Ch. 12 Other quantum phenomena *[141 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

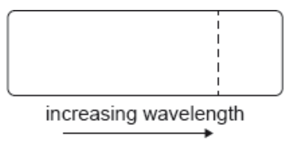
C. $\frac{1}{2}$

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

Markscheme

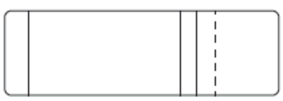
D

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. A particle of fixed energy is close to a potential barrier. *[1 mark]*

Which changes to the width of the barrier and to the height of the barrier will always make the tunnelling probability greater?

	Width of the barrier	Height of the barrier
A.	increase	increase
B.	increase	decrease
C.	decrease	increase
D.	decrease	decrease

Markscheme

D

4. 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]*

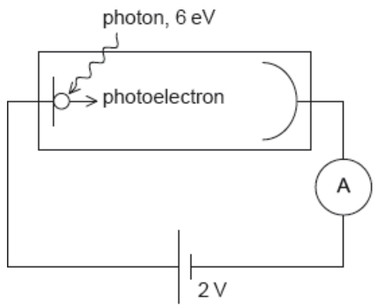
Which change in E and which change in Z is most likely to result in greater deviations from the Rutherford scattering model?

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

Markscheme

B

5. A photoelectric cell is connected in series with a battery of emf 2 V. Photons of energy 6 eV are incident on the cathode of the photoelectric cell. The work function of the surface of the cathode is 3 eV. *[1 mark]*



What is the maximum kinetic energy of the photoelectrons that reach the anode?

A. 1 eV

B. 3 eV

C. 5 eV

D. 8 eV

Markscheme

A

6. 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

7. 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

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8. 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.

9a. Identify the missing information for this decay. *[2 marks]*

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

Markscheme

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

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

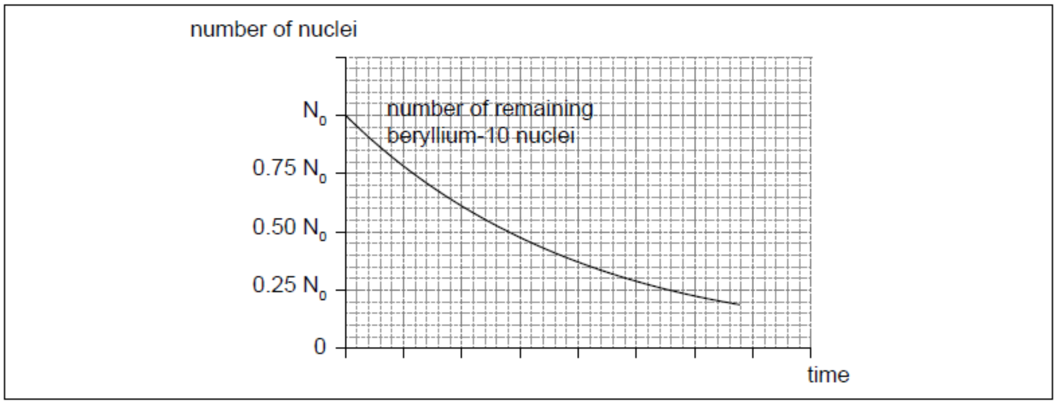
conservation of mass number ***AND*** charge ${}^{10}_{5}\text{B}, {}^{10}_{4}\text{Be}$

Do not accept V.

Accept $\overline{V}$ 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.

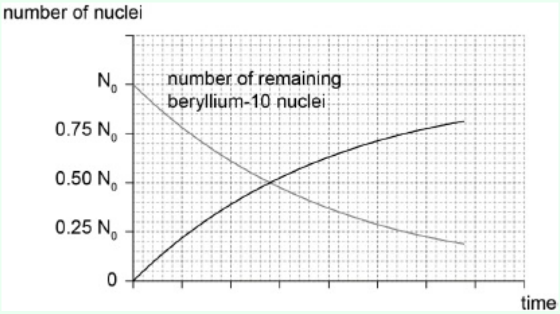


9b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

Markscheme

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

crosses given line at 0.50 N_0



[2 marks]

9c. 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

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

ALTERNATIVE 2

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

$\frac{1}{8} = e^{-\lambda}(4.3 \times 10^6)$ 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]

9d. 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 «= $\frac{\ln 2}{1.4 \times 10^6}$» = 4.95×10^{-7} «y^{-1}»

rearranging of $A = \lambda N_0 e^{-\lambda t}$ to give $-\lambda t = \ln \frac{8.0 \times 10^{-3} \times 365 \times 24 \times 60 \times 60}{4.95 \times 10^{-7} \times 7.6 \times 10^{11}}$ «= –0.400»

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

9e. State what is meant by thermal radiation. *[1 mark]*

Markscheme

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

[1 mark]

9f. 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]

9g. 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]

9h. 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

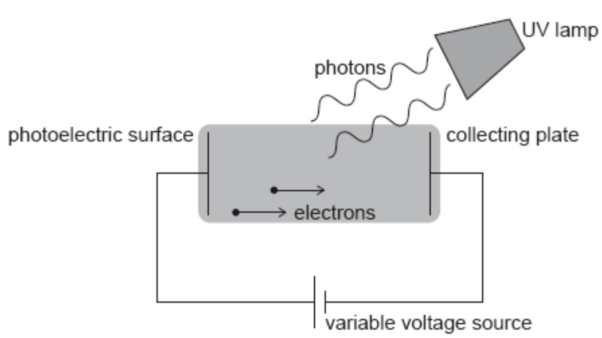
convection – movement of air currents

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.



10a. 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.

10b. 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».

10c. 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]

10d. 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

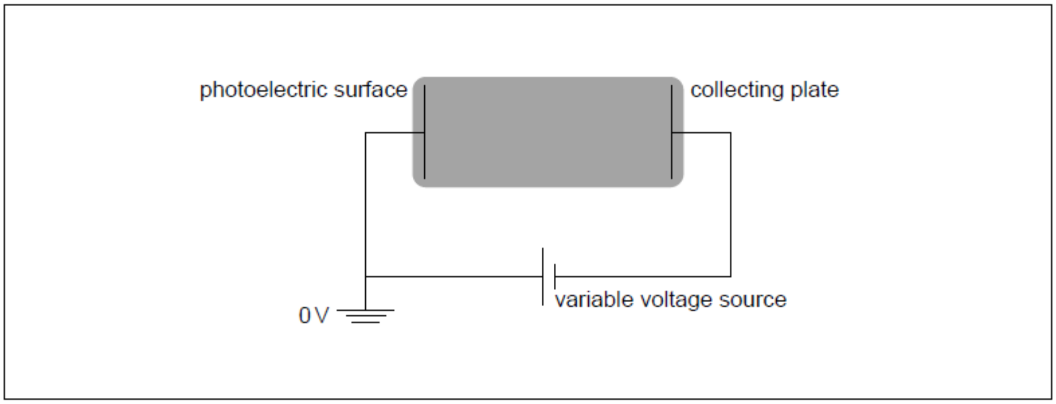
4.9 «V»

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.

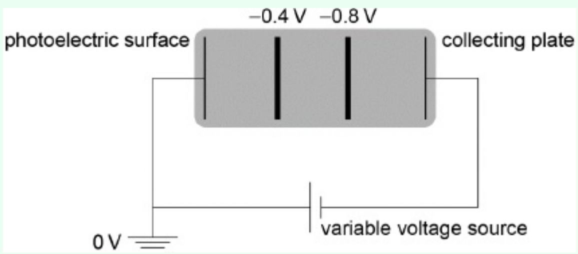


10e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. *[2 marks]*

Markscheme

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

labelled correctly



[2 marks]

10f. 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]

11a. Bohr modified the Rutherford model by introducing the condition $mvr = n\frac{h}{2\pi}$. Outline the reason for this modification. *[3 marks]*

Markscheme

the electrons accelerate and so radiate energy

they would therefore spiral into the nucleus/atoms would be unstable

electrons have discrete/only certain energy levels

the only orbits where electrons do not radiate are those that satisfy the Bohr condition «$mvr = n\frac{h}{2\pi}$»

[3 marks]

11b. Show that the speed v of an electron in the hydrogen atom is related to the radius r of the orbit by the expression *[1 mark]*

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

where k is the Coulomb constant.

Markscheme

$\frac{m_e v^2}{r} = \frac{ke^2}{r^2}$

OR

KE = $\frac{1}{2}$PE hence $\frac{1}{2}m_e v^2 = \frac{1}{2}\frac{ke^2}{r}$

«solving for v to get answer»

Answer given – look for correct working

[1 mark]

11c. Using the answer in (b) and (c)(i), deduce that the radius r of the electron's orbit in the ground state of hydrogen is given by the following expression. *[2 marks]*

$$r = \frac{h^2}{4\pi^2 k m_e e^2}$$

Markscheme

combining $v = \sqrt{\frac{ke^2}{m_e r}}$ with $m_e vr = \frac{h}{2\pi}$ using correct substitution

«*eg*
$m_e{}^2\frac{ke^2}{m_e r}r^2 = \frac{h^2}{4\pi^2}$»

correct algebraic manipulation to gain the answer

Answer given – look for correct working

Do not allow a bald statement of the answer for MP2. Some further working eg cancellation of m or r must be shown

[2 marks]

11d. Calculate the electron's orbital radius in (c)(ii). *[1 mark]*

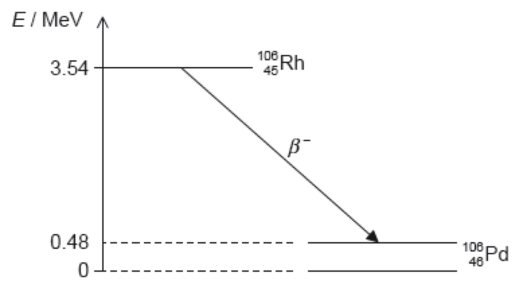
Markscheme

« $r = \frac{(6.63\times10^{-34})^2}{4\pi^2\times8.99\times10^9\times9.11\times10^{-31}\times(1.6\times10^{-19})^2}$ »

$r = 5.3 \times 10^{-11}$ «m»

[1 mark]

Rhodium-106 ($^{106}_{45}\mathrm{Rh}$) decays into palladium-106 ($^{106}_{46}\mathrm{Pd}$) by beta minus (β^-) decay. The diagram shows some of the nuclear energy levels of rhodium-106 and palladium-106. The arrow represents the β^- decay.



11e. Explain what may be deduced about the energy of the electron in the β^- decay. *[3 marks]*

Markscheme

the energy released is 3.54 – 0.48 = 3.06 «MeV»

this is shared by the electron and the antineutrino

so the electron's energy varies from 0 to 3.06 «MeV»

[3 marks]

11f. Suggest why the β^- decay is followed by the emission of a gamma ray photon. *[1 mark]*

Markscheme

the palladium nucleus emits the photon when it decays into the ground state «from the excited state»

[1 mark]

11g. Calculate the wavelength of the gamma ray photon in (d)(ii). *[2 marks]*

Markscheme

Photon energy

$E = 0.48 \times 10^6 \times 1.6 \times 10^{-19}$ = «7.68×10^{-14} *J*»

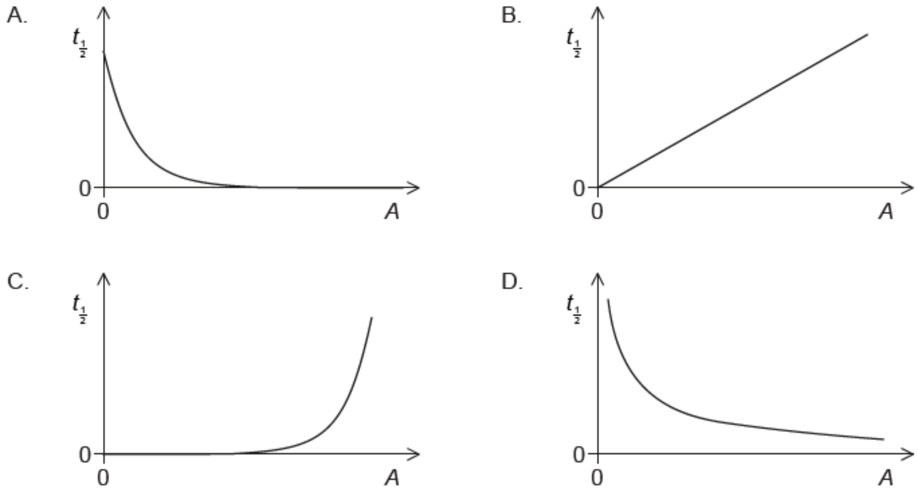
λ = « $\frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^8}{7.68\times10^{-14}}$ =» 2.6×10^{-12} «m»

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

Allow ECF from incorrect energy

[2 marks]

12. Samples of different radioactive nuclides have equal numbers of nuclei. Which graph shows the relationship between the half-life $t_{\frac{1}{2}}$ and the activity *A* for the samples? *[1 mark]*



Markscheme

D

13. Monochromatic electromagnetic radiation is incident on a metal surface. The kinetic energy of the electrons released from the metal *[1 mark]*

A. is constant because the photons have a constant energy.

B. is constant because the metal has a constant work function.

C. varies because the electrons are not equally bound to the metal lattice.

D. varies because the work function of the metal is different for different electrons.

Markscheme

C

14. A photon interacts with a nearby nucleus to produce an electron. What is the name of this process? *[1 mark]*

A. Pair annihilation

B. Pair production

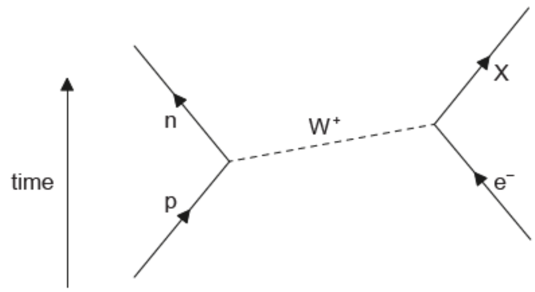
C. Electron diffraction

D. Quantum tunnelling

Markscheme

B

The Feynman diagram shows electron capture.



15a. 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.

15b. 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

15c. 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*

15d. State and explain **one** example of a scientific analogy. *[2 marks]*

Markscheme

two analogous situations stated

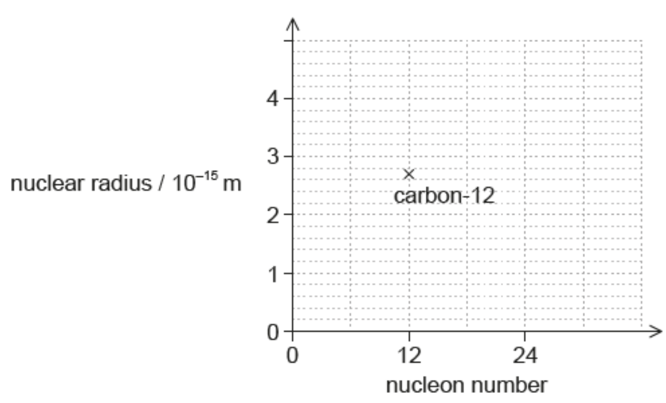
one element of the analogy equated to an element of physics

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 x 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.



15e. Plot the position of magnesium-24 on the graph. *[1 mark]*

Markscheme

correctly plotted

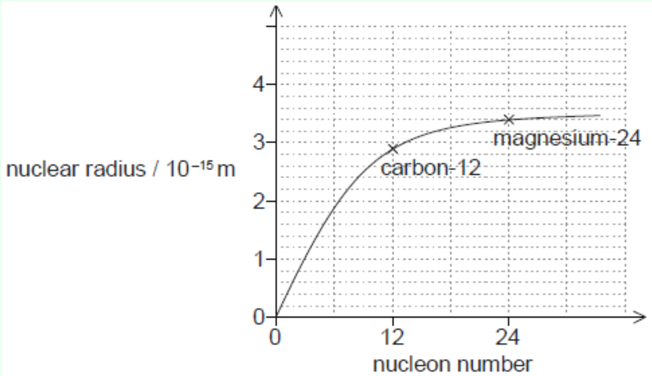
Allow ECF from (d)(i)

15f. 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



16. 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

17. 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

18. A photon of energy E and wavelength λ is scattered from an electron initially at rest. *[1 mark]*

What is the energy of the photon and the wavelength of the photon when the electron moves away?

	Energy of photon	Wavelength of photon
A.	greater than E	less than λ
B.	less than E	less than λ
C.	greater than E	greater than λ
D.	less than E	greater than λ

Markscheme

D

19. 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

20. When monochromatic light is incident on a metallic surface, electrons are emitted from the surface. The following changes are considered. *[1 mark]*

I. Increase the intensity of the incident light
II. Increase the frequency of light
III. Decrease the work function of the surface

Which changes will result in electrons of greater energy being emitted from the surface?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Markscheme

C

21. In the Bohr model for hydrogen an electron in the ground state has orbit radius r and speed v. In the first excited state the electron has orbit radius $4r$. What is the speed of the electron in the first excited state? *[1 mark]*

A. $\frac{v}{2}$

B. $\frac{v}{4}$

C. $\frac{v}{8}$

D. $\frac{v}{16}$

Markscheme

A

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22. A neutron of mass m is confined within a nucleus of diameter d. Ignoring numerical constants, what is an approximate expression for the kinetic energy of the neutron? *[1 mark]*

A. $\frac{h^2}{md^2}$

B. $\frac{h}{md}$

C. $\frac{mh^2}{d^2}$

D. $\frac{h}{m^2d}$

Markscheme

A

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23. A radioactive element has decay constant λ (expressed in s^{-1}). The number of nuclei of this element at $t = 0$ is N. What is the expected number of nuclei that will have decayed after 1 s? *[1 mark]*

A. $N\left(1 - e^{-\lambda}\right)$

B. $\frac{N}{\lambda}$

C. $Ne^{-\lambda}$

D. λN

Markscheme

A

Two observations about the photoelectric effect are

Observation 1: For light below the threshold frequency no electrons are emitted from the metal surface.

Observation 2: For light above the threshold frequency, the emission of electrons is almost instantaneous.

24a. Explain how each observation provides support for the particle theory but not the wave theory of light. *[4 marks]*

Observation 1: . . . .

. . . .

. . . .

. . . .

. . . .

Observation 2: . . . .

. . . .

. . . .

. . . .

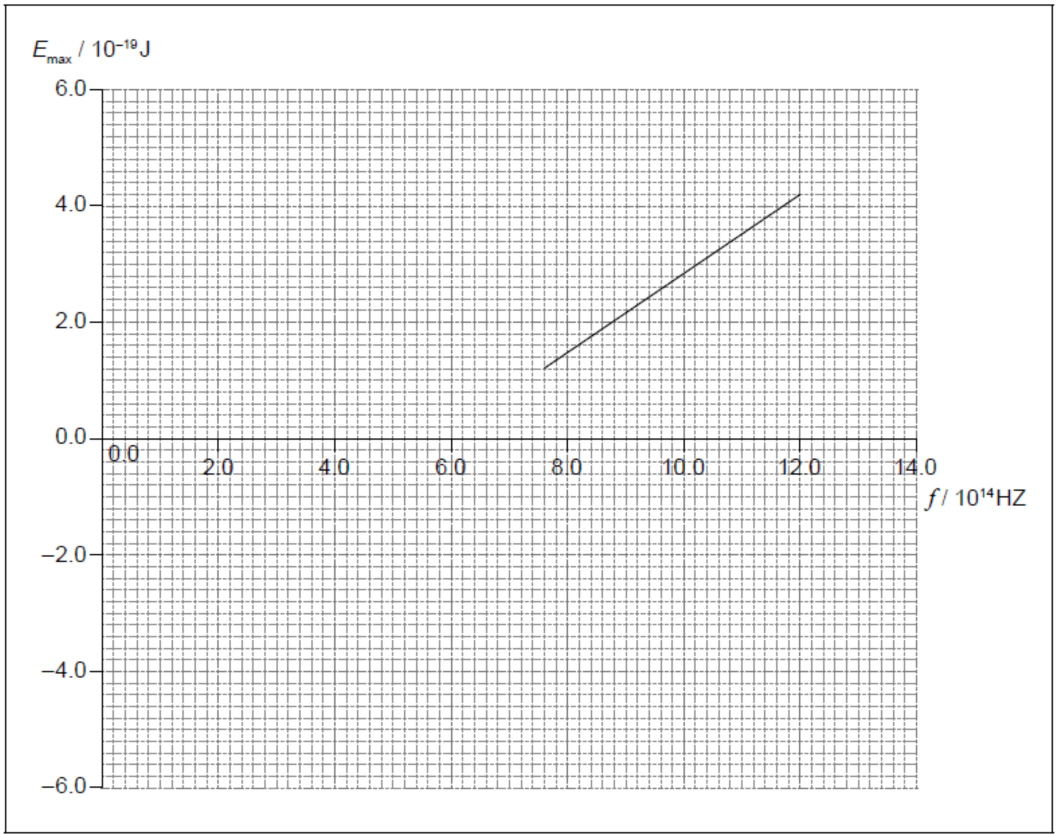
. . . .

Markscheme

Observation 1:
particle – photon energy is below the work function
OR
$E = hf$ and energy is too small «to emit electrons»
wave – the energy of an *em* wave is independent of frequency

Observation 2:
particle – a single electron absorbs the energy of a single photon «in an almost instantaneous interaction»
wave – it would take time for the energy to build up to eject the electron

The graph shows how the maximum kinetic energy E_{max} of electrons emitted from a surface of barium metal varies with the frequency f of the incident radiation.



24b. Determine a value for Planck's constant. *[2 marks]*

Markscheme

attempt to calculate gradient of graph = « $\frac{4.2\times10^{-19}}{6.2\times10^{14}}$ »

$= 6.8 - 6.9 \times 10^{-34}$ «Js»

Do not allow a bald answer of 6.63 x 10^{-34} Js or 6.6 x 10^{-34} Js.

24c. State what is meant by the work function of a metal. *[1 mark]*

Markscheme

ALTERNATIVE 1

minimum energy required to remove an electron «from the metal surface»

ALTERNATIVE 2

energy required to remove the least tightly bound electron «from the metal surface»

24d. Calculate the work function of barium in eV. *[2 marks]*

Markscheme

ALTERNATIVE 1

reading of *y* intercept from graph in range 3.8 – 4.2 × 10^{-19} «J»
conversion to eV = 2.4 – 2.6 «eV»

ALTERNATIVE 2

reading of x intercept from graph «5.8 – 6.0 × 10^{14} Hz» and using hf_0 to get 3.8 – 4.2 × 10^{-19} «J»
conversion to eV = 2.4 – 2.6 «eV»

24e. The experiment is repeated with a metal surface of cadmium, which has a greater work function. Draw a second line on the graph to represent the results of this experiment. *[2 marks]*

Markscheme

line parallel to existing line
to the right of the existing line

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{86}\mathrm{Ra}$) decays by alpha emission to form a nuclide known as radon (Rn).

25a. Write down the nuclear equation for this decay. *[2 marks]*

Markscheme

$^{4}_{2}\alpha$

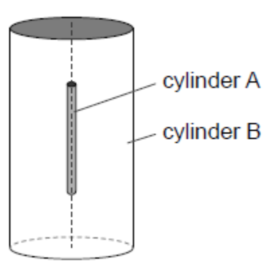
OR

$^{4}_{2}\mathrm{He}$

$^{222}_{86}\mathrm{Rn}$

*These **must** be seen on the right-hand side of the equation.*

At the start of the experiment, Rutherford and Royds put 6.2 x 10^{-4} mol of pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B.



The experiment lasted for 6 days. The decay constant of radium-226 is 1.4 x 10^{-11} s^{-1}.

25b. Deduce that the activity of the radium-226 is almost constant during the experiment. *[2 marks]*

Markscheme

ALTERNATIVE 1

6 days is 5.18 x 10^5 s

activity after 6 days is $A_0 e^{-1.4\times10^{-11}\times5.8\times10^5} \approx A_0$

OR

A = 0.9999927 A_0 ***or*** 0.9999927 λN_0

OR

states that index of e is so small that $\frac{A}{A_0}$ is ≈ 1

OR

$A - A_0 \approx 10^{-15}$ «s^{-1}»

ALTERNATIVE 2

shows half-life of the order of 10^{11} s or 5.0 x 10^{10} s

converts this to year «1600 y» or days and states half-life much longer than experiment compared to experiment

*Award **[1 max]** if calculations/substitutions have numerical slips but would lead to correct deduction.*

eg: failure to convert 6 days to seconds but correct substitution into equation will give MP2.

Allow working in days, but for MP1 must see conversion of λ or half-life to day^{-1}.

25c. Show that about 3 x 10^{15} alpha particles are emitted by the radium-226 in 6 days. *[3 marks]*

Markscheme

ALTERNATIVE 1

use of $A = \lambda N_0$

conversion to number of molecules = nN_A = 3.7 x 10^{20}

OR

initial activity = 5.2 x 10^9 «s^{-1}»

number emitted = (6 x 24 x 3600) x 1.4 x 10^{-11} x 3.7 x 10^{20} ***or*** 2.7 x 10^{15} alpha particles

ALTERNATIVE 2

use of $N = N_0 e^{-\lambda t}$

$N_0 = n \times N_A$ = 3.7 x 10^{20}

alpha particles emitted «= number of atoms disintegrated = $N - N_0$ =» $N_0\left(1 - e^{-\lambda\times6\times24\times3600}\right)$ ***or*** 2.7 x 10^{15} alpha particles

Must see correct substitution or answer to 2+ sf for MP3

At the start of the experiment, all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of cylinder A to form helium gas in cylinder B.

25d. The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin. *[1 mark]*

Markscheme

alpha particles highly ionizing

OR

alpha particles have a low penetration power

OR

thin glass increases probability of alpha crossing glass

OR

decreases probability of alpha striking atom/nucleus/molecule

Do not allow reference to tunnelling.

25e. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3 x 10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B over the 6 day period. Helium is a monatomic gas. *[3 marks]*

Markscheme

conversion of temperature to 291 K

p = 4.5 x 10^{-9} x 8.31 x «$\frac{291}{1.3 \times 10^{-5}}$»

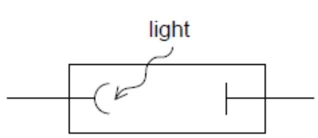
OR

p = 2.7 x 10^{15} x 1.3 x 10^{-23} x «$\frac{291}{1.3 \times 10^{-5}}$»

0.83 ***or*** 0.84 «Pa»

Allow ECF for 2.7 x 10^{15} from (b)(ii).

Yellow light of photon energy 3.5 x 10^{-19} J is incident on the surface of a particular photocell.



26a. Calculate the wavelength of the light. *[1 mark]*

Markscheme

wavelength = «$\frac{hc}{E} = \frac{1.99 \times 10^{-25}}{3.5 \times 10^{-19}} =$» 5.7 x 10^{-7} «m»

If no unit assume m.

26b. Electrons emitted from the surface of the photocell have almost no kinetic energy. Explain why this does not contradict the law of conservation of energy. *[2 marks]*

Markscheme

«potential» energy is required to leave surface

Do not allow reference to "binding energy".
Ignore statements of conservation of energy.

all/most energy given to potential «so none left for kinetic energy»

26c. Radiation of photon energy 5.2 x 10^{-19} J is now incident on the photocell. Calculate the maximum velocity of the emitted electrons. *[2 marks]*

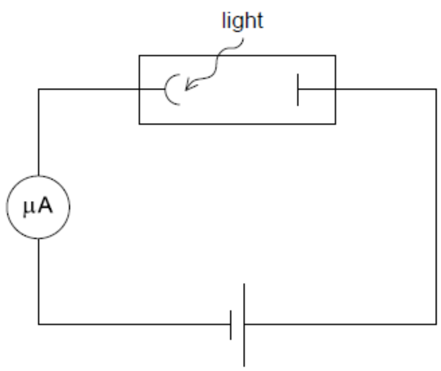
Markscheme

energy surplus = 1.7 x 10^{-19} J

$v_{max} = \sqrt{\frac{2 \times 1.7 \times 10^{-19}}{9.1 \times 10^{-31}}} = 6.1 \times 10^5$ «m s^{-1}»

*Award **[1 max]** if surplus of 5.2 x 10^{-19}J used (answer: 1.1 x 10^6 m s^{-1})*

The photocell is connected to a cell as shown. The photoelectric current is at its maximum value (the saturation current).



Radiation with a greater photon energy than that in (b) is now incident on the photocell. The intensity of this radiation is the same as that in (b).

26d. Describe the change in the number of photons per second incident on the surface of the photocell. *[1 mark]*

Markscheme

«same intensity of radiation so same total energy delivered per square metre per second»

light has higher photon energy so fewer photons incident per second

Reason is required

26e. State and explain the effect on the maximum photoelectric current as a result of increasing the photon energy in this way. *[3 marks]*

Markscheme

1:1 correspondence between photon and electron

so fewer electrons per second

current smaller

Allow ECF from (c)(i)
Allow ECF from MP2 to MP3.

27. Pair production by a photon occurs in the presence of a nucleus. For this process, which of momentum and energy are conserved? *[1 mark]*

	Momentum	Energy
A.	not conserved	not conserved
B.	not conserved	conserved
C.	conserved	not conserved
D.	conserved	conserved

Markscheme

D

28. 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

29. Which of the following, observed during a radioactive-decay experiment, provide evidence for the existence of nuclear energy levels? *[1 mark]*

I. The spectrum of alpha particle energies
II. The spectrum of beta particle energies
III. The spectrum of gamma ray energies

A. I and II only

B. I and III only

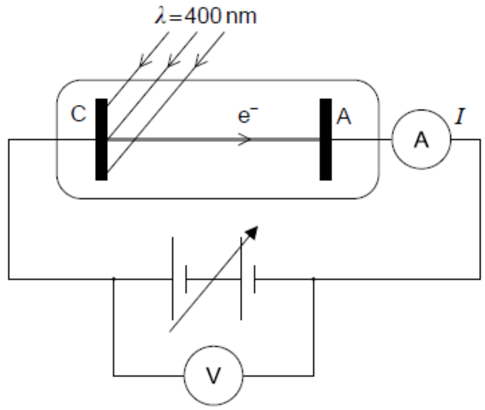
C. II and III only

D. I, II and III

Markscheme

B

An apparatus is used to investigate the photoelectric effect. A caesium cathode C is illuminated by a variable light source. A variable power supply is connected between C and the collecting anode A. The photoelectric current *I* is measured using an ammeter.



30a. A current is observed on the ammeter when violet light illuminates C. With V held constant the current becomes zero when the violet light is replaced by red light of the same intensity. Explain this observation. *[3 marks]*

Markscheme

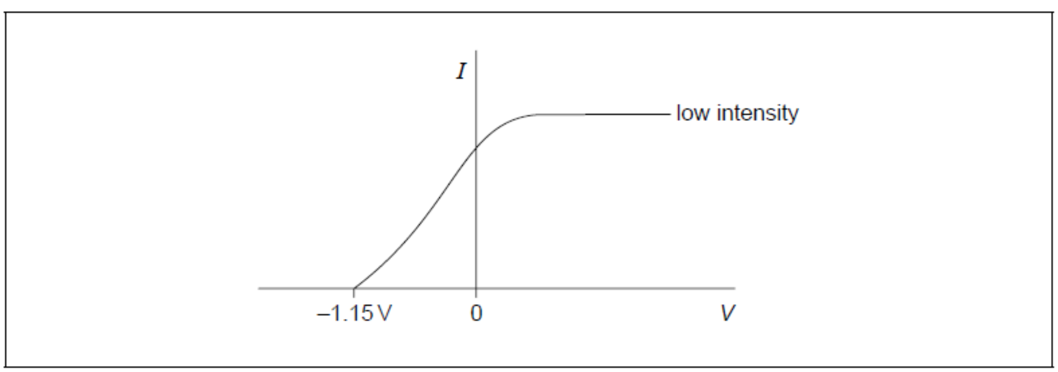
reference to photon
OR
energy = *hf* ***or*** $=\frac{hc}{\lambda}$

violet photons have greater energy than red photons

when *hf* > Φ ***or*** photon energy> work function then electrons are ejected

frequency of red light < threshold frequency «so no emission»
OR
energy of red light/photon < work function «so no emission»

30b. The graph shows the variation of photoelectric current *I* with potential difference *V* between C and A when violet light of a particular intensity is used. *[6 marks]*



The intensity of the light source is increased without changing its wavelength.

(i) Draw, on the axes, a graph to show the variation of *I* with *V* for the increased intensity.

(ii) The wavelength of the violet light is 400 nm. Determine, in eV, the work function of caesium.

(iii) *V* is adjusted to +2.50V. Calculate the maximum kinetic energy of the photoelectrons just before they reach A.

Markscheme

i

line with same negative intercept «–1.15V»

otherwise above existing line everywhere and of similar shape with clear plateau

Award this marking point even if intercept is wrong.

ii

$\frac{hc}{\lambda e} = $ «$\frac{6.63\times10^{-34}\times3\times10^{8}}{40\times10^{-9}\times1.6\times10^{-19}}$ =» 3.11 «eV»

Intermediate answer is 4.97×10^{-19} J.

Accept approach using f *rather than c/λ*

«3.10 – 1.15 =» 1.96 «eV»
*Award **[2]** for a bald correct answer in eV.*
*Award **[1 max]** if correct answer is given in J* (3.12×10^{-19} J).

iii

«KE = *qVs* =» 1.15 «eV»

OR

1.84 x 10^{-19} «J»

Allow ECF from MP1 to MP2.

adds 2.50 eV = 3.65 eV

OR

5.84 x 10^{-19} J

Must see units in this question to identify energy unit used.
*Award **[2]** for a bald correct answer that includes units.*
*Award **[1 max]** for correct answer without units.*

31a. 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

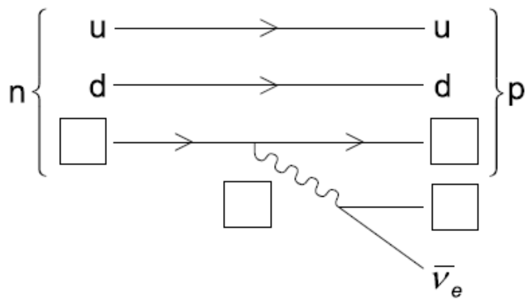
charge: –1 «e» ***or*** negative ***or*** *K^-*

strangeness: –1

baryon number: 0

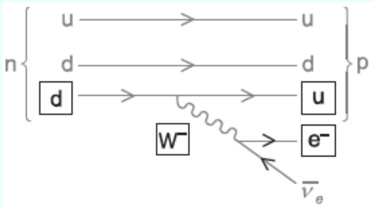
Negative signs required.
Award **[2]** for three correct answers, **[1 max]** for two correct answer and **[0]** for one correct answer.

31b. 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.

31c. 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.*

32. Which of the following experiments provides evidence for the existence of matter waves? *[1 mark]*

A. Scattering of alpha particles

B. Electron diffraction

C. Gamma decay

D. Photoelectric effect

Markscheme

B

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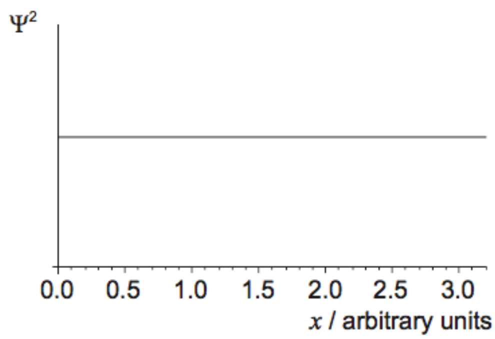
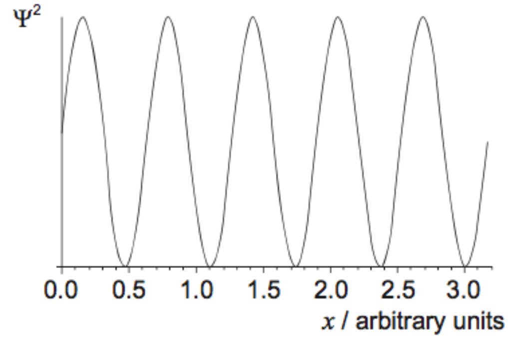
33. The graphs show the variation with distance x of the square of the amplitude Ψ^2 of the wave function of a particle. Which graph corresponds to a particle with the largest uncertainty in momentum? *[1 mark]*

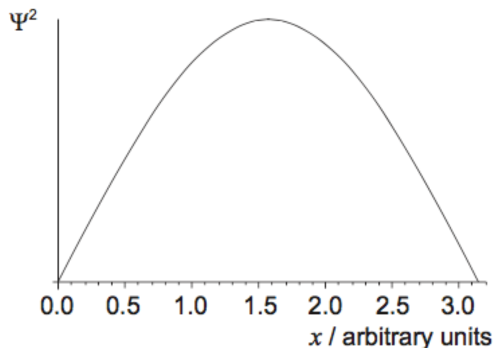
A.



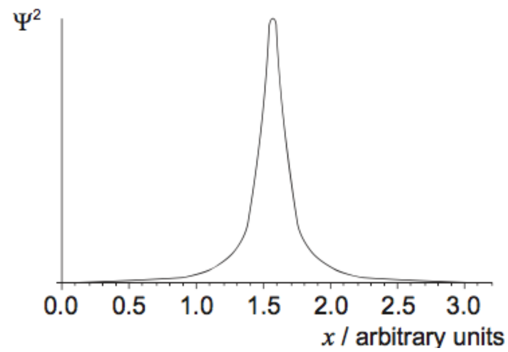
B.



C.



D.



Markscheme

D

34. 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

35. Different metal surfaces are investigated in an experiment on the photoelectric effect. A graph of the variation of the maximum kinetic energy of photoelectrons with the frequency of the incident light is drawn for each metal. Which statement is correct? *[1 mark]*

A. All graphs have the same intercept on the frequency axis.

B. The work function is the same for all surfaces.

C. All graphs have the same slope.

D. The threshold frequency is the same for all surfaces.

Markscheme

C

36. A pure sample of mass m of a radioactive substance with half-life $T_{\frac{1}{2}}$ has an initial activity A_0. *[1 mark]*

What are the half-life and the initial activity of a pure sample of mass 2 *m* of the same radioactive substance?

	Half-life	Initial activity
A.	$T_{\frac{1}{2}}$	A_0
B.	$T_{\frac{1}{2}}$	$2A_0$
C.	$2T_{\frac{1}{2}}$	A_0
D.	$2T_{\frac{1}{2}}$	$2A_0$

Markscheme

B

37. Nuclear density *[1 mark]*

A. is constant because the volume of a nucleus is proportional to its nucleon number.

B. is constant because the volume of a nucleus is proportional to its proton number.

C. depends on the nucleon number of the nucleus.

D. depends on the proton number of the nucleus.

Markscheme

A

38a. 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»

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

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

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

OR

1.44×10^{-42}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.

38b. 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

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38c. 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

$\Delta x\approx7\times10^{-15}$ m

$\Delta p\approx\frac{6.63\times10^{-34}}{4\pi\times7\times10^{-15}} \ll= 7.54\times10^{-21}\text{Ns}\gg$

$E\approx\ll\frac{\Delta p^2}{2m} = \frac{(7.54\times10^{-21})^2}{2\times6.6\times10^{-27}} = 4.3\times10^{-15}\text{J} = 26897\text{eV}\gg\approx0.027\text{MeV}$

Accept $\Delta x\approx3.5\times10^{-15}$m or $\Delta x\approx1.4\times10^{-14}$m leading to $E\approx0.11$MeV or 0.0067MeV.

Answer must be in MeV.