Surname	Centre Number	Candidate Number
Other Names		2

GCE A LEVEL

1420U30–1

PHYSICS – A2 unit 3
Oscillations and Nuclei

2 hours 15 minutes

	For Examiner's use only		
	Question	Maximum Mark	Mark Awarded
Section A	1.	13	
	2.	13	
	3.	27	
	4.	18	
	5.	9	
	6.	20	
Section B	7.	20	
	Total	120	

ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet.**

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.
You may use a pencil for graphs and diagrams only.
Write your name, centre number and candidate number in the spaces at the top of this page.
Answer **all** questions.
Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B**.
Section **A**: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.
Section **B**: 20 marks. Comprehension. You are advised to spend about 40 minutes on this section.
The number of marks is given in brackets at the end of each question or part-question.
The assessment of the quality of extended response (QER) will take place in question **4(c)**.

1. The first law of thermodynamics may be written as:

$$\Delta U = Q - W$$

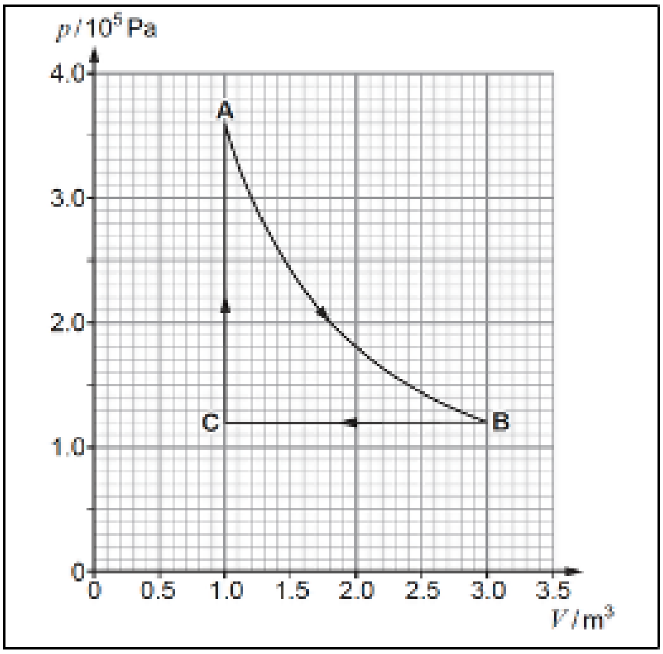
(a) State the meaning of: [3]

ΔU ______________________________

Q ______________________________

W ______________________________

(b) A fixed mass of gas is taken around the closed cycle A → B → C → A.



(i) Ian claims A → B is an isothermal process. State what is an isothermal process and show this is an isothermal process.

[4]

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(ii) Determine the approximate amount of work done in the expansion **AB**

[2]

(iii) Hence or otherwise, calculate the net heat flow over the whole cycle ABCA

[4]

2. This question is about Kinetic Theory.

The balloon has a volume of 0.009 m^3 at atmospheric pressure, 1.01×10^5 Pa, and a temperature of 323 K.

(a) (i) Write two assumptions of the kinetic theory of gases.

[2]

(ii) Given that the balloon is filled with Helium gas. Calculate the r.m.s. of the molecules inside of this balloon. (Mean relative molecular mass of Helium = 4)

[4]

(b) The balloon is released from the ground and reaches an altitude of 10 km. At this altitude, the temperature is far lower than at ground level.

(i) Explain what is meant by ‘heat’

[1]

(ii) Explain why the rate of flow of heat through the walls of the balloon eventually approaches zero.

[2]

(iii) At an altitude of 10 km, the pressure in the balloon reaches 28kPa whilst the surrounding atmosphere is at a pressure of 25kPa.

Natalie states, ‘The rms speed of helium molecules in the balloon at this altitude is the same as that of the oxygen molecules in the atmosphere surrounding the balloon because they are at the same temperature’.

Mona states, ‘The helium in the balloon and oxygen in the atmosphere must have different rms speeds as they are at different pressures.’

Evaluate these statements. (Relative molecular mass of oxygen = 32)

[4]

3. Decay is a process which is spontaneous.

(a) Define the term 'spontaneous'.

[1]

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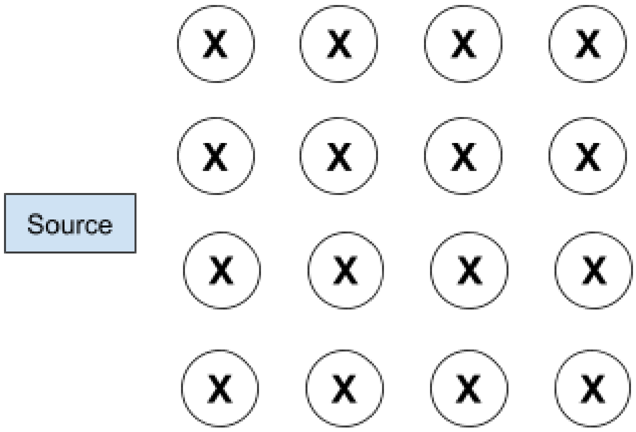
(b) A magnetic field can be used as a detector to identify the source of the particle. Draw the path of alpha, beta and gamma particles when passing through the magnetic field. [3]



(c) The half life of Caesium – 138 is 108 days.

(i) From the equation $A = A_0 e^{-\lambda t}$ derive the formula $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$

[3]

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(ii) Calculate the decay constant of Caesium – 138.

[2]

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(d) Radioactive decay may be investigated in a laboratory using a dice analogy.

A student has 128 standard identical six sided dice, with one side painted black.

(i) Calculate the decay constant of this experiment.

[1]

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(ii) The student then throws all the dice and discards all the dice which landed on the black face. The student recorded the number of dice thrown and the number of discarded dice.

Complete the table below by filling in the blanks for the Number of Dice Remaining.

[1]

Number of Thrown	Number of Dice Thrown	Number of Dice Discard	Number of Dice Remaining
1	128	20	________
2	108	10	________
3	98	11	________
4	87	12	________
5	75	10	________
6	65	8	________
7	57	5	________
8	52	7	________
9	45	8	________
10	37	7	________
11	30	8	________
12	22	4	________
13	18	1	________
14	14	4	________
15	10	6	________
16	4	2	________
17	2	0	________
18	2	2	________

(iii) Using the information above, describe the trend of the graph, and explain the result. [3]

(iv) Discuss to what extent the observation agrees with those expected from theory. [3]

(e) A sample of carbon-14 has a mass of 150 g. Calculate:

(i) The number of nuclei present (the mass of a carbon-14 atom is 14.00 u) [1]

(ii) Its decay constant (the half-life of carbon-14 is 5730 years). [2]

(iii) The initial activity of the 150 g sample of carbon-14. [2]

(iv) The activity after 2400 years [2]

(v) The mass of carbon-14 after 11460 years. [2]

(vi) The time for the activity of carbon-14 to decrease to 10% of its initial value. [2]

4. Nuclear energy can be released by fission or fusion.

(a) Complete the following equation by filling in the blank spaces.

[2]

$$^{236}_{92}U \longrightarrow {}^{\dots\dots}_{\dots\dots}e^{-} + {}^{\dots\dots}_{\dots\dots}Np$$

(b) Uranium – 235 has an initial activity of 232 MBq and a half life of 101 years. Calculate the mass of this radioactive substance after 1010 years (the mass of uranium – 235 atoms is 235u).

[5]

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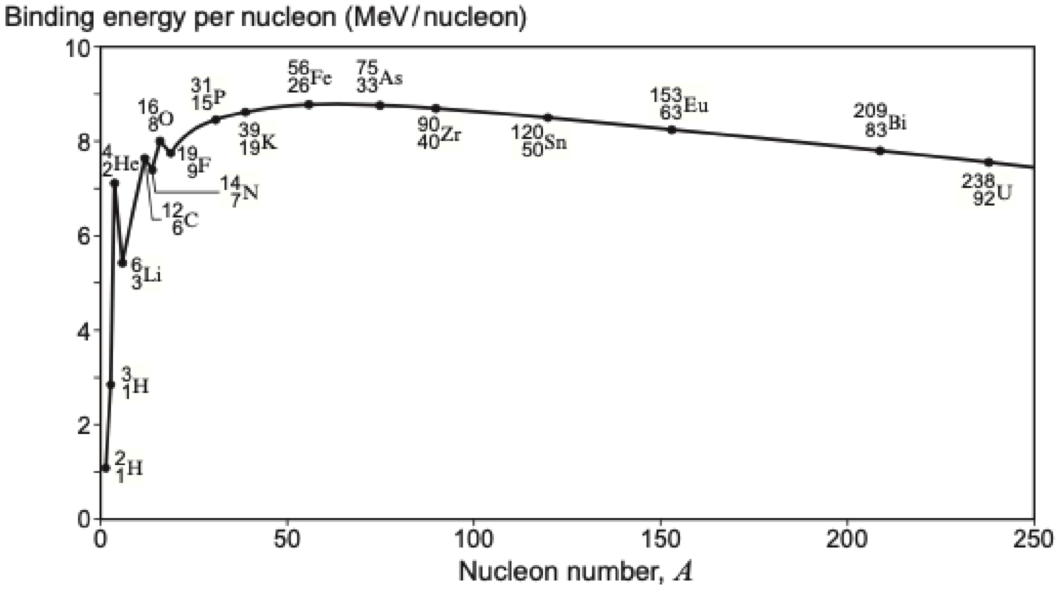


(c) Use the graph to explain why energy is released during nuclear fusion and nuclear fission.
[6 QER]

(d) Calculate, in MeV, the binding energy per nucleon for a nucleus of $^{236}_{92}U$.

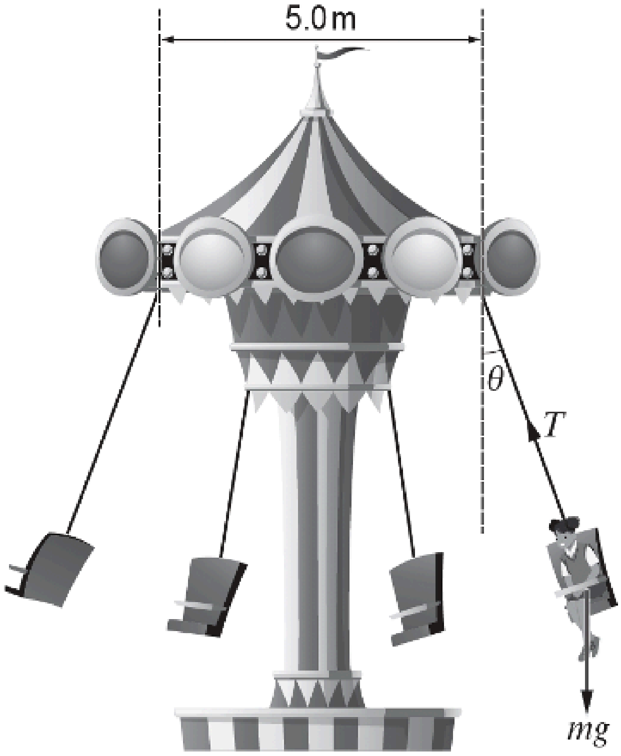
[2]

	Mass/GeV/c^2
$^{236}_{92}U$	219.8750
n	0.93956
p	0.93827

(e) Discuss the advantages and disadvantages of using nuclear power as their main source of energy for a country.

[3]

5. Rhiannon is sitting on a rotating ride in a fun fair. Her speed and the angle, θ, are constant.



(a) Explaining your reasoning, show that the tension, T, in the cable is given by:

$$T\cos\theta = mg$$

[2]

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(b) The distance between the top of the cable and Rhiannon;s centre of mass is 3.0m. Explain why the radius of Rhiannon's circular path is given by:

$$r = 2.5 + 3.0 \sin\theta$$

[1]

(c) The combined mass of Rhiannon and the seat is 52.0kg and the tension in the cable is 550N. Calculate:

(i) the angle θ;

[2]

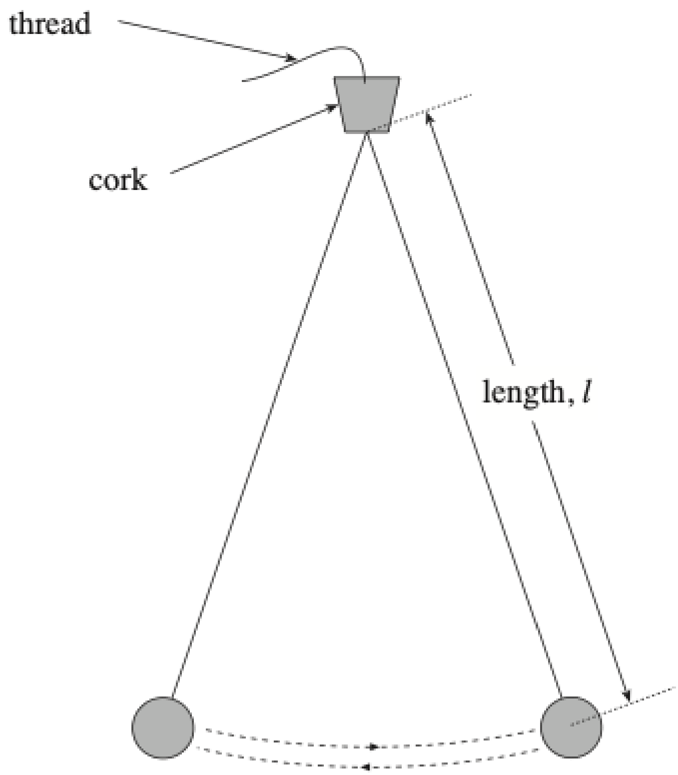
(ii) the radius of Rhiannon's circular path;

[1]

(iii) Rhiannon's speed;

[3]

6. A Physics student performed an experiment to determine a value for the acceleration due to gravity, g.



(a) (i) Clearly describe the energy changes when the pendulum is in motion.

[2]

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(ii) Explain why the pendulum eventually comes to rest.

[1]

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(b) Measurements for an oscillating simple pendulum are given in the table below, where l is the length of the pendulum and T_{10} is the time taken for 10 oscillations. For each value of l four values of T_{10} are measured.

l / m	√(t) / m^{½}	T_{10} / s	Mean T_{10} / s	Uncertainty T_{10} / s
1.000	1.00	42, 39, 40, 41	41	2
1.200	1.10	45, 42, 44, 45	44	2
1.400		48, 50, 49, 52		
1.600		51, 53, 50, 53		
1.800		54, 56, 55, 58		
2.000		57, 59, 58, 61		

(i) **Complete the table** by determining √(t), the mean time for 10 oscillations, and the uncertainty in T_{10}. Give your answer to suitable significant figures.

[3]

(ii) According to the equation, explain how the student can determine a value for acceleration due to gravity, g.

$$T = 2\pi\sqrt{\frac{l}{g}}$$

[3]

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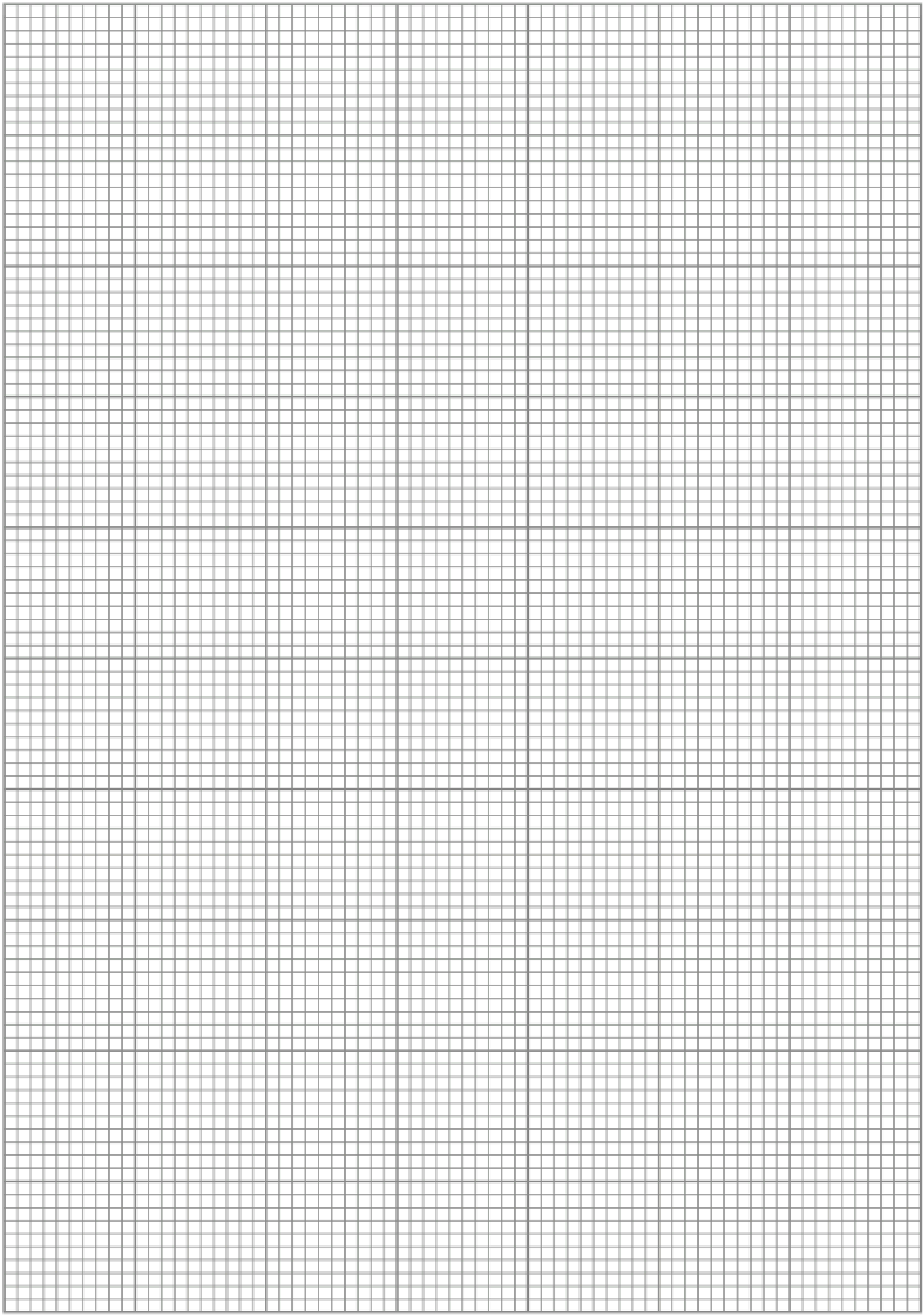
(iii) Another student recorded a different set of data. Use the method described in part (ii), **plot a graph** on the following page.

[5]

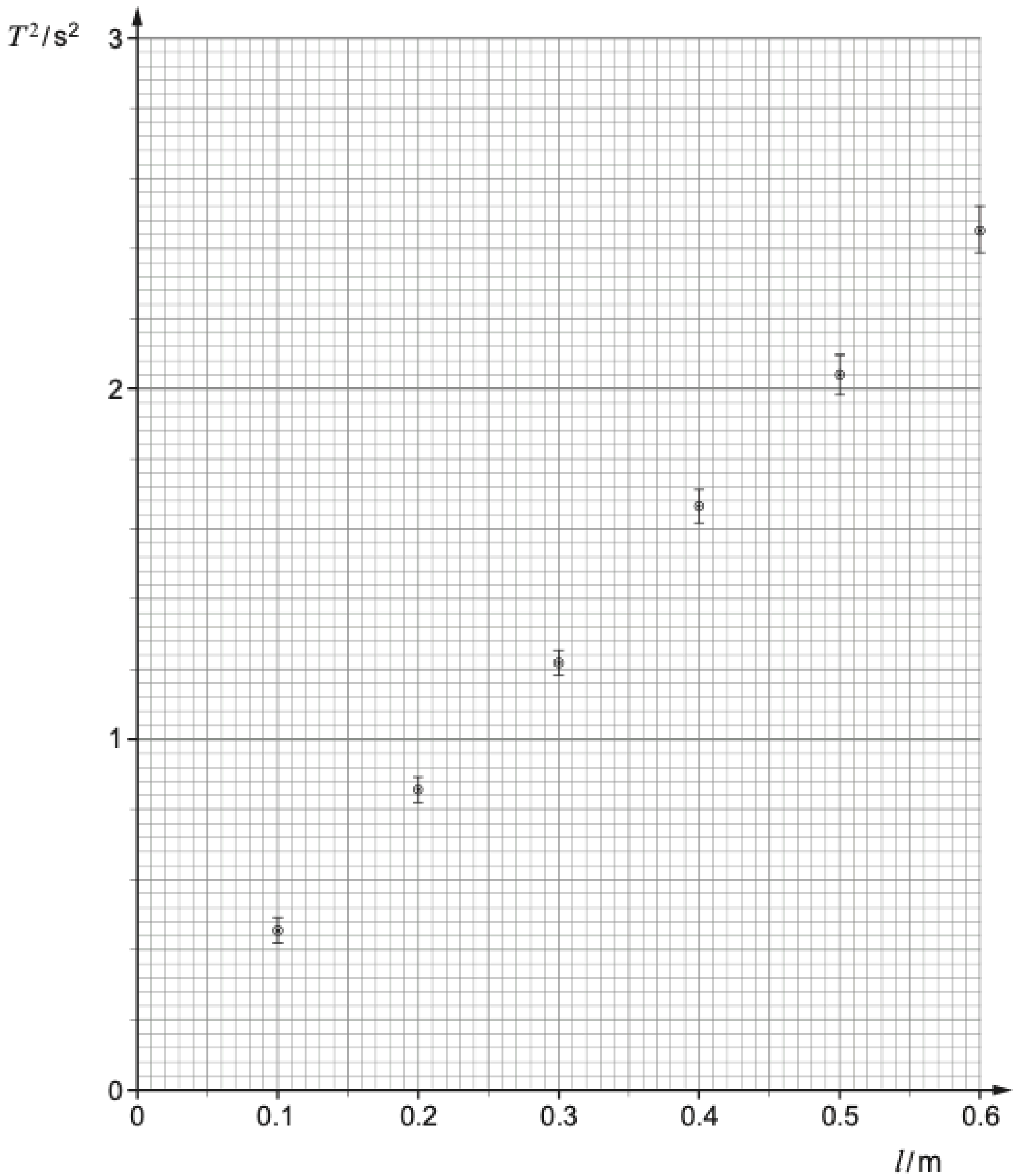
Length, l / cm	Time for 5 oscillations /s	T^2 / s^2
0.200	4.55	0.828
0.400	6.20	1.538
0.600	7.80	2.434
0.800	8.90	3.168
1.000	9.95	3.960



(iv) Using the graph above, determine a value for acceleration due to gravity, g.

[3]

(c) A third student performed the experiment in another approach. They have plotted a graph of T^2 against *l*.



(i) **Draw two lines** on the graph with maximum and minimum gradient.

[1]

(ii) Describe the line of best fit for the graph above.

[2]

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Section B

Answer **all** questions.

7. Read through the following article carefully. Paragraph

The Physics of Gravitational Waves

In September 2015, humanity achieved something remarkable – the first direct detection of 1
gravitational waves. These ripples in spacetime, predicted by Einstein's general theory of
relativity a century earlier, were finally observed by the Laser Interferometer
Gravitational-Wave Observatory (LIGO). The detection came from two black holes, each
about 30 times the mass of our Sun, spiraling into each other and merging some 1.3 billion
light years away.

Einstein's theory tells us that accelerating masses produce gravitational waves that travel
at the speed of light. However, these waves are incredibly weak. Even the collision of two 2
massive black holes causes spacetime to stretch and compress by only about one part in
10^{21}. To put this in perspective, if the distance between Earth and the nearest star (other
than the Sun) changed by this amount, we would only be looking at a change equivalent to
the width of a human hair.

LIGO detects these tiny changes using laser interferometry. The detector consists of two
perpendicular arms, each 4 km long, arranged in an L-shape. A laser beam is split and 3
sent down both arms simultaneously. The beams reflect off mirrors at the ends of the arms
and return to recombine at the beam splitter. When a gravitational wave passes through,
it stretches one arm while compressing the other, causing a detectable shift in the
interference pattern of the recombined beams.

The sensitivity required is extraordinary. LIGO must detect changes in arm length of about
10^{-18} m, which is approximately one-thousandth the diameter of a proton. To achieve this, 4
the mirrors must be isolated from all external vibrations including seismic activity, thermal
fluctuations, and even quantum noise. The mirrors are suspended as pendulums, which
act as mechanical filters for high-frequency vibrations.

The strain, h, produced by a gravitational wave is defined as the fractional change in length:
$h = \Delta L/L$ 5
where ΔL is the change in arm length and L is the original length of the arm. For LIGO's
4 km arms and a typical detected strain of 10^{-21}, the change in length is only 4×10^{-18} m.

Gravitational waves carry energy away from their source. The power radiated by a binary
system of two masses m_1 and m_2 orbiting with angular frequency ω at separation r is given 6
approximately by:
$P = (32/5) \times (G^4/c^5) \times (m_1 m_2)^2(m_1 + m_2)/r^5$
This shows that gravitational radiation is only significant for very massive objects in close
proximity moving at high speeds.

As binary systems lose energy through gravitational radiation, the orbit gradually shrinks
and the orbital frequency increases – a process called inspiral. The frequency of the 7
gravitational waves detected is twice the orbital frequency because the system produces
two "compressions" of spacetime per orbit as each mass passes through the same point.

The gravitational wave signal from a binary merger has three distinct phases visible in the
data. First is the inspiral phase, where the objects spiral closer together over thousands of 8
orbits, producing waves of gradually increasing frequency and amplitude. Then comes the
merger phase, where the two objects combine in a violent collision lasting only milliseconds.
Finally, the ringdown phase occurs as the merged object settles into its final configuration,
much like a struck bell gradually stops ringing.

LIGO's laser operates at a wavelength of 1064 nm in vacuum. However, the effective optical
path length is dramatically increased through the use of Fabry-Pérot cavities. Each arm 9
acts as a resonant cavity where the light bounces back and forth approximately 280 times
before exiting, effectively increasing the arm length to around 1120 km for the purposes of
detecting the phase shift.

The discovery of gravitational waves has opened an entirely new window on the universe.
Unlike electromagnetic radiation, gravitational waves pass through matter almost completely 10
unimpeded. This means we can observe events that would be invisible to traditional
telescopes, such as black hole mergers. Furthermore, by comparing the arrival times of
gravitational waves at different detectors around the world, scientists can triangulate the
source position in the sky. The detection of gravitational waves from a neutron star merger
in 2017, combined with simultaneous observation by conventional telescopes, marked the
beginning of multi-messenger astronomy and promises to revolutionize our understanding of
the cosmos.

7. Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

(a) Calculate the distance to the nearest star (other than the Sun) mentioned in paragraph 2, if the change in distance equivalent to "the width of a human hair" is taken to be 0.10 mm.

[2]

(b) (i) Explain why LIGO uses two perpendicular arms rather than a single arm to detect gravitational waves (see paragraph 3).

[2]

(ii) A gravitational wave passes through LIGO with a strain of 1.2×10^{-21}. Calculate the change in length, ΔL, of one 4.0 km arm (see paragraphs 4 and 5).

[2]

(c) The mirrors in LIGO have a mass of 40 kg and are suspended as pendulums. Calculate the time period of oscillation if the effective length of the pendulum is 0.50 m. Explain why this suspension system helps isolate the mirrors from high-frequency vibrations (see paragraph 4).

[3]

(d) Show that the change in length that LIGO must detect (10^{-18} m) is indeed approximately one-thousandth the diameter of a proton. Take the diameter of a proton to be 1.7×10^{-15} m (see paragraph 4).

[2]

(e) Explain why the frequency of gravitational waves is twice the orbital frequency of a binary system (see paragraph 7).

[2]

(f) (i) The light in LIGO's arms bounces back and forth 280 times. Show that this gives an effective optical path length of approximately 1120 km for a 4.0 km arm (see paragraph 9).

[2]

(ii) Calculate the wavelength of LIGO's laser light when traveling through the arm cavities, given that the refractive index of the evacuated cavity is 1.00 and the vacuum wavelength is 1064 nm (see paragraph 9).

[1]

(g) A binary black hole system has two black holes of equal mass $M = 30M_\odot$ (where $M_\odot = 2.0 \times 10^{30}$ kg) orbiting at a separation of $r = 300$ km.

(i) Use the relationship between orbital velocity and centripetal force to show that the angular frequency ω of this system is approximately 190 rad s^{-1}.

[3]

(ii) Calculate the frequency of the gravitational waves produced by this system (see paragraph 7).

[1]

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