera with freeze frame facility, where time between frames is known. Apply marking points as for the stroboscope.
			Safeguards to ensure accuracy **Stroboscope:** Any two from • Use frequency such that positions of mass are close together on photograph. • distance scale close to oscillating mass or camera set back from mass to reduce parallax. • Camera should be directed at equilibrium point or at 90° to oscillation. **or** **Motion sensor:** Any two from	B1 × 2	

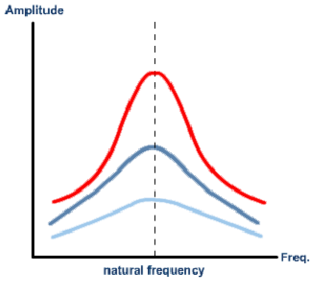
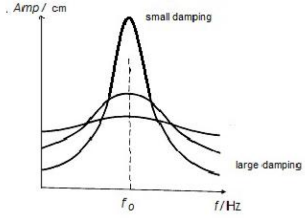
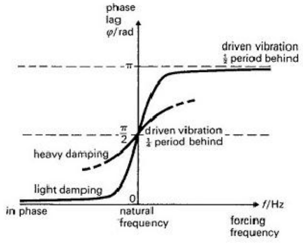
			• Any attached reflector should not cause damping. • Motion sensor directed along line of oscillation or motion sensor signal blocked by supports so must be as near to line of oscillation as possible. • Use thin supports to reduce reflections.		
			Total	**4**	
4	a	i	$a = (-)\ 4\pi^2 f^2 x = 4 \times 9.87 \times 4900 \times 0.004$	C1	**allow** 774 ($m\ s^{-2}$)
			$a = 770\ (m\ s^{-2})$	A1	
		ii	**1** sketch showing one wavelength and 140 (Hz)	B1	both sketch and value required for 1 mark
			2 driving force is around nodal point / AW;	B1	**max** 3 of the 4 marking points
			points either side of nodal point try to move in opposite directions when force in one direction / AW;	B1	
			move magnet to antinodal point; ¼ of distance between clamps	B1	**not** increase current
	b	i	$f \alpha \sqrt{T}$ so $f = 70/\sqrt{2} = 49$ or 50 Hz	B1	
		ii	**1** μ increases / goes up by 0.4%	B1	**allow** +0.4% NOT 0.4%
			2 0.2%,	B1	**or** half of answer to **(ii)1**
			f is lower because μ is bigger and μ is on the bottom of the formula	B1	**or** greater inertia present with same restoring force / other physical argument
			Total	**10**	
5			Force the mass to oscillate with a periodic force. (AW)	B1	
			The mass oscillates at maximum amplitude when the forcing frequency is equal to the natural frequency of the spring−mass system. (AW)	B1	
			Total	**2**	
6			EPE decreases (from bottom to top)	B1 B1 B1 B1	**Not** EPE becomes 0 (or negative)

			GPE increases (from bottom to top) KE starts at zero, finishes at zero and max at equilibrium point. Air gains thermal energy / Total energy (of mass and spring) decreases over time		**Allow** for the first two marking points: description that refers to total potential energy starts at maximum, is minimum at equilibrium point and max again at top, provided total potential energy is stated to be the sum of EPE and GPE **Allow** as alternative for first three marks: EPE to KE and GPE in bottom half EPE and KE to GPE in top half EPE at start to GPE at top
			Total	**4**	
7			**Level 3 (5–6 marks)** ✓✓ Clear procedure / measurements and analysis. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.* **Level 2 (3–4 marks)** ✓✓ Some procedure / measurements and analysis *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*	**6**	**Indicative scientific points may include:** To gain 2 or more marks, both procedure and analysis statements are needed. **Procedure** Level 3 • Frequency / period of oscillation measured using an oscilloscope attached to signal generator or use data from motion sensor or multimeter. • adjust the frequency in small increments close to the resonant frequency. Level 2 • means of measuring amplitude (use ultrasound motion sensor or ruler adjacent to spring)

			Level 1 (1–2 marks) ✓✓ Limited procedure / measurements and / or limited analysis *There is a line of reasoning presented with some structure. The information presented in the most part relevant and supported by some evidence.* **0 marks** *No response or no response worthy of credit.*		• repeat and determine an average amplitude at a given frequency • range of frequency either side of resonant frequency Level 1 • vary the frequency using signal generator • measure the amplitude of oscillations • plot a graph of amplitude against frequency **Supporting Analysis** Level 3 • non zero intercept (can be stated or shown on graph) • y-intercept labelled as driving amplitude **or** lower frequencies amplitude = amplitude of driver • higher frequencies the system does not have sufficient freedom to react to driver so amplitude tends to zero. Level 2 • sketch of frequency vs amplitude graph showing peak (or statement) • sketch graph shows frequency tends to zero at higher frequency (or stated in words) • peak labelled **or** maximum amplitude occurs when the natural frequency is equal to the driving frequency. Level 1 • amplitude depends on driven frequency • appreciation that this is an investigation into resonance

			Total	6	
8	a	i	Reaction time or error in starting and/or stopping watch. Longer time (to measure) gives smaller percentage/relative/fractional uncertainty (due to reaction time) (or vice versa)	1 1	Not just human error or random error. ALLOW uncertainty reduced to $\frac{1}{10}$ or 10% (of previous value)
		ii	1.613 2.085 2.375	1	All values calculated correctly to 4 SF:
		iii	*x*-axis suitably scaled and labelled as *L* (ignore units), using at least half of the printed graph grid, minimum distance between scale marking is 3 large squares. *y*-axis suitably scaled and labelled as T^2 (ignore units), using at least half of the printed graph grid, minimum distance between scale marking is 3 large squares. Points plotted correctly (to within half a small square) Acceptable straight line of best fit drawn. Line must not have kinks or be too thick or hairy and must be long enough to cover all the plotted points.	1 1 1 1	Do not allow awkward scales including those going up in multiples of 3. Smallest acceptable x-axis scale is 1 large square:0.05m. Put tick/cross by *x*-axis. Smallest acceptable y-axis scale is 1 large square:0.2s^2. Put tick/cross by *y*-axis. Do not award for blobs (points with diameter > ½ small square. Put tick/cross by the third plot. Best line should be just to the left of the top plot and almost through the bottom plot. If all 4 plots are correct the line should not pass through the origin. Put tick/cross near top of line.
		iv	Calculation of gradient of line using co-ordinates of 2 points on the drawn line at least half the length of the drawn line apart. Evaluat\ulated gradient value, $g = \frac{4\pi^2}{gradient}$.	1 1	Gradient $= \frac{dy}{dx}$, and denominator should be at least 0.15m. Using data points from the table is only acceptable if the points are on the drawn line (by half a small square) A good line in part (iii) will give range 9 < g < 11 m s^{-2} A raw value for g (eg 9.81) scores zero. Working must be shown.
	b		ANY 2 from: Same (absolute) uncertainty/resolution/precision. Time period for shorter pendulums is less (hence percentage uncertainty in	2	 ALLOW same instrument used to measure

			time is greater) Uncertainty in time is more significant than uncertainty in length. Uncertainty in time is increased because T^2.		
			Total	**11**	
9			* **Level 3 (5–6 marks)** Marshals argument in a clear manner and includes clear explanation of three strands: • describing a resonance experiment • simple harmonic oscillator and meaning of resonance • typical results including the effect of damping *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*	B1 x 6	**Indicative scientific points may include:** **resonance experiment mechanical or electrical oscillator** • labelled diagram of hacksaw oscillator driven by massive pendulum or electromagnet coil OR • mass on vertical spring driven by signal generator OR • resonant bottle driven by small speaker OR • LCR circuit driven by sig. gen. OR • Barton's pendulums • coupling by spring / magnetic force • varying driving frequency through natural frequency • measuring the amplitude or phase response • how to vary damping by air resistive force on card mechanically OR accept by resistance *R* in *LCR* circuit
			Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument **or** covers all three at a superficial manner and does not include enough indicative points for level 3. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*		**resonance** • the large increase in A as $f_{DRIVER} \approx f_{NATURAL}$ • maximum energy transfer • analogy of child on swing driven by regular pushes • the phase relationship between driver and driven changing through resonance
			Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the*		**typical results including the effect of damping** • graphs or description of response curve • typical resonance peak curves • broadening and lowering of peak due to damping • $\pi/2$ phase shift at resonance driver leading driven • in phase at lower f or out of phase at higher f

			evidence may not be clear. **0 marks** No response or no response worthy of credit  		• effect of damping on steepness of phase transition  
			Total	**6**	