



GCE A LEVEL

1420U30 – 1

THURSDAY, 6 JUNE 2024 – MORNING

**PHYSICS – A2 UNIT 3
OSCILLATIONS AND NUCLEI**

2 hour 15 minutes plus your additional time allowance

Surname: _____

First name(s): _____

Centre Number: _____

Candidate Number: **2** _____

For Examiner's Use Only			
	Question	Maximum Mark	Mark Awarded
Section A	1.	10	
	2.	10	
	3.	11	
	4.	23	
	5.	7	
	6.	7	
	7.	12	
Section B	8.	20	
	Total	100	

ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a DATA BOOKLET.

ITEMS INCLUDED WITH QUESTION PAPER

A separate Diagram Booklet.

A separate Information Booklet.

The Diagram Booklet **MUST** be handed in to the invigilators and sent for marking.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball – point pen or your usual method.

Write your name, centre number and candidate number in the spaces on the front cover.

Answer **ALL** questions.

Write your answers in the spaces provided. If you run out of space, use the additional page(s) at the back of this booklet taking care to number the question(s) correctly.

(Turn over)

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 3 (a).

(Turn over)

2. (a) Explain what is meant by
‘centripetal acceleration’.

[2 marks]

continued on the next page . . .

(Turn over)

Question 2 continued

2. (b) The Earth has a radius of approximately **6370 km** and rotates about its axis once each day. A student stands at the equator.

(i) Show that the angular velocity of the student is approximately

$$7 \times 10^{-5} \text{ rad s}^{-1}$$

[2 marks]

continued on the next page . . .

(Turn over)

Question 2 (b) continued

2. (b) (ii) Determine the centripetal acceleration of the student.

[2 marks]

(iii) I. Determine the speed of the student around the circular path.

[2 marks]

continued on the next page . . .

(Turn over)

Question 2 (b) (iii) continued

2. (b) (iii) II. The student says, “this is a very high speed so my answer must be incorrect as I would feel the effects of this speed.” Discuss whether or not the student is correct.

[2 marks]

(Total for Question 2 = 10 marks)

(Turn over)

3. (a) Describe an experiment to investigate the variation of intensity of gamma radiation with the distance from a source. Consider the experimental set-up, data collection and analysis to confirm an inverse square law relationship (space has been provided for a diagram).

Question 3 continued

3. (b) Gamma radiation is known to cause cancer and microwaves are thought by some to be linked to brain cancer.

(i) Calculate the energy of a photon of:

**I. gamma radiation of wavelength
1.0 pm.**

[2 marks]

continued on the next page . . .

(Turn over)

Question 3 (b) (i) continued

3. (b) (i) II. microwave radiation of frequency 1.8 GHz.

[1 mark]

(ii) Some people claim that mobile phone usage increases the rate of brain cancer, while others say that it does not cause significant damage. What steps can be taken to investigate who is correct?

[2 marks]

(Total for Question 3 = 11 marks)

(Turn over)

4. Refer to the graph provided for Question 4 in the separate Diagram Booklet.

A 0.030 kg mass is suspended from a light, vertical spring. A student sets the mass to oscillate vertically. The position of the oscillating mass is tracked using a datalogger.

Measurements, taken over a time interval of approximately 1.50 s , are shown on the graph. The amplitude during this interval was 1.5 cm .

- (a) DRAW ON THE GRID the curve of best fit.

[2 marks]

- (b) Explain what is meant by the 'period of the oscillation'. Use the graph to support your answer.

[2 marks]

continued on the next page . . .

(Turn over)

Question 4 continued

4. (c) COMPLETE the expression for the displacement, y , of the mass.

$$y = 1.5 \cos \left(\left(\frac{2\pi}{\quad} \right) t \dots\dots \right) \text{ cm}$$

[2 marks]

- (d) (i) By drawing a tangent to the displacement–time curve, show that the maximum velocity of the oscillating mass is approximately 10 cm s^{-1}

[3 marks]

continued on the next page . . .

(Turn over)

Question 4 (d) continued

4. (d) (ii) Refer to the diagram for Question 4 (d) (ii) in the separate Diagram Booklet.

The diagram is a blank labelled grid of velocity against time. **SKETCH** the velocity–time graph for the oscillating mass on the grid.

[3 marks]

- (e) Catrin suggests that the 0.030 kg mass is oscillating with simple harmonic motion.

- (i) State what is meant by ‘simple harmonic motion’.

[2 marks]

continued on the next page . . .

(Turn over)

Question 4 (e) continued

4. (e) (ii) Calculate the value of the spring constant.

[3 marks]

continued on the next page . . .

(Turn over)

5. Bethan investigates damped oscillations and notices that the amplitude of an oscillating system decreases from 1.5 ± 0.1 cm to 0.5 ± 0.1 cm in 12 minutes.

(a) Suggest what causes the decrease in amplitude.

[1 mark]

- (b) This reduction in amplitude may be represented by:

$$A = A_0 e^{-\lambda t}$$

where A is the amplitude at time t , A_0 is the initial amplitude, and λ is a characteristic constant for the system.

By determining the maximum and minimum possible values of λ , determine its value and its ABSOLUTE uncertainty.

(Turn over)

Question 5 continued

- 5. (c) Give ONE example of damped motion that occurs in everyday life.**

[1 mark]

(Total for Question 5 = 7 marks)

Question 6 continued

6. (b) Calculate the activity of the $^{14}_6\text{C}$ after 7000 years as a percentage of its original activity.

[3 marks]

(Total for Question 6 = 7 marks)

(Turn over)

7. (a) State THREE assumptions of the kinetic theory of ideal gases.

[3 marks]

continued on the next page . . .

(Turn over)

Question 7 continued

7. (b) A container of fixed volume contains oxygen gas.

**Five molecules in the gas have
speeds 480, 521, 436, 445 and 503 m s⁻¹**

**(i) Determine the rms speed of these five
molecules.**

[2 marks]

continued on the next page . . .

(Turn over)

Question 7 (b) continued

- 7. (b) (ii) Determine the temperature of a sample of oxygen gas whose molecules have this rms speed.
(Relative molecular mass of oxygen = 32)**

[3 marks]

continued on the next page . . .

(Turn over)

Refer to SECTION B in the separate Information Booklet.

Answer all parts of Question 8 in your own words. Direct quotes from the original article will not be awarded marks.

8. (a) (i) Explain how Einstein's photoelectric equation arises from EQUATION 1 ($E = hf$) and the principle of conservation of energy (see Paragraphs 1 and 2).

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 (a) continued

- 8. (a) (ii) The intensity of light does not affect the maximum kinetic energy of photoelectrons emitted from the cathode of a photocell. State what electrical quantity is proportional to the intensity.**

[1 mark]

continued on the next page . . .

(Turn over)

Question 8 continued

8. (b) Show how the substitution

for r in EQUATION 3 $\left(p^2 = \frac{m_e e^2}{4\pi\epsilon_0 r} \right)$

using EQUATION 2 $\left(r = \frac{nh}{2\pi p} \right)$

gives EQUATION 4 $\left(p = \frac{m_e e^2}{2\epsilon_0 nh} \right)$

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 continued

8. (c) (i) Use EQUATION 9

$$\left(\text{Total energy (in eV)} = -\frac{m_e e^3}{8 \epsilon_0^2 n^2 h^2} \right)$$

to show that the energy of the $n = 1$ state of hydrogen is -13.6 eV .

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 (c) continued

8. (c) (ii) Use EQUATION 10

$$\left(\text{Total energy (in eV)} = -\frac{13.6}{n^2} \right)$$

to explain why the ionisation energy of hydrogen is 13.6 eV .

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 continued

8. (e) Explain how quantum tunnelling will provide a lower than expected value for V

(see EQUATION 11 $\left(eV = \frac{hc}{\lambda} \right)$
and Paragraph 14).

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 continued

8. (f) (i) Explain why an increased temperature provides a greater current in a LED (see Paragraph 15).

[2 marks]

(ii) Calculate a typical thermal kinetic energy of a particle at room temperature in eV and use this to explain why it is difficult to measure the “switch – on” voltage of a diode accurately.

(Turn over)

[4 marks]

TOTAL FOR SECTION B = 20 MARKS

END OF PAPER

TOTAL FOR PAPER = 100 MARKS

(Turn over)



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OSCILLATIONS AND NUCLEI**

**The Diagram Booklet MUST be handed in
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Diagram Booklet

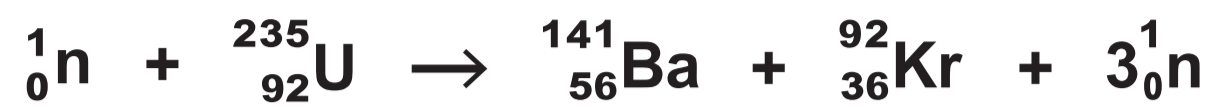
Surname: _____

First name(s): _____

Centre Number: _____

Candidate Number: 2 _____

Question 1



Masses:

$${}^{235}_{92}\text{U} = 235.043\,930\text{ u}$$

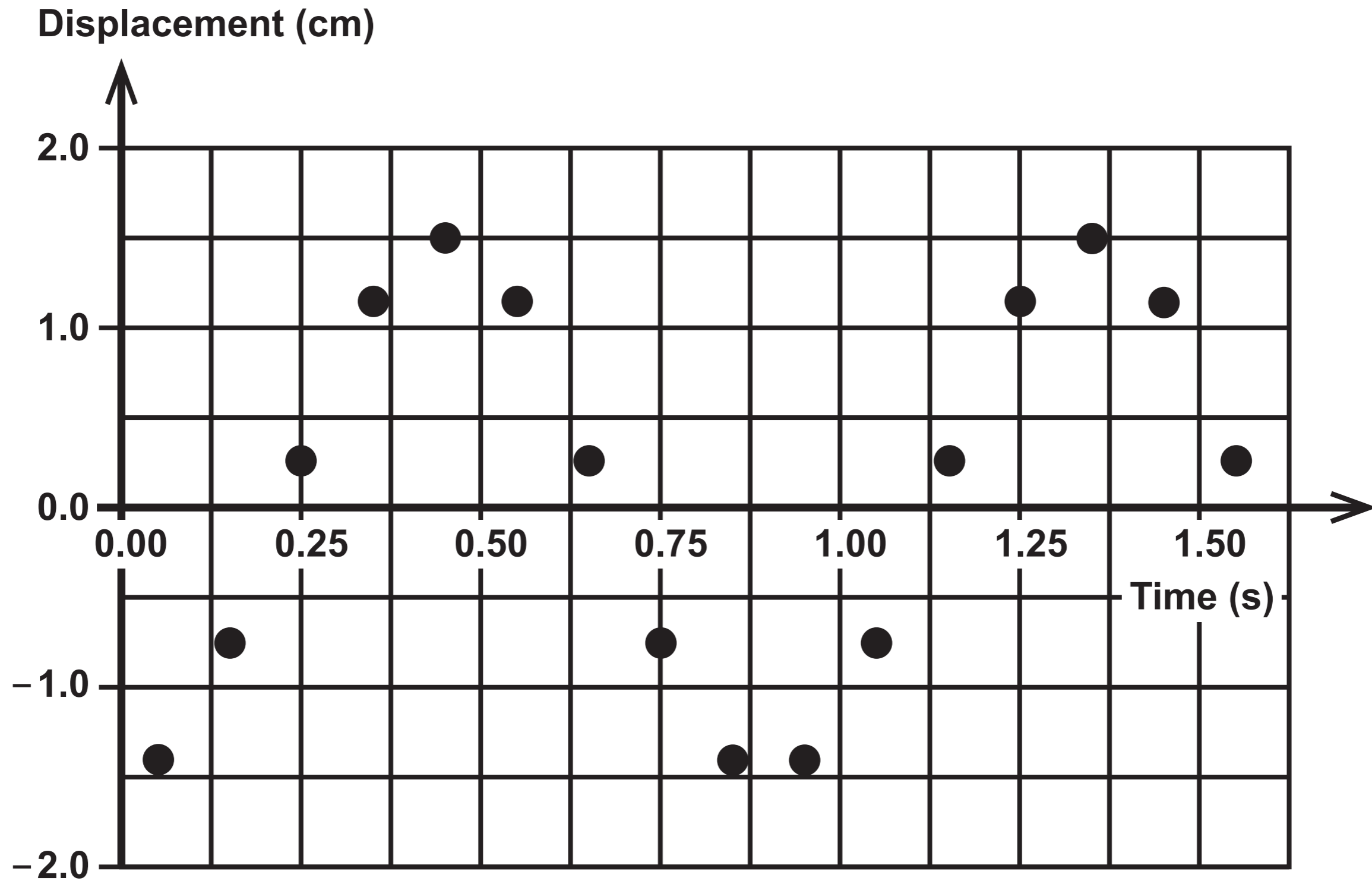
$${}^{141}_{56}\text{Ba} = 140.914\,412\text{ u}$$

$${}^{92}_{36}\text{Kr} = 91.926\,156\text{ u}$$

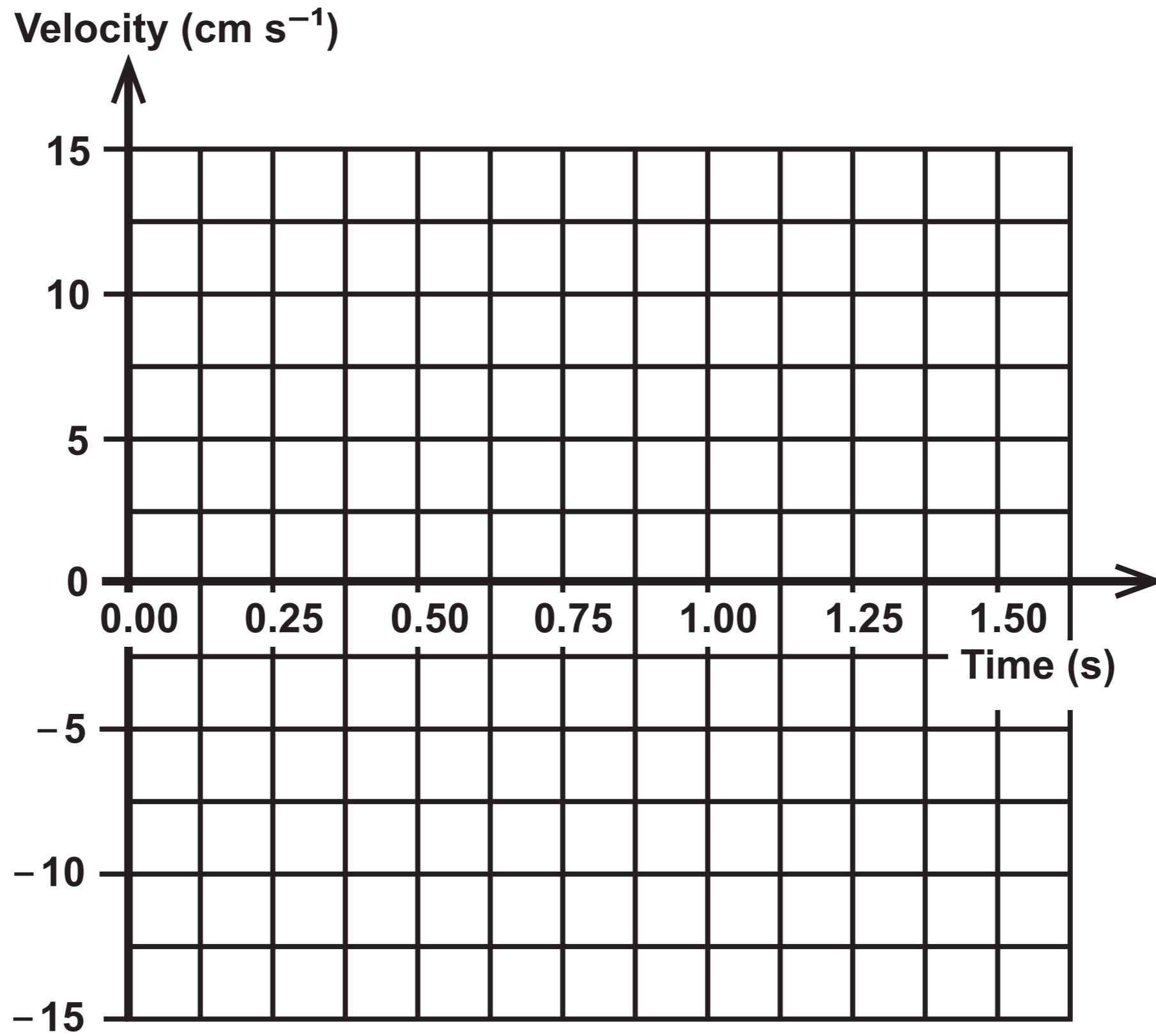
$$m_{\text{neutron}} = 1.008\,665\text{ u}$$

$$1\text{ u} = 931\text{ MeV}$$

Question 4



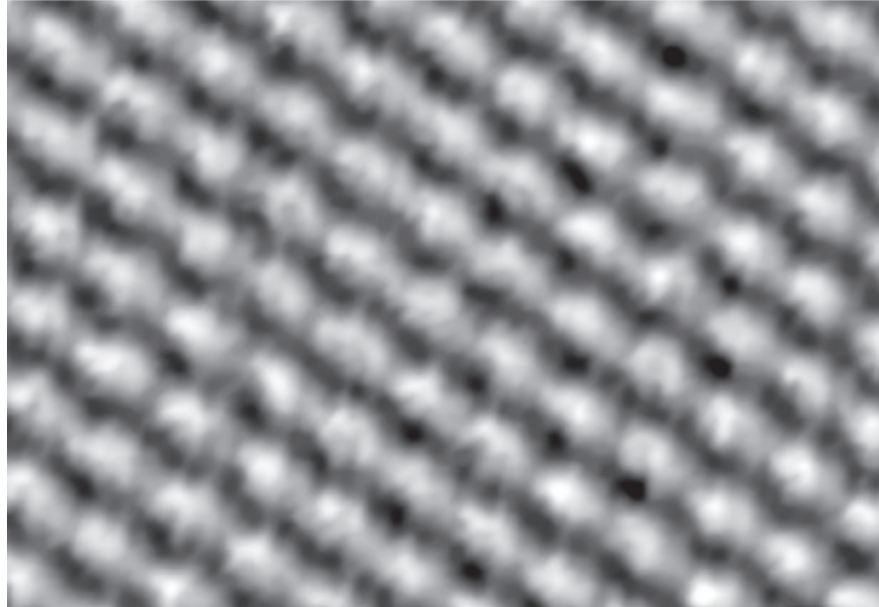
Question 4 (d) (ii)



Question 8

Paragraph 12

0 0.5 nm





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Information Booklet

PHYSICS – A2 UNIT 3

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SECTION B

Read through the following article carefully.

SOME INTERESTING ASPECTS OF QUANTUM PHYSICS**Paragraph 1**

The whole idea of quantum physics usually starts with the idea that the energy of photons is quantised. Following the work of Planck and Einstein, the smallest packet of electromagnetic energy (the photon) has an energy given by:

EQUATION 1

$$***E = hf***$$

continued on the next page . . .

(Turn over)

Paragraph 2

This simple little equation is no stranger to A level physics students but within six years of its inception it had solved the problems of black body radiation (by not allowing too many high energy photons) and the photoelectric effect (by explaining why the kinetic energy of photoelectrons depends on the wavelength of light and not its intensity).

continued on the next page . . .

(Turn over)

Paragraph 3

In **1913**, quantum physics took another enormous leap when Niels Bohr applied it to electron orbitals in atoms. In his new theory, the energy levels of electrons are quantised and electromagnetic radiation is emitted or absorbed when electrons make jumps from one quantised level to another. In a later interpretation of the Bohr theory, the circumference of any electron orbit must be a whole number of electron wavelengths (so that the electron's de Broglie wavelength leads to a stationary wave).

EQUATION 2

$$n \frac{h}{p} = 2\pi r \longrightarrow r = \frac{nh}{2\pi p}$$

continued on the next page . . .

(Turn over)

Paragraph 4

where n is an integer, p is the momentum of the electron and r the radius of its orbit. If we are concerned with the hydrogen atom, equating the electrostatic force between the proton and electron with the centripetal force leads to EQUATION 3 (m_e and e are the mass and charge of an electron and ϵ_0 the permittivity of free space).

EQUATION 3

$$\frac{m_e v^2}{r} = \frac{e^2}{4\pi\epsilon_0 r^2} \quad p^2 = \frac{m_e e^2}{4\pi\epsilon_0 r}$$

continued on the next page . . .

(Turn over)

Paragraph 5

Substituting for r in EQUATION 3 from EQUATION 2 gives:

EQUATION 4

$$p = \frac{m_e e^2}{2\epsilon_0 n h}$$

and the starting point of EQUATION 3 can also be used to show that the kinetic energy of the electron in its orbit is given by:

EQUATION 5

$$\frac{1}{2} m_e v^2 = \frac{e^2}{8\pi\epsilon_0 r}$$

continued on the next page . . .

(Turn over)

Paragraph 6

However, the electrostatic potential energy of the electron and proton in hydrogen is:

EQUATION 6

$$PE = -\frac{e^2}{4\pi\epsilon_0 r}$$

so that the total energy of the hydrogen atom is:

EQUATION 7

Total energy =

$$PE+KE = -\frac{e^2}{4\pi\epsilon_0 r} + \frac{e^2}{8\pi\epsilon_0 r} = -\frac{e^2}{8\pi\epsilon_0 r}$$

continued on the next page . . .

Paragraph 7

Using EQUATIONS 4 and 7 and the rather useful relationship:

EQUATION 8

$$\text{KE} = \frac{p^2}{2m}$$

it is reasonably straightforward to show that the total energy of the hydrogen atom is:

EQUATION 9

$$\text{Total energy (in eV)} = -\frac{p^2}{2m} = -\frac{m_e e^3}{8\epsilon_0^2 n^2 h^2}$$

continued on the next page . . .

(Turn over)

Paragraph 8

It turns out that when the integer $n = 1$, we have the ground state of hydrogen and $n = 2$ corresponds to the first excited state etc. By inputting $n = 1$ into EQUATION 9, we find that the energy of the ground state of hydrogen is approximately -13.6 eV .

Hence, the total energy of the n^{th} level of hydrogen (in eV) is given by EQUATION 10

EQUATION 10

$$\text{Total energy (in eV)} = -\frac{13.6}{n^2}$$

continued on the next page . . .

(Turn over)

Paragraph 9

The success and accuracy of Niels Bohr's theory of the hydrogen atom was almost unbelievable and meant that quantum physics was well and truly established as the main research topic in science for the next century.

Paragraph 10

When, in 1926, Erwin Schrödinger developed the quantum mechanical wave equation, there was another explosion in quantum physics research. Schrödinger's publication of 1926 included a complete (non – relativistic) solution of the hydrogen atom which is the foundation of the whole subject of chemistry!

continued on the next page . . .

(Turn over)

Paragraph 11

Another highlight directly obtainable from his famous wave equation is the concept of quantum mechanical tunnelling—where particles can tunnel through energy barriers that are too high for them. This is the explanation for alpha particles escaping from large nuclei in the process of alpha decay. The strong nuclear force is so great that the energy required for an alpha particle to escape a nucleus is far too big and no alpha particles should ever be detected. However, this tunnelling effect means that there is a small but finite chance that alpha particles can, indeed, escape.

Paragraph 12

This tunnelling effect has also led to microscopes that can “see” individual atoms e.g. the graphite atoms in the hexagonal pattern in the image provided for Question 8 paragraph 12 in the separate Diagram Booklet.

continued on the next page . . .

(Turn over)

Paragraph 13

Not only does quantum tunnelling occur in scanning tunnelling microscopes and radioactive alpha emission, it also had quite a significant effect on an experiment you carried out in Year 12.

Paragraph 14

It turns out that, when you carried out the LED experiment to measure the Planck constant, the relevant voltage was not the voltage applied to the LED when the tiniest amount of light was just about visible. That light could well be the result of quantum tunnelling and you will be putting a value of V into Equation 11 that is too small.

EQUATION 11

$$eV = \frac{hc}{\lambda}$$

continued on the next page . . .

(Turn over)

Paragraph 15

There are other complications to the design of LEDs that make obtaining the value of the Planck constant from this experiment inaccurate. One obvious factor is that an increased temperature allows more electrons to jump (rather than tunnel) across the energy gap. Other factors are the doping, thickness and position of the Fermi energy level but at this point I'm afraid we are getting a little too technical and should call it a day.