Ch 12 *[130 marks]*

1. Two radioactive nuclides, X and Y, have half-lives of 50 s and 100 s respectively. At time t = 0 samples of X and Y contain the same number of nuclei. *[1 mark]*

   What is $\frac{\text{number of nuclei of X undecayed}}{\text{number of nuclei of Y undecayed}}$ when t = 200 s?

   A. 4

   B. 2

   C. $\frac{1}{2}$

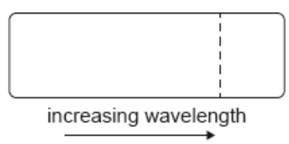
   D. $\frac{1}{4}$

Markscheme

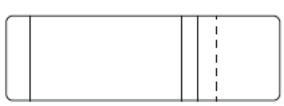
D

---

2. According to the Bohr model for hydrogen, visible light is emitted when electrons make transitions from excited states down to the state with n = 2. The dotted line in the following diagram represents the transition from n = 3 to n = 2 in the spectrum of hydrogen. *[1 mark]*



   Which of the following diagrams could represent the visible light emission spectrum of hydrogen?

A.


B.


C.


D.


Markscheme

B

3. Alpha particles with energy E are directed at nuclei with atomic number Z. Small deviations from the predictions of the Rutherford scattering model are observed. *[1 mark]*

Which change in E and which change in Z is most likely to result in greater deviations from the Rutherford scattering model?

	E	Z
A.	increase	increase
B.	increase	decrease
C.	decrease	increase
D.	decrease	decrease

Markscheme

B

4. Which of the following is evidence for the wave nature of the electron? *[1 mark]*

A. Continuous energy spectrum in β^- decay

B. Electron diffraction from crystals

C. Existence of atomic energy levels

D. Existence of nuclear energy levels

Markscheme

B

5. An electron of initial energy E tunnels through a potential barrier. What is the energy of the electron after tunnelling? *[1 mark]*

A. greater than E

B. E

C. less than E

D. zero

Markscheme

B

6. Two samples X and Y of different radioactive isotopes have the same initial activity. Sample X has twice the number of atoms as sample Y. The half-life of X is *T*. What is the half-life of Y? *[1 mark]*

A. 2*T*

B. *T*

C. $\frac{T}{2}$

D. $\frac{T}{4}$

Markscheme

C

The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus (*β*–) decay to form a stable boron (B) nuclide.

7a. Identify the missing information for this decay. *[2 marks]*

$$^{10}_{\square}\mathrm{Be} \rightarrow {}^{\square}_{5}\mathrm{B} + {}^{\square}_{\square}\mathrm{e} + {}^{0}_{0}\square$$

Markscheme

$^{10}_{4}\mathrm{Be} \rightarrow {}^{10}_{5}\mathrm{B} + {}^{0}_{-1}\mathrm{e} + \overline{\mathrm{V}}_{\mathrm{e}}$

antineutrino ***AND*** charge ***AND*** mass number of electron ${}^{0}_{-1}\mathrm{e}$, $\overline{\mathrm{V}}$

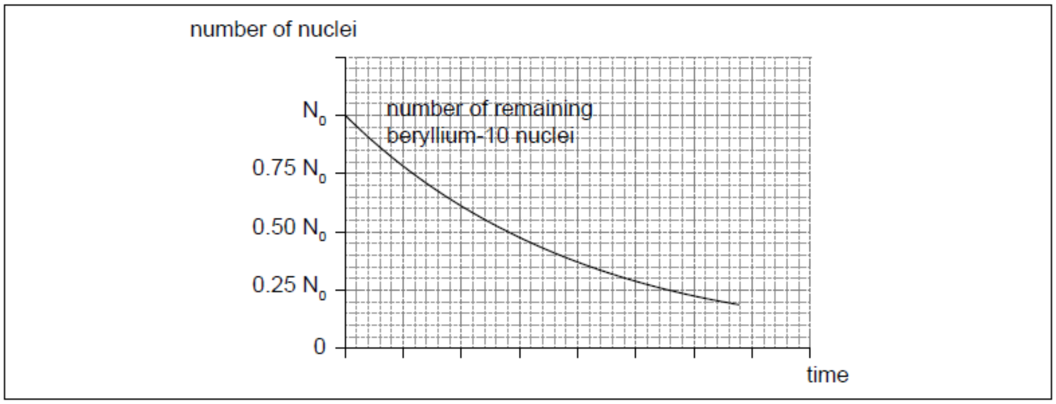
conservation of mass number ***AND*** charge ${}^{10}_{5}\mathrm{B}$, ${}^{10}_{4}\mathrm{Be}$

Do not accept V.

Accept $\bar{V}$ *without subscript e.*

[2 marks]

The initial number of nuclei in a pure sample of beryllium-10 is N_0. The graph shows how the number of remaining **beryllium** nuclei in the sample varies with time.

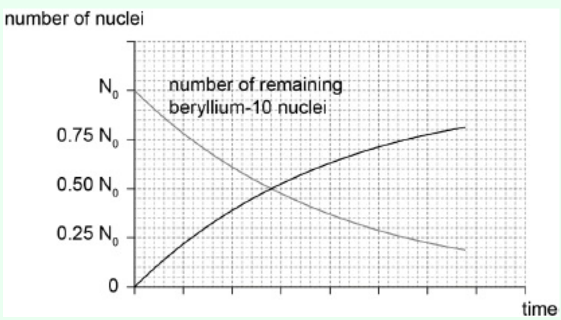


7b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

Markscheme

correct shape *ie* increasing from 0 to about 0.80 N_0

crosses given line at 0.50 N_0



[2 marks]

7c. After 4.3×10^6 years, *[3 marks]*

$$\frac{\text{number of produced boron nuclei}}{\text{number of remaining beryllium nuclei}} = 7.$$

Show that the half-life of beryllium-10 is 1.4×10^6 years.

Markscheme

ALTERNATIVE 1

fraction of Be = $\frac{1}{8}$, 12.5%, or 0.125

therefore 3 half lives have elapsed

$t_{\frac{1}{2}} = \frac{4.3\times10^6}{3} = 1.43 \times 10^6$ «≈ 1.4×10^6» «y»

ALTERNATIVE 2

fraction of Be = $\frac{1}{8}$, 12.5%, or 0.125

$\frac{1}{8} = \mathrm{e}^{-\lambda}(4.3 \times 10^6)$ leading to $\lambda = 4.836 \times 10^{-7}$ «y»$^{-1}$

$\frac{\ln 2}{\lambda}$ = 1.43×10^6 «y»

Must see at least one extra sig fig in final answer.

[3 marks]

7d. Beryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6×10^{11} atoms of beryllium-10. The present activity of the sample is 8.0×10^{-3} Bq. *[3 marks]*

Determine, in years, the age of the sample.

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

λ «= $\frac{\ln 2}{1.4\times10^{6}}$» = 4.95×10^{-7} «y^{-1}»

rearranging of $A = \lambda N_0 e^{-\lambda t}$ to give $-\lambda t = \ln \frac{8.0\times10^{-3}\times365\times24\times60\times60}{4.95\times10^{-7}\times7.6\times10^{11}}$ «= –0.400»

$t = \frac{-0.400}{-4.95\times10^{-7}} = 8.1 \times 10^{5}$ «y»

Allow ECF from MP1

[3 marks]

An ice sample is moved to a laboratory for analysis. The temperature of the sample is –20 °C.

7e. State what is meant by thermal radiation. *[1 mark]*

. . . .

. . . .

. . . .

Markscheme

emission of (infrared) electromagnetic/infrared energy/waves/radiation.

[1 mark]

7f. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. *[2 marks]*

. . . .

. . . .

. . . .

Markscheme

the (peak) wavelength of emitted em waves depends on temperature of emitter/reference to Wein’s Law

so frequency/color depends on temperature

[2 marks]

7g. Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. *[2 marks]*

Markscheme

$\lambda = \frac{2.90 \times 10^{-3}}{253}$

= 1.1×10^{-5} «m»

Allow ECF from MP1 (incorrect temperature).

[2 marks]

7h. The temperature in the laboratory is higher than the temperature of the ice sample. Describe **one** other energy transfer that occurs between the ice sample and the laboratory. *[2 marks]*

Markscheme

from the laboratory to the sample

conduction – contact between ice and lab surface.

OR

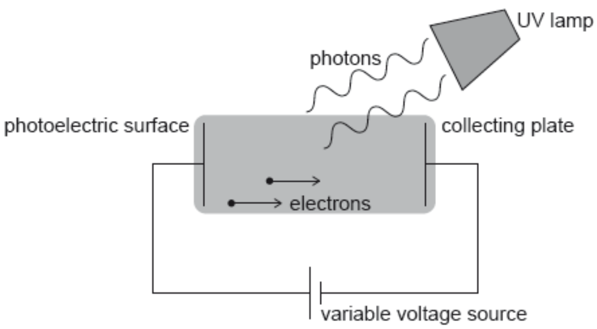
convection – movement of air currents

Must clearly see direction of energy transfer for MP1.

Must see more than just words “conduction” or “convection” for MP2.

[2 marks]

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



8a. Show that the energy of photons from the UV lamp is about 10 eV. *[2 marks]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

$E_1 = -13.6$ «eV» $E_2 = -\frac{13.6}{4} = -3.4$ «eV»

energy of photon is difference $E_2 - E_1 = 10.2$ «≈ 10 eV»

Must see at least 10.2 eV.

[2 marks]

The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

8b. Calculate, in J, the maximum kinetic energy of the emitted electrons. *[2 marks]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

$10 - 5.1 = 4.9$ «eV»

$4.9 \times 1.6 \times 10^{-19} = 7.8 \times 10^{-19}$ «J»

Allow 5.1 *if* 10.2 *is used to give* 8.2×10^{-19} «J».

8c. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. *[2 marks]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

EPE produced by battery

exceeds maximum KE of electrons / electrons don't have enough KE

For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.

[2 marks]

8d. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. *[1 mark]*

. . . .

. . . .

. . . .

Markscheme

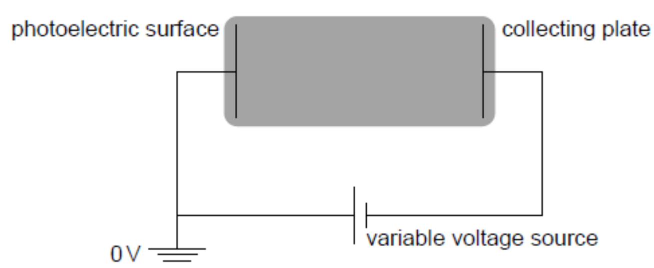
4.9 «V»

Allow 5.1 if 10.2 is used in (b)(i).

Ignore sign on answer.

[1 mark]

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.

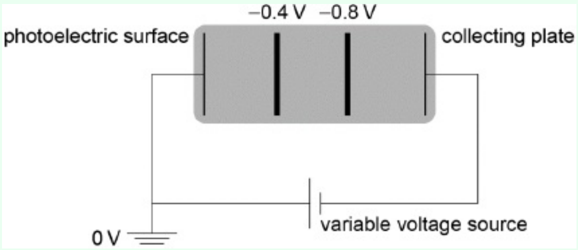


8e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. *[2 marks]*

Markscheme

two equally spaced vertical lines (judge by eye) at approximately 1/3 and 2/3

labelled correctly



[2 marks]

8f. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. *[2 marks]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

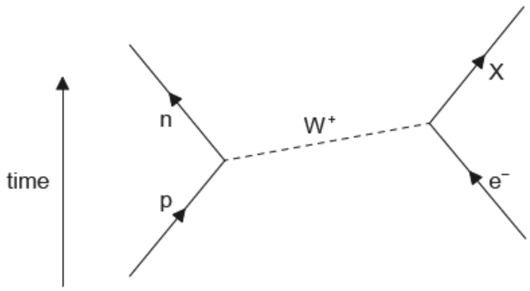
kinetic energy at collecting plate = 0.9 «eV»

speed = « $\sqrt{\frac{2\times0.9\times1.6\times10^{-19}}{9.11\times10^{-31}}}$ » = 5.6×10^5 «ms^{-1}»

Allow ECF from MP1

[2 marks]

The Feynman diagram shows electron capture.



9a. State and explain the nature of the particle labelled X. *[3 marks]*

Markscheme

«electron» neutrino

it has a lepton number of 1 «as lepton number is conserved»

it has a charge of zero/is neutral «as charge is conserved»
OR
it has a baryon number of 0 «as baryon number is conserved»

Do not allow antineutrino

Do not credit answers referring to energy

Particles can be used in scattering experiments to estimate nuclear sizes.

9b. Outline how these experiments are carried out. *[2 marks]*

Markscheme

«high energy particles incident on» thin sample

detect angle/position of deflected particles

reference to interference/diffraction/minimum/maximum/numbers of particles

Allow "foil" instead of thin

9c. Outline why the particles must be accelerated to high energies in scattering experiments. *[3 marks]*

....

....

....

....

....

....

Markscheme

$\lambda \propto \frac{1}{\sqrt{E}}$ ***OR*** $\lambda \propto \frac{1}{E}$

so high energy gives small λ

to match the small nuclear size

Alternative 2

$E = hf$/energy is proportional to frequency

frequency is inversely proportional to wavelength/ $c = f\lambda$

to match the small nuclear size

Alternative 3

higher energy means closer approach to nucleus

to overcome the repulsive force from the nucleus

so greater precision in measurement of the size of the nucleus

Accept inversely proportional

Only allow marks awarded from ***one*** *alternative*

9d. State and explain **one** example of a scientific analogy. *[2 marks]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

two analogous situations stated

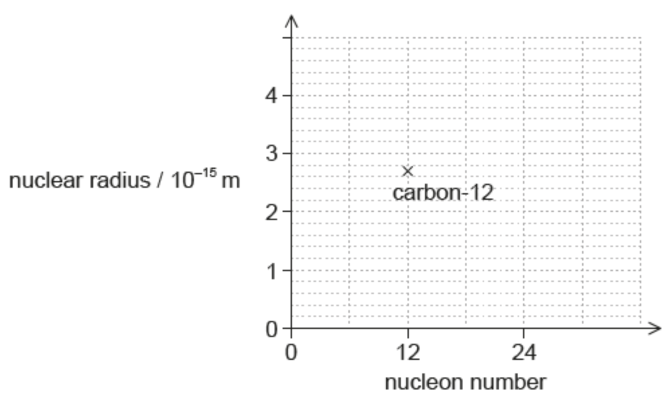
one element of the analogy equated to an element of physics

eg: moving away from Earth is like climbing a hill where the contours correspond to the equipotentials

Atoms in an ideal gas behave like pool balls

The forces between them only act during collisions

Electron diffraction experiments indicate that the nuclear radius of carbon-12 is 2.7×10^{-15} m. The graph shows the variation of nuclear radius with nucleon number. The nuclear radius of the carbon-12 is shown on the graph.



9e. Plot the position of magnesium-24 on the graph. *[1 mark]*

Markscheme

correctly plotted

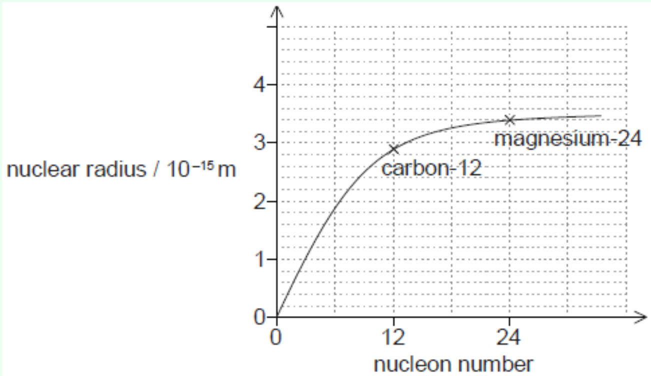
Allow ECF from (d)(i)

9f. Draw a line on the graph, to show the variation of nuclear radius with nucleon number. *[2 marks]*

Markscheme

single smooth curve passing through both points with decreasing gradient

through origin



---

10. The diameter of a silver-108 ($^{108}_{47}Ag$) nucleus is approximately three times that of the diameter of a nucleus of *[1 mark]*

A. $^{4}_{2}He.$

B. $^{7}_{3}Li.$

C. $^{11}_{5}B.$

D. $^{20}_{10}Ne.$

Markscheme

A

11. What can be used to calculate the probability of finding an electron in a particular region of space? *[1 mark]*

A. $\frac{\text{Planck's constant}}{4\pi\times\text{uncertainty in energy}}$

B. $\frac{\text{Planck's constant}}{4\pi\times\text{uncertainty in speed}}$

C. The magnitude of the wave function

D. The magnitude of the (wave function)^2

Markscheme

D

---

12. Electron capture can be represented by the equation *[1 mark]*

$p + e^{-} \rightarrow X + Y$.

What are X and Y?

	X	Y
A.	proton	positron
B.	electron	positron
C.	neutron	electron antineutrino
D.	neutron	electron neutrino

Markscheme

D

13. An electron of mass *m* has an uncertainty in its position *r*. What is the uncertainty in the speed of this electron? *[1 mark]*

A. $\frac{h}{4\pi r}$

B. $\frac{hr}{4\pi m}$

C. $\frac{hm}{4\pi r}$

D. $\frac{h}{4\pi mr}$

Markscheme

D

14a. A particular K meson has a quark structure $\bar{u}s$. State the charge, strangeness and baryon number for this meson. *[2 marks]*

Charge: . . . .

Strangeness: . . . .

Baryon number: . . . .

Markscheme

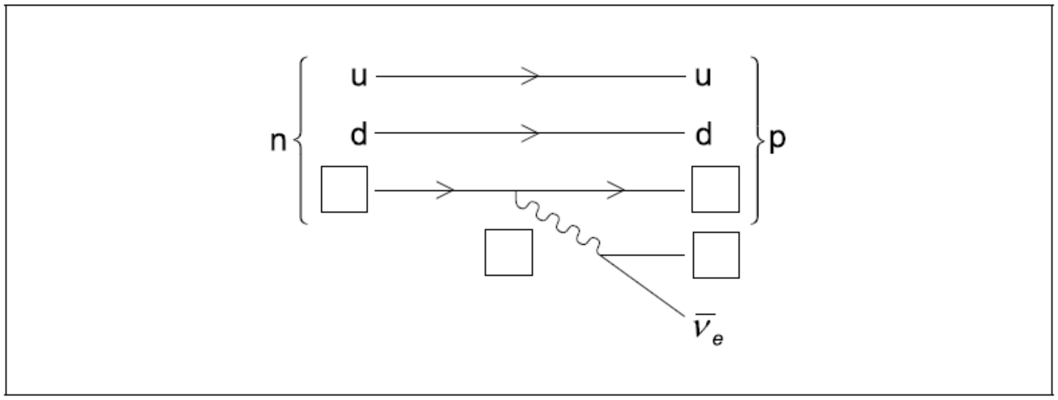
charge: –1 «e» ***or*** negative ***or*** K^{-}

strangeness: –1

baryon number: 0

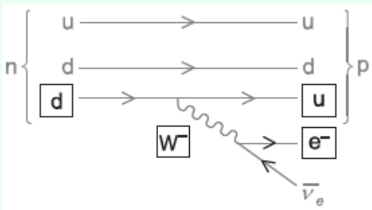
Negative signs required.
Award **[2]** for three correct answers, **[1 max]** for two correct answer and **[0]** for one correct answer.

14b. The Feynman diagram shows the changes that occur during beta minus (β^-) decay. *[3 marks]*



Label the diagram by inserting the **four** missing particle symbols **and** the direction of the arrows for the decay particles.

Markscheme



correct symbols for both missing quarks

exchange particle and electron labelled W ***or*** W^- and e ***or*** e^-

*Do not allow W^+ **or** e^+ **or** β^+. Allow β **or** β^-.*

arrows for both electron and anti-neutrino correct

Allow ECF from previous marking point.

14c. C-14 decay is used to estimate the age of an old dead tree. The activity of C-14 in the dead tree is determined to have **fallen to** 21% of its original value. C-14 has a half-life of 5700 years. *[4 marks]*

(i) Explain why the activity of C-14 in the dead tree decreases with time.

(ii) Calculate, in years, the age of the dead tree. Give your answer to an appropriate number of significant figures.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

Markscheme

i

number of C-14 atoms/nuclei are decreasing

OR

decreasing activity proportional to number of C-14 atoms/nuclei

OR

$A = A_0 e^{-\lambda t}$ so A decreases as t increases

Do not allow "particles"

Must see reference to atoms or nuclei or an equation, just "C-14 is decreasing" is not enough.

ii

$0.21 = (0.5)^n$

OR

$$0.21 = e^{-\left(\frac{\ln 2\times t}{5700}\right)}$$

n = 2.252 half-lives or t =1 2834 «y»

Early rounding to 2.25 gives 12825 y

13000 y rounded correctly to two significant figures:

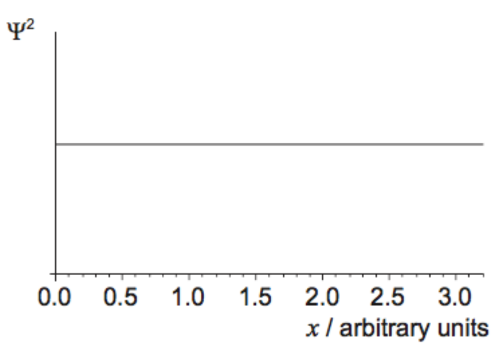
Both needed; answer must be in year for MP3.

Allow ECF from MP2.

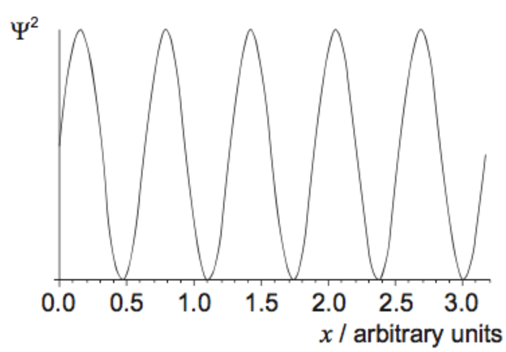
*Award **[3]** for a bald correct answer.*

15. The graphs show the variation with distance x of the square of the amplitude Ψ^2 of the wave function of a particle. Which graph corresponds to a particle with the largest uncertainty in momentum? *[1 mark]*

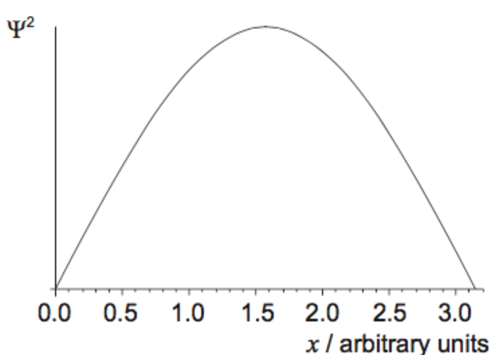
A.



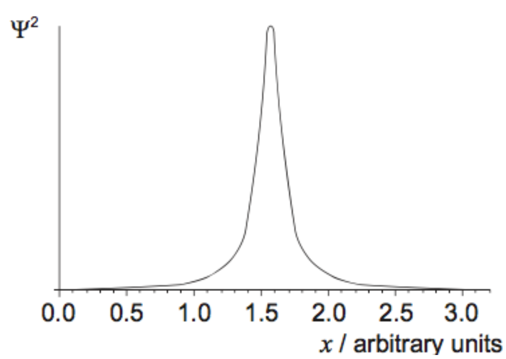
B.



C.



D.



Markscheme

D

16. Deviations from Rutherford scattering are detected in experiments carried out at high energies. What can be deduced from these deviations? *[1 mark]*

A. The impact parameter of the collision

B. The existence of a force different from electrostatic repulsion

C. The size of alpha particles

D. The electric field inside the nucleus

Markscheme

B

17a. An alpha particle with initial kinetic energy 32 MeV is directed head-on at a nucleus of gold-197 $\left({}^{197}_{79}\mathrm{Au}\right)$. *[5 marks]*

(i) Show that the distance of closest approach of the alpha particle from the centre of the nucleus is about 7×10^{-15}m.

(ii) Estimate the density of a nucleus of ${}^{197}_{79}\mathrm{Au}$ using the answer to (a)(i) as an estimate of the nuclear radius.

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

(i)
32 MeV converted using $32\times10^{6}\times1.6\times10^{-19}$ «$=5.12\times10^{-12}$J»

$$d = \ll \frac{kQq}{E} = \frac{8.99\times10^{9}\times2\times79\times\left(1.6\times10^{-19}\right)^{2}}{32\times10^{6}\times1.6\times10^{-19}} = \gg \frac{8.99\times10^{9}\times2\times79\times1.6\times10^{-19}}{32\times10^{6}}$$

OR 7.102×10^{-15}m

«$d\approx7\times10^{-15}$m»

Must see final answer to 2+ SF unless substitution is completely correct with value for k explicit.
Do not allow an approach via $r = R_0A^{\frac{1}{3}}$.

(ii)
$m\approx197\times1.661\times10^{-27}$
OR
3.27×10^{-25}kg

$$V = \frac{4\pi}{3}\times\left(7\times10^{-15}\right)^{3}$$

OR

$1.44\times10^{-42}\text{m}^{-3}$

$$\rho = \ll \frac{m}{V} = \frac{3.2722\times10^{-25}}{1.4368\times10^{-42}} = \gg 2.28\times10^{17}\approx2\times10^{17}\text{kgm}^{-3}$$

Allow working in MeV: 1.28×10^{47}MeVc^{-2}m^{-3}.
Allow ECF from incorrect answers to MP1 or MP2.

17b. The nucleus of ${}^{197}_{79}\text{Au}$ is replaced by a nucleus of the isotope ${}^{195}_{79}\text{Au}$. Suggest the change, if any, to your answers to (a)(i) and (a)(ii). *[2 marks]*

Distance of closest approach:

Estimate of nuclear density:

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

Distance of closest approach: charge ***or*** number of protons ***or*** force of repulsion is the same so distance is the same

Estimate of nuclear density: « $\rho \propto \frac{A}{\left(A^{\frac{1}{3}}\right)^3}$ so» density the same

17c. An alpha particle is confined within a nucleus of gold. Using the uncertainty principle, estimate the kinetic energy, in MeV, of the alpha particle. *[3 marks]*

....

....

....

....

....

....

Markscheme

$\Delta x \approx 7 \times 10^{-15}$ m

$\Delta p \approx \frac{6.63 \times 10^{-34}}{4\pi \times 7 \times 10^{-15}} \ll= 7.54 \times 10^{-21}\mathrm{Ns} \gg$

$E \approx \ll \frac{\Delta p^2}{2m} = \frac{(7.54 \times 10^{-21})^2}{2 \times 6.6 \times 10^{-27}} = 4.3 \times 10^{-15}\mathrm{J} = 26897\mathrm{eV} \gg \approx 0.027\mathrm{MeV}$

Accept $\Delta x \approx 3.5 \times 10^{-15}$m or $\Delta x \approx 1.4 \times 10^{-14}$m leading to E≈0.11MeV or 0.0067MeV.
Answer must be in MeV.

18. When electromagnetic radiation falls on a photocell, electrons of mass m_e are emitted, provided the frequency of the radiation is greater than f_0. What is the maximum speed of the electron when radiation of frequency f falls on the photocell? *[1 mark]*

A. $\sqrt{\frac{2hf}{m_e}}$

B. $\sqrt{\frac{2h(f-f_0)}{m_e}}$

C. $\sqrt{\frac{hf}{m_e}}$

D. $\sqrt{\frac{h(f-f_0)}{m_e}}$

Markscheme

B

19. A particle has a de Broglie wavelength λ and kinetic energy E. What is the relationship between λ and E? *[1 mark]*

A. $\lambda \propto E^{\frac{1}{2}}$

B. $\lambda \propto E$

C. $\lambda \propto E^{-\frac{1}{2}}$

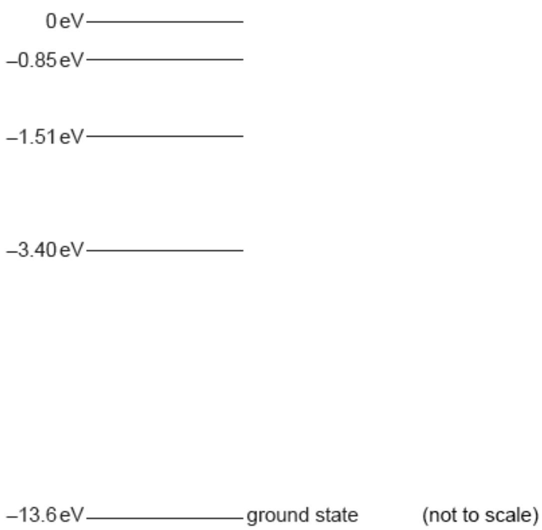
D. $\lambda \propto E^{-1}$

Markscheme

C

This question is about energy level transitions.

Some of the electron energy levels for a hydrogen atom are shown.



A hydrogen atom is excited to the -1.51 eV level.

20a. On the diagram, label using arrows all the possible transitions that might occur as the hydrogen atom returns to the ground state. *[1 mark]*

Markscheme

only the three correct arrows on diagram;

(–1.51 to –3.40, –1.15 to –13.6 and –3.40 to –13.6)

20b. State the energy in eV of the maximum wavelength photon emitted as the hydrogen atom returns to the ground state. *[1 mark]*

. . . .

. . . .

. . . .

Markscheme

1.89 eV; *(allow ECF from diagram)*

Monochromatic radiation is incident on gaseous hydrogen. All the hydrogen atoms are in the ground state. Describe what could happen to the radiation and to the hydrogen atoms if the incident photon energy is equal to

20c. 10.2 eV. *[2 marks]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Markscheme

photon is absorbed;

electron (in a hydrogen atom) raised to higher/–3.40 eV/excited state;

20d. 9.0 eV. *[1 mark]*

. . . .

. . . .

. . . .

Markscheme

no absorption / photon pass through;

21. Which phenomenon provides evidence for the wave nature of an electron? *[1 mark]*

A. Line spectra of atoms

B. Photoelectric effect

C. Beta decay of nuclei

D. Scattering of electrons by a crystal

Markscheme

D

22. A particular radioactive substance decays and emits both β^+ particles and neutrinos. *[1 mark]*
Which describes the nature of the energy spectrum of the β^+ particles and the nature of the energy spectrum of the neutrinos?

	Energy spectrum of β^+ particles	Energy spectrum of neutrinos
A.	discrete	discrete
B.	discrete	continuous
C.	continuous	discrete
D.	continuous	continuous

Markscheme

D

This question is in two parts. **Part 1** is about thermal properties of matter. **Part 2** is about quantum physics.

Part 1 Thermal properties of matter

23a. Three ice cubes at a temperature of 0ºC are dropped into a container of water at a temperature of 22ºC. The mass of each ice cube is 25 g and the mass of the water is 330 g. The ice melts, so that the temperature of the water decreases. The thermal capacity of the container is negligible. *[8 marks]*

(i) The following data are available.

Specific latent heat of fusion of ice = 3.3×10^{5} J kg^{-1}
Specific heat capacity of water = 4.2×10^{3} J kg^{-1} K^{-1}

Calculate the final temperature of the water when all of the ice has melted. Assume that no thermal energy is exchanged between the water and the surroundings.

(ii) Explain how the first law of thermodynamics applies to the water when the ice cubes are dropped into it.

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

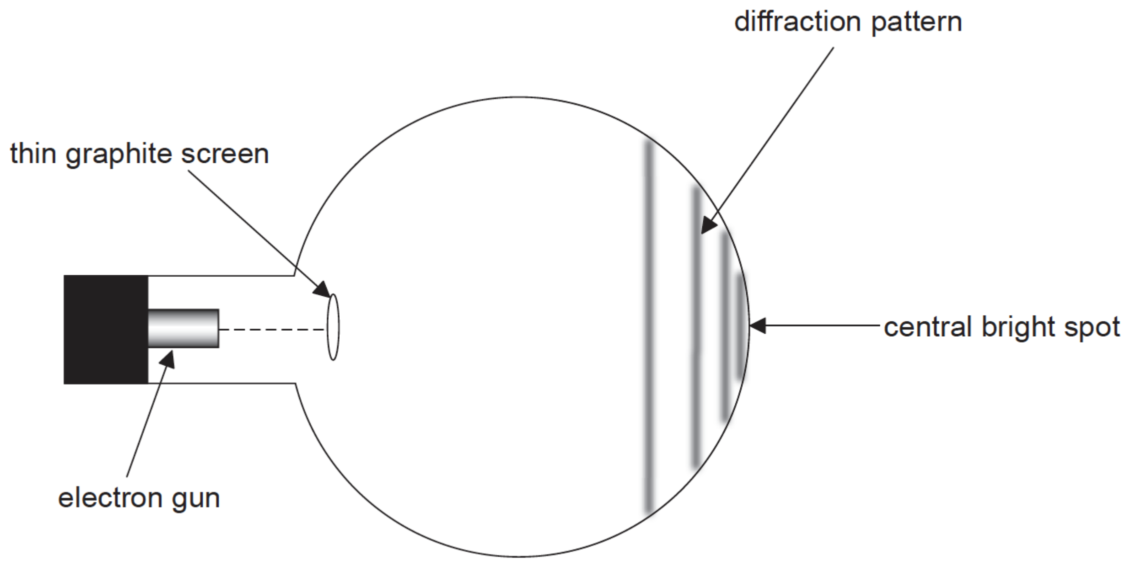
Markscheme

(i) use of M×4.2×103×Δ θ;
ml = 75×10–3×3.3×105 / 24750 J;
recognition that melted ice warms and water cools to common final temperature;
3.4°C;

(ii) work done on water by dropping cubes / negligible work done;
W negative or unchanged;
water gives thermal energy to ice;
Q negative;
water cools to a lower temperature;
Δ U negative / U decreases;

Part 2 Quantum physics

The diagram shows the end of an electron diffraction tube.



A pattern forms when diffracted electrons are incident on a fluorescent layer at the end of the tube.

23b. Explain how the pattern demonstrates that electrons have wave properties. *[3 marks]*

Markscheme

bright and dark rings/circles / circular fringes;
maximum and minimum / constructive and destructive;
mention of interference / mention of superposition;
link to interference being characteristic of waves;

23c. Electrons are accelerated to a speed of 3.6×10^{7} ms^{-1} by the electric field. *[5 marks]*

(i) Calculate the de Broglie wavelength of the electrons.

(ii) The cathode and anode are 22 mm apart and the field is uniform.
The potential difference between the cathode and the anode is 3.7 kV.
Show that the acceleration of the electrons is approximately $3\times10^{16} ms^{-2}$.

Markscheme

(i) (p=mev=) 3.28×10–23Ns;

$$\lambda = \left(\frac{\mathrm{h}}{\mathrm{p}} = \frac{6.63\times10^{-34}}{3.28\times10^{-23}} =\right) 2.02\times10^{-11}\mathrm{m};$$

(ii) $E = \left(\frac{\Delta V}{\Delta x}\right) = \frac{3.7\times10^{3}}{22\times10^{-3}} \left(= 1.68\times10^{5}\right) \mathrm{Vm}^{-1};$

$F = (Eq) = 1.68\times10^{5}\times1.6\times10^{-19} = \left(2.69\times10^{-14}\right)\mathrm{N};$

$a = \frac{F}{m} = \left(\frac{2.69\times10^{-14}}{9.11\times10^{-31}}\right) = 2.95\times10^{16}\mathrm{ms}^{-2};$

or

use of appropriate equation, eg v2 = u2 + 2as;
correct substitution (ignoring powers of ten);
a=2.95×1016 ms–2

23d. State what can be deduced about an electron from the amplitude of its associated wavefunction. *[2 marks]*

Markscheme

square of amplitude (of wavefunction);
(proportional to) probability of finding an electron (at a particular point);

23e. An electron reaching the central bright spot on the fluorescent screen has a small uncertainty in its position. Outline what the Heisenberg uncertainty principle is able to predict about another property of this electron. *[2 marks]*

....

....

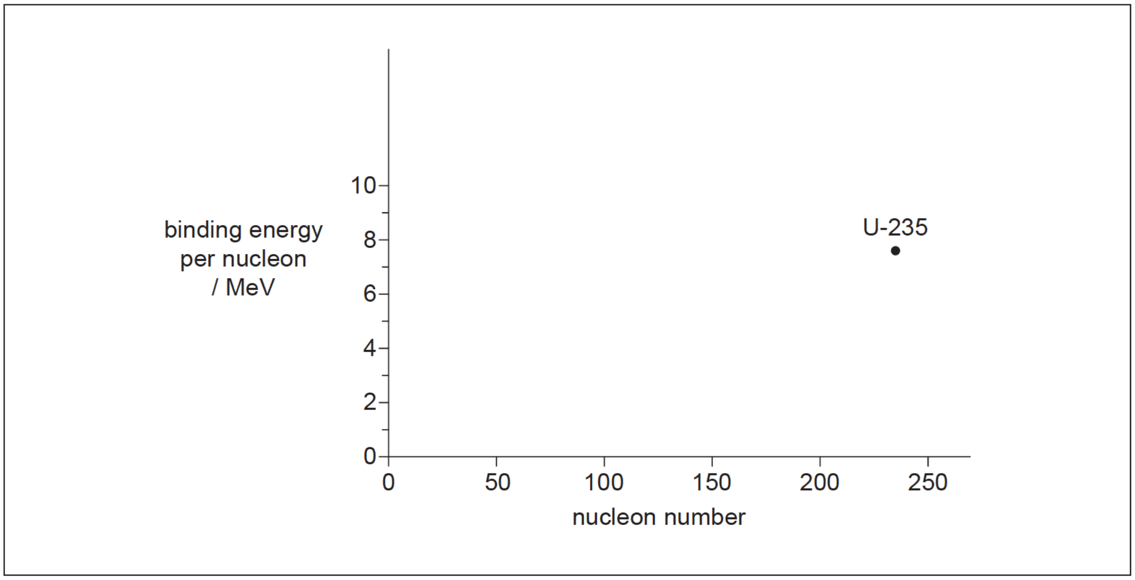
....

Markscheme

relates position to momentum (or velocity);
large uncertainty in momentum / most information on momentum is lost;

Part 2 Nuclear energy and radioactivity

The graph shows the variation of binding energy per nucleon with nucleon number. The position for uranium-235 (U-235) is shown.



24. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). *[4 marks]*

(i) State the nuclear equation for this decay.

(ii) A sample of rock contains a mass of 5.6 mg of U-235 at the present day. The half-life of U-235 is 7.0×10^8 years. Determine the initial mass of the U-235 if the rock sample was formed 3.9×10^9 years ago.

....

....

....

....

....

....

Markscheme

(i) ${}^{235}_{92}\mathrm{U} \rightarrow {}^{231}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$; *(allow He for α; treat charge indications as neutral)*

(ii) $\lambda = \frac{1\mathrm{n}2}{7.0\times10^{8}}\left(= 9.9\times10^{-10}\mathrm{year}^{-1}\right)$;

$m_0 = 5.6\mathrm{e}^{3.9\times10^{9}\times9.9\times10^{-10}}\,(\mathrm{mg})$

266 mg; } *(unit must match eg: allow 266 mg or 0.226 g but not 266 g or 0.266 kg)*

or

number of half-lives $= \left(\frac{3.9\times10^{9}}{7\times10^{8}} =\right) 5.57$

initial mass = 5.6×25.57 ;

266 mg; } *(unit must match eg: allow 266 mg or 0.226 g but not 266 g or 0.266 kg)*

*Award **[3]** for a bald correct answer.*

This question is in two parts. **Part 1** is about current electricity. **Part 2** is about atoms.

Part 1 Current electricity

25a. A 24Ω resistor is made from a conducting wire. *[8 marks]*

(i) The diameter of the wire is 0.30 mm and the wire has a resistivity of $1.7 \times 10^{-8}\ \Omega$ m. Calculate the length of the wire.

(ii) A potential difference of 12V is applied between the ends of the wire. Calculate the acceleration of a free electron in the wire.

(iii) Suggest why the average speed of the free electron does not keep increasing even though it is being accelerated.

....

....

....

....

....

....

Markscheme

(i) $l=\frac{\pi d^2R}{4\rho}$ seen / correct substitution

into equation: $24=\frac{l\times1.7\times10^{-8}}{\pi\times\left(0.15\times10^{-3}\right)^2}$; } *(condone use of r for*

$\frac{\mathrm{d}}{2}$ *in first alternative)*

99.7 (m);

*Award **[2]** for bald correct answer.*

*Award **[1 max]** if area is incorrectly calculated, answer is 399 m if conversion to radius ignored, ie: allow ECF for second marking point if area is incorrect provided working clear.*

(ii) electric field=$\left(\frac{12}{99.7}=\right)0.120\left(\mathrm{Vm}^{-1}\right)$; *(allow ECF from (a)(i))*

electric force=(*e*×*E*=0.120×1.6×10-19 =)1.92×10-20(N);

acceleration$=\left(\frac{F}{m}=\frac{1.92\times10^{-20}}{9.1\times10^{-31}}=\right)2.11\times10^{10}(ms^{-2})$; } *(5.27×10^{9} if radius used in (a)(i) allow as ECF)*

or

work done on electron = (Vq =)12×1.6×10-19 ;

energy gained by electron = *m*e×*a*×distance travelled = 9.11 × 10-31 × *a* × 99.8;

2.11×1010 (ms-2);

*Award **[3]** for a bald correct answer.*

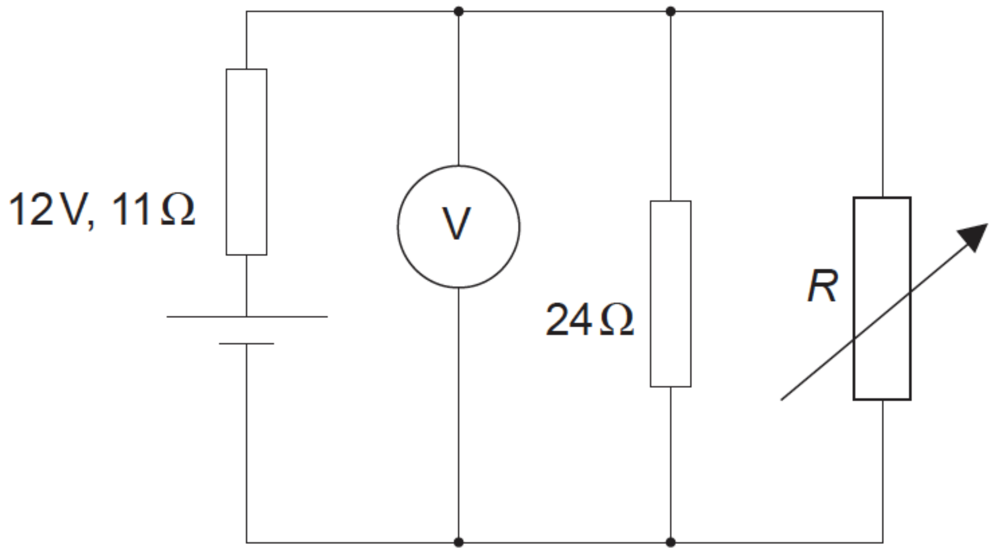
(iii) free electrons collide with ions and other electrons;

speed decreases during collisions / transfer their kinetic during collisions;

kinetic energy transferred to heat / wires have resistance;

and speed increases/acceleration until next collision;

25b. An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance *R*. The supply has an emf of 12V and an internal resistance of 11Ω. *[7 marks]*



Power supplies deliver maximum power to an external circuit when the resistance of the external circuit equals the internal resistance of the power supply.

(i) Determine the value of *R* for this circuit at which maximum power is delivered to the external circuit.

(ii) Calculate the reading on the voltmeter for the value of *R* you determined in (b)(i).

(iii) Calculate the power dissipated in the 24Ω resistor when the maximum power is being delivered to the external circuit.

....

....

....

....

....

....

Markscheme

(i) use of total resistance = 11Ω; *(can be seen in second marking point)*
$\frac{1}{11}=\frac{1}{R}+\frac{1}{24}$;
20.3(Ω);

(ii) as current is same in resistor network and cell and resistance is same, half of emf must appear across resistor network;
6.0 (V);

or

$I=\frac{12}{(11+11)}=0.545\,(\mathrm{A})$;
V=(0.545×11=) 6.0(V);

Other calculations are acceptable.
*Award **[2]** for a bald correct answer.*

(iii) pd across 2Ω=6.0V; *(allow ECF from(b)(ii))*
$\left(\frac{V^2}{R}=\frac{36}{24}=\right)1.5\,(\mathrm{W})$;
*Award **[2]** for a bald correct answer.*

Part 2 Atoms

25c. State what is meant by the wavefunction of an electron. *[1 mark]*

....

....

....

Markscheme

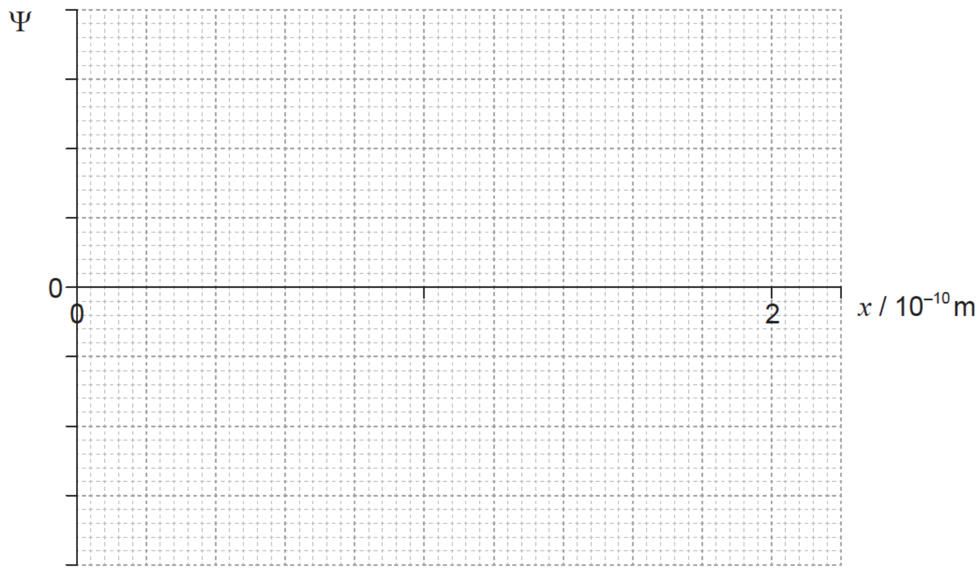
measure of the probability of finding an electron (at a particular place and time);

25d. An electron is confined in a length of 2.0 $\times$ 10^{-10} m. *[9 marks]*

(i) Determine the uncertainty in the momentum of the electron.

(ii) The electron has a momentum of 2.0 $\times$ 10^{-23}Ns. Determine the de Broglie wavelength of the electron.

(iii) On the axes, sketch the variation of the wavefunction Ψ of the electron in (d)(ii) with distance *x*. You may assume that $\Psi=0$ when $x=0$.



(iv) Identify the feature of your graph in (d)(iii) that gives the probability of finding the electron at a particular position and at a particular time.

....

....

....

....

....

....

....

....

....

....

....

....

....

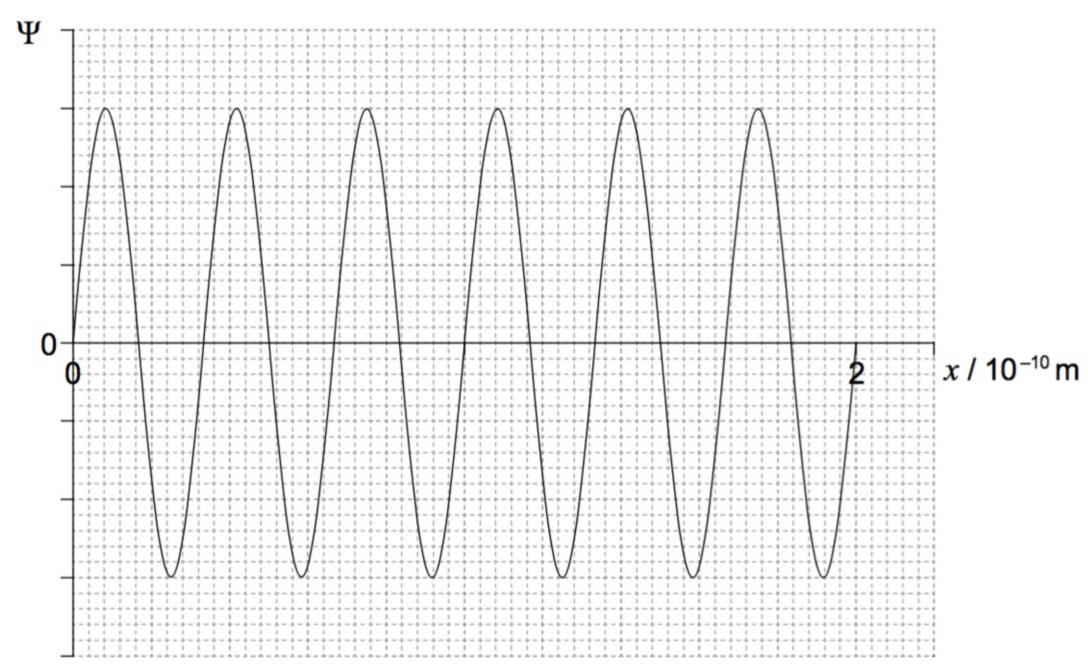
....

Markscheme

(i) $\Delta p = \frac{h}{4\pi\Delta x}$ and $\Delta x = 2.0\times10^{-10}$; *(both needed)*
2.64×10–25(Ns); *(also accept 5.28×10–25(Ns))*
*Award **[2]** for a bald correct answer.*

(ii) $\lambda = \frac{h}{p}\left(= \frac{6.63\times10^{-34}}{2\times10^{-23}}\right)$;
3.3×10-11 (m);
*Award **[2]** for a bald correct answer.*

(iii)



periodic behaviour shown anywhere between 0 nm and 0.2 nm;
6 loops/repetitions shown anywhere between 0 nm and 0.2nm; } *(allow ECF for division of 2×10^{-10} by answer to d(ii))*
wavefunction completely fills from 0 nm to 0.2 nm and does not go beyond;

(iv) amplitude of Ψ/graph;
squared;