Surname	Centre Number	Candidate Number
First name(s)		2

wjec cbac

GCE A LEVEL

1420U30-1

S24-1420U30-1

THURSDAY, 6 JUNE 2024 – MORNING

PHYSICS – A2 unit 3
Oscillations and Nuclei

2 hours 15 minutes

	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**	

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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 **3(a)**.

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SECTION A

Answer **all** questions.

1. A fission reaction of uranium is:

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \longrightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

Masses:

$^{235}_{92}\text{U}$ = 235.043 930 u $^{141}_{56}\text{Ba}$ = 140.914 412 u $^{92}_{36}\text{Kr}$ = 91.926 156 u

m_{neutron} = 1.008 665 u 1 u = 931 MeV

(a) Calculate the energy released in this reaction giving your answer in MeV. [4]

(b) If 1.2 kg of $^{235}_{92}\text{U}$ undergoes this reaction, show that the total energy released is approximately 8.5×10^{13} J. [3]

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(c) An engineer at a nuclear power station claims that over two billion 11 W light bulbs could be powered for 1 hour by the energy released in part (b). Discuss whether or not her claim is correct. [One billion = 1×10^9] [3]

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2. (a) Explain what is meant by 'centripetal acceleration'. [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 7×10^{-5} rad s^{-1}. [2]

(ii) Determine the centripetal acceleration of the student. [2]

(iii) I. Determine the speed of the student around the circular path. [2]

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]

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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). [6 QER]

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(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]

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II. microwave radiation of frequency 1.8 GHz. [1]

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(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]

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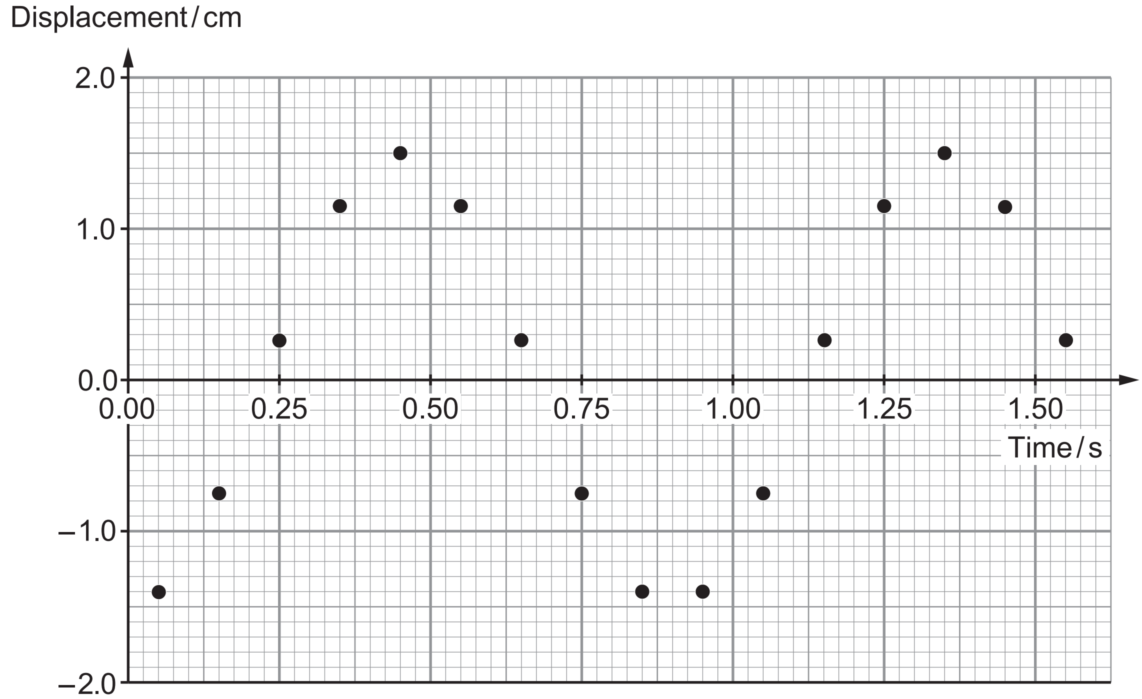
4. A 0.030 kg mass is suspended from a light, vertical spring. A student sets the mass to oscillate vertically. The position of the oscillating mass is tracked using a datalogger. Measurements, taken over a time interval of approximately 1.50 s, are shown on the graph below. The amplitude during this interval was 1.5 cm.



(a) **Draw on the grid** above the curve of best fit. [2]

(b) Explain what is meant by the 'period of the oscillation'. Use the graph to support your answer. [2]

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(c) **Complete** the expression for the displacement, y, of the mass. [2]

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

Examiner only

(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]

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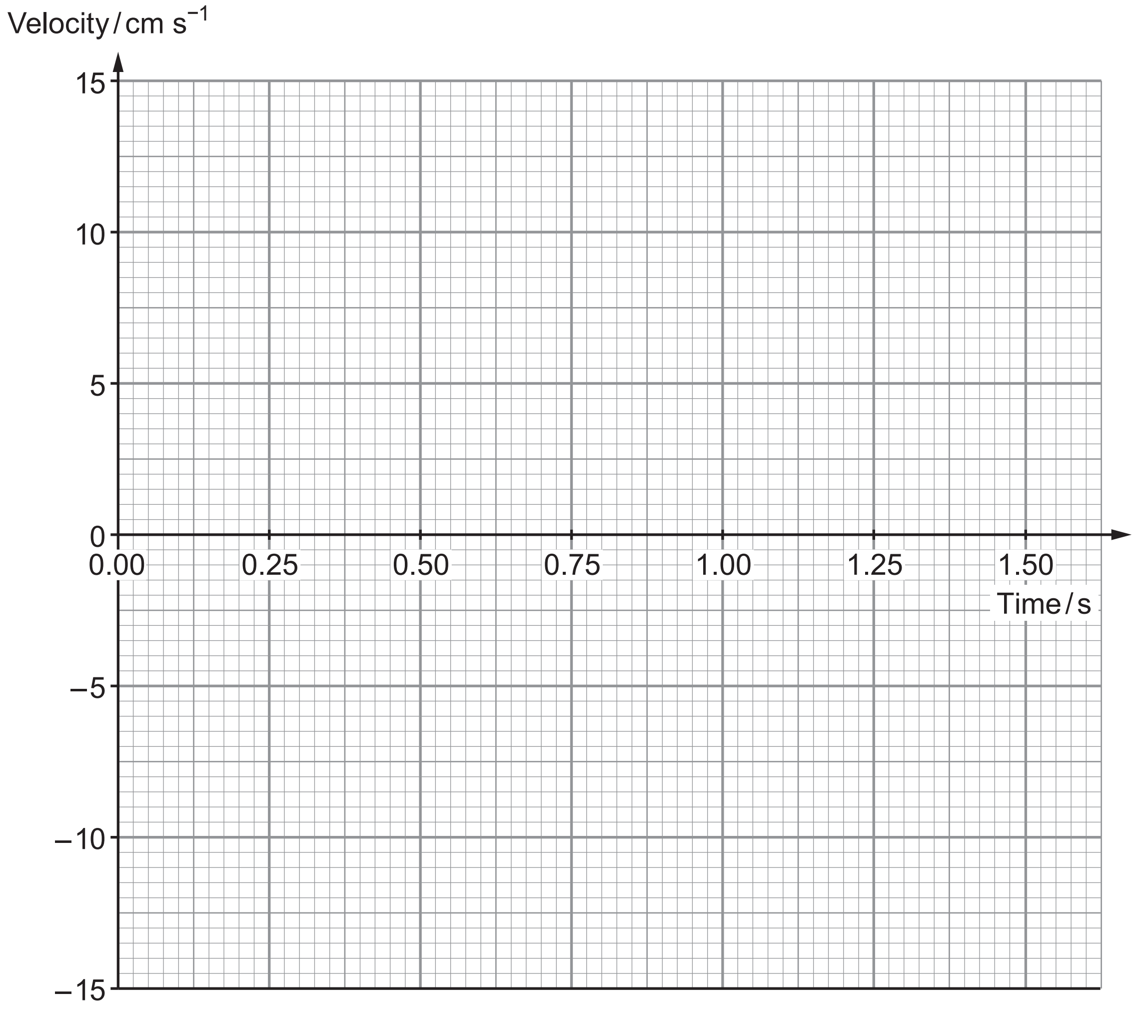
(ii) **Sketch** the velocity-time graph for the oscillating mass on the grid below. [3]



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(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]

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(ii) Calculate the value of the spring constant. [3]

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(f) Catrin also claims that the maximum elastic potential energy stored by the spring is far greater than the maximum kinetic energy of the mass. Evaluate whether or not this claim is correct.

Amplitude of the motion = 1.5 cm

Mass = 0.030 kg

Maximum speed = approximately 10 cm s^{-1} [6]

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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]

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(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. [5]

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(c) Give **one** example of damped motion that occurs in everyday life. [1]

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6. The beta decay of ${}^{14}_{6}\mathrm{C}$ can be used for dating organic samples. The half-life of ${}^{14}_{6}\mathrm{C}$ is 5730 years.
The percentage of ${}^{14}_{6}\mathrm{C}$ atoms in a piece of wood from an old boat is found to have **decreased by** 30% since it was formed from living material.

(a) Estimate the age of the boat. [4]

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(b) Calculate the activity of the ${}^{14}_{6}\mathrm{C}$ after 7000 years as a percentage of its original activity. [3]

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7. (a) State **three** assumptions of the kinetic theory of ideal gases. [3]

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(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]

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(ii) Determine the temperature of a sample of oxygen gas whose molecules have this rms speed. (Relative molecular mass of oxygen = 32.) [3]

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(c) Gareth states that when the temperature of the gas is doubled both the rms speed of the molecules and the pressure are doubled. Determine whether or not Gareth is correct. [4]

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SECTION B

Answer **all** questions.

8. Read through the following article carefully. Paragraph

Some Interesting Aspects of Quantum Physics

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: 1

$$E = hf \quad \textbf{Equation 1}$$

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). 2

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). 3

$$n\frac{h}{p} = 2\pi r \quad \rightarrow \quad r = \frac{nh}{2\pi p} \quad \textbf{Equation 2}$$

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). 4

$$\frac{m_e v^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2} \quad \rightarrow \quad p^2 = \frac{m_e e^2}{4\pi\varepsilon_0 r} \quad \textbf{Equation 3}$$

Substituting for r in Equation 3 from Equation 2 gives: 5

$$p = \frac{m_e e^2}{2\varepsilon_0 nh} \quad \textbf{Equation 4}$$

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:

$$\frac{1}{2}m_e v^2 = \frac{e^2}{8\pi\varepsilon_0 r} \quad \textbf{Equation 5}$$

However, the electrostatic potential energy of the electron and proton in hydrogen is: 6

$$\mathrm{PE} = -\frac{e^2}{4\pi\varepsilon_0 r} \quad \textbf{Equation 6}$$

so that the total energy of the hydrogen atom is:

$$\text{Total energy} = \mathrm{PE} + \mathrm{KE} = -\frac{e^2}{4\pi\varepsilon_0 r} + \frac{e^2}{8\pi\varepsilon_0 r} = -\frac{e^2}{8\pi\varepsilon_0 r} \quad \textbf{Equation 7}$$

Using Equations 4 and 7 and the rather useful relationship: 7

$$\mathrm{KE} = \frac{p^2}{2m} \quad \textbf{Equation 8}$$

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

$$\text{Total energy (in eV)} = -\frac{p^2}{2m} = -\frac{m_e e^3}{8{\varepsilon_0}^2 n^2 h^2} \quad \textbf{Equation 9}$$

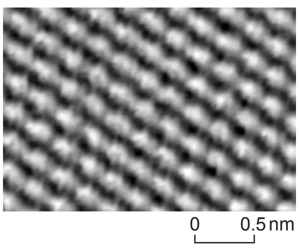
It turns out that when the integer n = 1, we have the ground state of hydrogen and n = 2
corresponds to the first excited state etc. By inputting n = 1 into Equation 9, we find that 8
the energy of the ground state of hydrogen is approximately -13.6 eV. Hence, the total
energy of the n^{th} level of hydrogen (in eV) is given by Equation 10.

$$\text{Total energy (in eV)} = -\frac{13.6}{n^2} \quad \textbf{Equation 10}$$

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 9
research topic in science for the next century.

When, in 1926, Erwin Schrödinger developed the quantum mechanical wave equation,
there was another explosion in quantum physics research. Schrödinger's publication of 10
1926 included a complete (non-relativistic) solution of the hydrogen atom which is the
foundation of the whole subject of chemistry!

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 11
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.



This tunnelling effect has also led to microscopes that can "see"
individual atoms e.g. the graphite atoms in the hexagonal pattern in 12
the image.

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 13
carried out in Year 12.

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 14
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.

$$eV = \frac{hc}{\lambda} \quad \textbf{Equation 11}$$

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. 15
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.

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

(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]

(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]

(b) Show how the substitution for r in Equation 3 $\left(p^2 = \frac{m_e e^2}{4\pi\varepsilon_0 r}\right)$ using Equation 2 $\left(r = \frac{nh}{2\pi p}\right)$ gives Equation 4 $\left(p = \frac{m_e e^2}{2\varepsilon_0 nh}\right)$. [2]

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(c) (i) Use Equation 9 $\left(\text{Total energy (in eV)} = -\dfrac{m_e e^3}{8\varepsilon_0{}^2 n^2 h^2}\right)$ to show that the energy of the $n = 1$ state of hydrogen is −13.6 eV. [2]

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(ii) Use Equation 10 $\left(\text{Total energy (in eV)} = -\dfrac{13.6}{n^2}\right)$ to explain why the ionisation energy of hydrogen is 13.6 eV. [2]

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(d) A student suggests that the hydrogen 656 nm red line is emitted from a hydrogen atom when an electron drops from the second excited level ($n = 3$) to the first excited level ($n = 2$). Determine whether or not this is true.

Use Equation 10 $\left(\text{Total energy (in eV)} = -\dfrac{13.6}{n^2}\right)$. [3]

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(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]

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(f) (i) Explain why an increased temperature provides a greater current in a LED (see Paragraph 15). [2]

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(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. [4]

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END OF PAPER

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