Ch. 7 *[231 marks]*

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

1a. Identify the missing information for this decay. *[1 mark]*

$${}^{10}_{\square}Be \rightarrow {}^{\square}_{5}B + \beta + \overline{\upsilon}$$

Markscheme

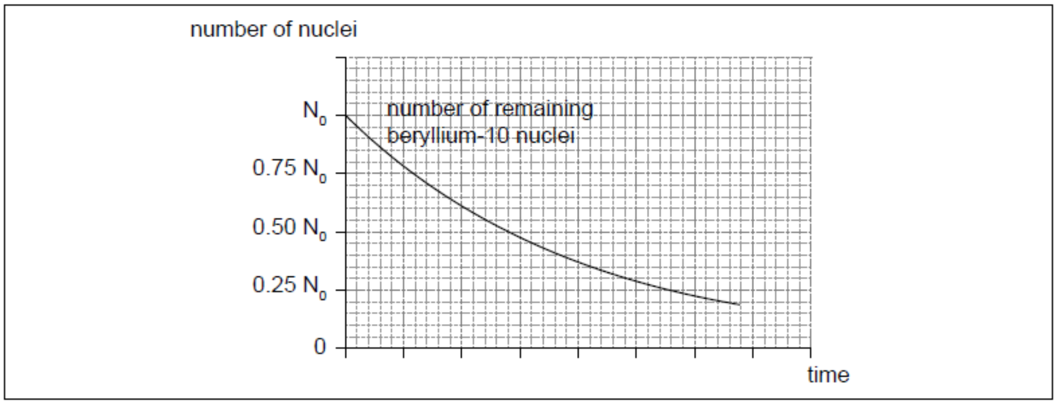
${}^{10}_{4}Be \rightarrow {}^{10}_{5}B + \beta + \overline{V}_{e}$

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

*Correct identification of both missing values required for **[1]**.*

[1 mark]

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.

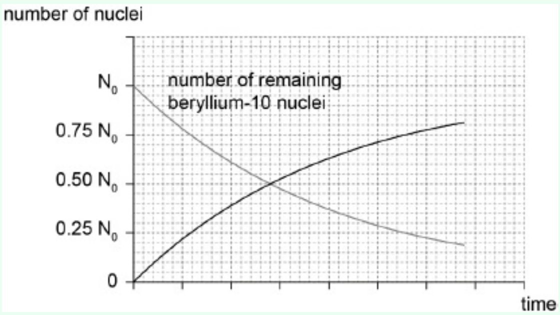


1b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

Markscheme

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

crosses given line at 0.50 N_0



[2 marks]

1c. 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 λ = 4.836 × 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]

1d. Beryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6 × 10^{11} atoms of beryllium-10. State the number of remaining beryllium-10 nuclei in the sample after 2.8 × 10^6 years. *[1 mark]*

Markscheme

1.9 × 10^{11}

[1 mark]

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

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

Markscheme

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

[1 mark]

1f. 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]

1g. 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]

1h. Derive the units of intensity in terms of fundamental SI units. *[2 marks]*

Markscheme

correct units for Intensity (allow *W, Nms^{-1} OR Js^{-1} in numerator)*

rearrangement into proper SI units = kgs^{-3}

Allow ECF for MP2 if final answer is in fundamental units.

[2 marks]

2a. Rutherford constructed a model of the atom based on the results of the alpha particle scattering experiment. Describe this model. *[2 marks]*

Markscheme

«most of» the mass of the atom is confined within a very small volume/nucleus

«all» the positive charge is confined within a very small volume/nucleus

electrons orbit the nucleus «in circular orbits»

[2 marks]

Rhodium-106 ($^{106}_{45}\mathrm{Rh}$) decays into palladium-106 ($^{106}_{46}\mathrm{Pd}$) by beta minus (β^-) decay.

The binding energy per nucleon of rhodium is 8.521 MeV and that of palladium is 8.550 MeV.

2b. State what is meant by the binding energy of a nucleus. *[1 mark]*

Markscheme

the energy needed to separate the nucleons of a nucleus

OR

energy released when a nucleus is formed from its nucleons

*Allow neutrons **AND** protons for nucleons*

Don't allow constituent parts

[1 mark]

2c. Show that the energy released in the β^- decay of rhodium is about 3 MeV. *[1 mark]*

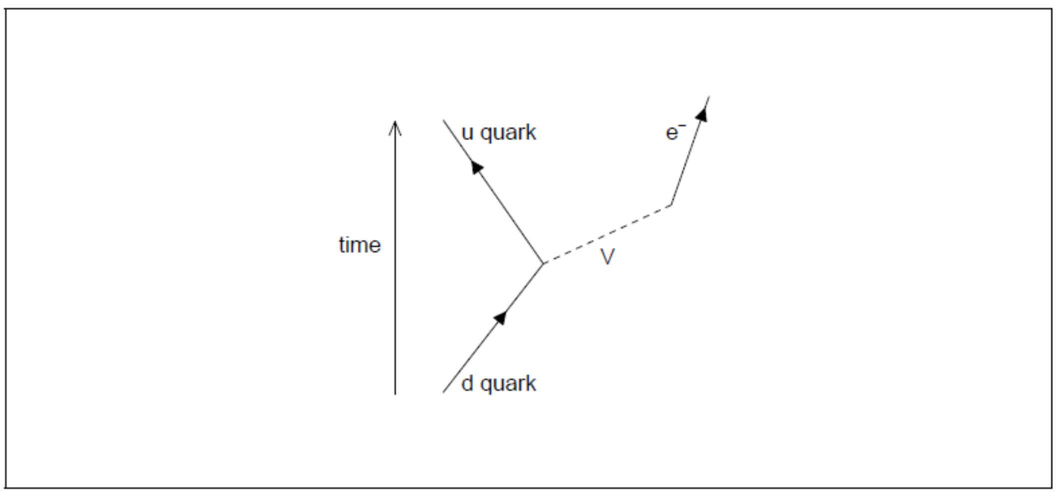
Markscheme

Q = 106 × 8.550 – 106 × 8.521 = 3.07 «MeV»

«$Q \approx$ 3 Me V»

[1 mark]

β^- decay is described by the following incomplete Feynman diagram.



2d. Draw a labelled arrow to complete the Feynman diagram. *[1 mark]*

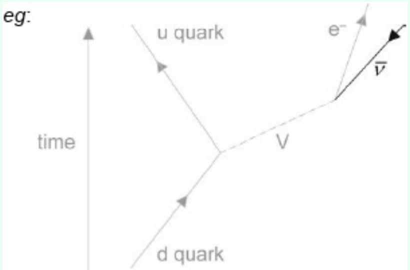
Markscheme

line with arrow as shown labelled anti-neutrino/$\bar{v}$

Correct direction of the "arrow" is essential

The line drawn must be "upwards" from the vertex in the time direction i.e. above the horizontal

***eg**:*



[1 mark]

2e. Identify particle V. *[1 mark]*

Markscheme

V = W^-

[1 mark]

3a. 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]

3b. 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]

3c. 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 $m_e v r = \frac{h}{2\pi}$ 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]

3d. Calculate the electron's orbital radius in (c)(ii). *[1 mark]*

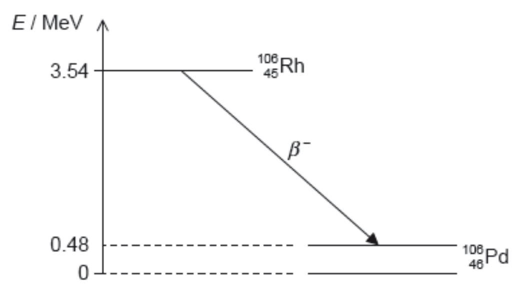
Markscheme

« $r = \frac{(6.63 \times 10^{-34})^2}{4\pi^2 \times 8.99 \times 10^9 \times 9.11 \times 10^{-31} \times (1.6 \times 10^{-19})^2}$»

$r = 5.3 \times 10^{-11}$ «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.



3e. 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]

3f. 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]

3g. 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»

$\lambda =$ «

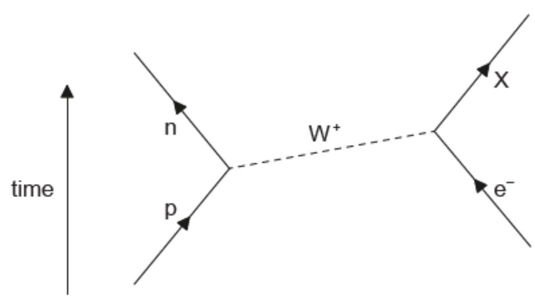
$\frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{7.68 \times 10^{-14}} =$» 2.6×10^{-12} «m»

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

Allow ECF from incorrect energy

[2 marks]

The Feynman diagram shows electron capture.



4a. Deduce that X must be an electron neutrino. *[2 marks]*

Markscheme

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 credit answers referring to energy

4b. Distinguish between hadrons and leptons. *[2 marks]*

Markscheme

hadrons experience strong force

OR

leptons do not experience the strong force

hadrons made of quarks/not fundamental

OR

leptons are not made of quarks/are fundamental

hadrons decay «eventually» into protons

OR

leptons do not decay into protons

Accept leptons experience the weak force

Allow "interaction" for "force"

5a. 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.

5b. 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

5c. 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*

5d. State and explain **one** example of a scientific analogy. *[2 marks]*

Markscheme

two analogous situations stated

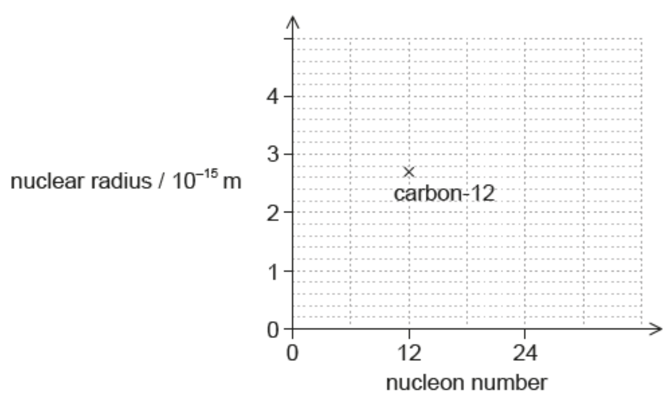
one element of the analogy equated to an element of physics

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.



5e. Plot the position of magnesium-24 on the graph. *[1 mark]*

Markscheme

correctly plotted

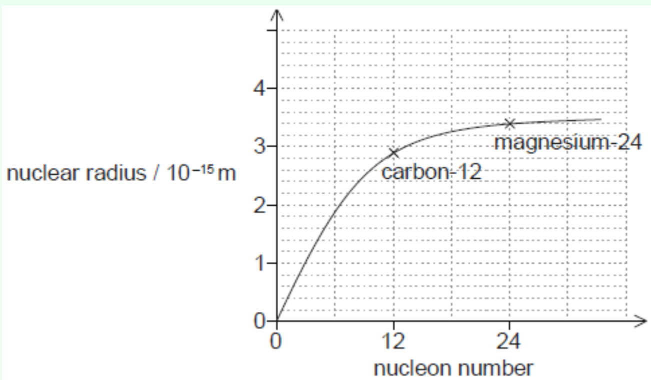
Allow ECF from (d)(i)

5f. 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



6a. State the quark structures of a meson and a baryon. *[2 marks]*

Meson: ....

....

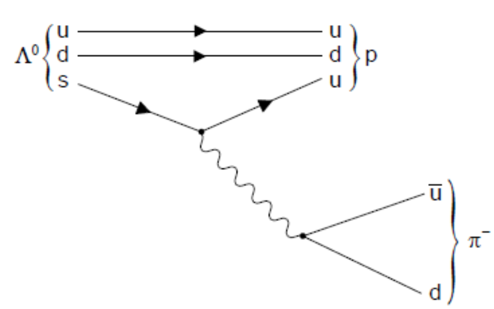
Baryon: ....

....

Markscheme

Meson: quark-antiquark pair
Baryon: 3 quarks

A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.



6b. Explain which interaction is responsible for this decay. *[2 marks]*

Markscheme

Alternative 1

strange quark changes «flavour» to an up quark

changes in quarks/strangeness happen only by the weak interaction

Alternative 2

Strangeness is not conserved in this decay «because the strange quark changes to an up quark»

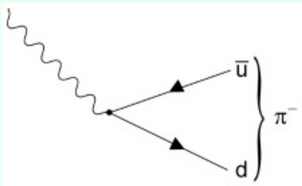
Strangeness is not conserved during the weak interaction

Do not allow a bald answer of weak interaction.

6c. Draw arrow heads on the lines representing $\bar{u}$ and d in the π^-. *[1 mark]*

Markscheme

arrows drawn in the direction shown



*Both needed for **[1]** mark.*

6d. Identify the exchange particle in this decay. *[1 mark]*

Markscheme

W^-

Do not allow W or W⁺.

6e. Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators. *[1 mark]*

Markscheme

it lowers the cost to individual nations, as the costs are shared

international co-operation leads to international understanding ***OR*** historical example of co-operation ***OR*** co-operation always allows science to proceed

large quantities of data are produced that are more than one institution/research group can handle co-operation allows effective analysis

Any one.

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

7a. Write down the missing values in the nuclear equation for this decay. *[1 mark]*

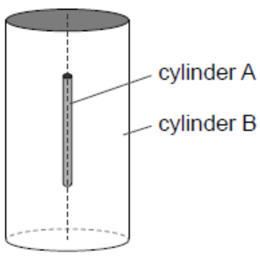
$$^{226}_{88}\text{Ra} \rightarrow {}^{\dots\dots}_{86}\text{Rn} + {}^{\dots\dots}_{2}\alpha$$

Markscheme

222 ***AND*** 4

Both needed.

7b. Rutherford and Royds put some pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B. *[1 mark]*



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.

The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin.

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

---

7c. Rutherford and Royds expected 2.7 x 10^{15} alpha particles to be emitted during the experiment. 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. *[3 marks]*

Markscheme

conversion of temperature to 291 K

p = 4.5 x 10^{-9} x 8.31 x «$\frac{2.91}{1.3\times10^{-5}}$»

OR

p = 2.7 x 10^{15} x 1.38 x 10^{-23} x «$\frac{2.91}{1.3\times10^{-5}}$»

0.83 or 0.84 «Pa»

7d. Rutherford and Royds identified the helium gas in cylinder B by observing its emission spectrum. Outline, with reference to atomic energy levels, how an emission spectrum is formed. *[3 marks]*

Markscheme

electron/atom drops from high energy state/level to low state

energy levels are discrete

wavelength/frequency of photon is related to energy change ***or*** quotes $E = hf$ ***or*** $E = \frac{hc}{\lambda}$

and is therefore also discrete

7e. The work was first reported in a peer-reviewed scientific journal. Outline why Rutherford and Royds chose to publish their work in this way. *[1 mark]*

Markscheme

peer review guarantees the validity of the work
OR
means that readers have confidence in the validity of work

OWTTE

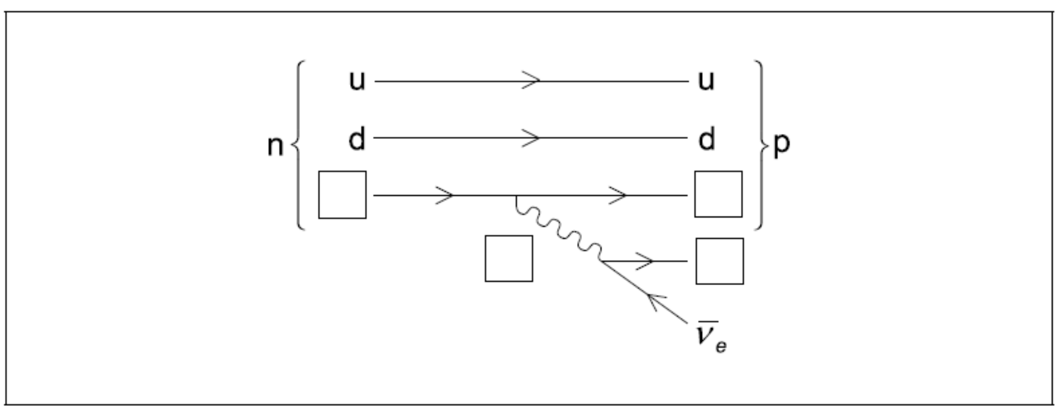
8a. A particular K meson has a quark structure $\bar{u}s$. State the charge on this meson. *[1 mark]*

Markscheme

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

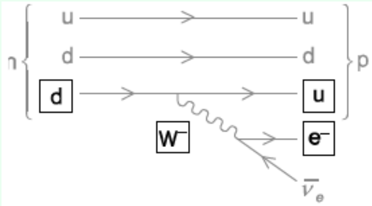
Negative signs required.

8b. The Feynman diagram shows the changes that occur during beta minus (β^-) decay. *[2 marks]*



Label the diagram by inserting the **four** missing particle symbols.

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^-

8c. Carbon-14 (C-14) is a radioactive isotope which undergoes beta minus (β^-) decay to the stable isotope nitrogen-14 (N-14). Energy is released during this decay. Explain why the mass of a C-14 nucleus and the mass of a N-14 nucleus are slightly different even though they have the same nucleon number. *[2 marks]*

Markscheme

decay products include an electron that has mass
OR
products have energy that has a mass equivalent
OR
mass/mass defect/binding energy converted to mass/energy of decay products

«so»

mass C-14 > mass N-14
OR
mass of *n* > mass of *p*
OR
mass of *d* > mass of *u*

Accept reference to "lighter" and "heavier" in mass.
Do not accept implied comparison, eg "C-14 has greater mass". Comparison must be explicit as stated in scheme.

9a. 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

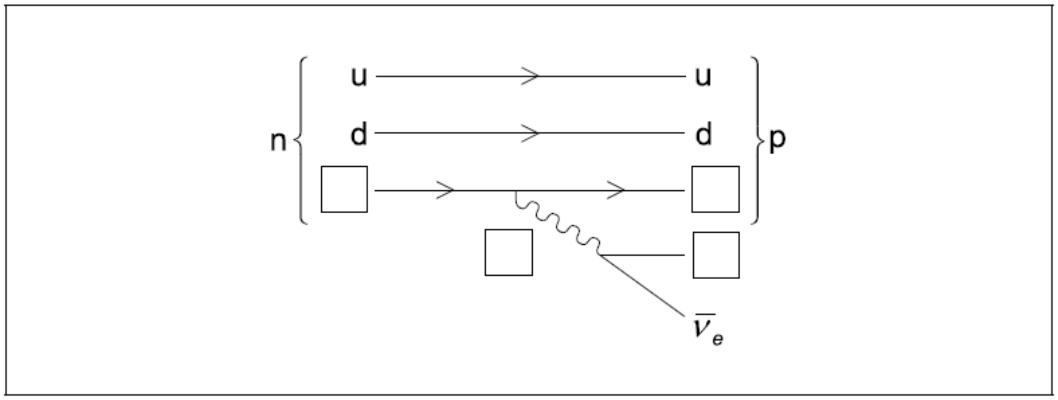
charge: –1 «e» ***or*** negative ***or*** *K^-*

strangeness: –1

baryon number: 0

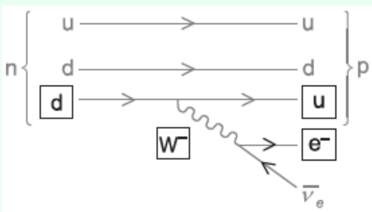
Negative signs required.
Award **[2]** for three correct answers, **[1 max]** for two correct answer and **[0]** for one correct answer.

9b. 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.

9c. 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.*

This question is in **two** parts. **Part 1** is about the nuclear model of the atom and radioactive decay. **Part 2** is about waves.

Part 1 Nuclear model of the atom and radioactive decay

10a. Outline how the evidence supplied by the Geiger–Marsden experiment supports the nuclear model of the atom. *[4 marks]*

Markscheme

most undeflected/pass straight through;

hence mostly empty space;

few deflected; *(allow "bent", "reflect", "bounce back" etc)*

hence small dense nucleus;

positive / positively charged;

10b. Outline why classical physics does not permit a model of an electron orbiting the nucleus. *[3 marks]*

Markscheme

electron accelerated / mention of centripetal force;

should radiate EM waves/energy;

and spiral into the nucleus;

The nuclide radium-226 $\left({}^{226}_{88}\mathrm{Ra}\right)$ decays into an isotope of radon (Rn) by the emission of an alpha particle and a gamma-ray photon.

10c. State what is meant by the terms nuclide and isotope. *[2 marks]*

Nuclide:

Isotope:

Markscheme

nuclide: nucleus characterized by specified number of protons and neutrons/its constituents;

isotope: nuclide with same number of protons / same element and different numbers of nucleons/neutrons;

10d. Construct the nuclear equation for the decay of radium-226. *[3 marks]*

$${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{\dots\dots}_{\dots\dots}\mathrm{Rn} + {}^{\dots\dots}_{\dots\dots}\mathrm{He} + {}^{\dots\dots}_{\dots\dots}\gamma$$

Markscheme

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

${}^{4}_{2}\mathrm{He}$ ***or*** ${}^{0}_{0}\gamma$;

top and bottom numbers balanced correctly;

10e. Radium-226 has a half-life of 1600 years. Determine the time, in years, it takes for the activity of radium-226 to fall to $\frac{1}{64}$ of its original activity. *[2 marks]*

Markscheme

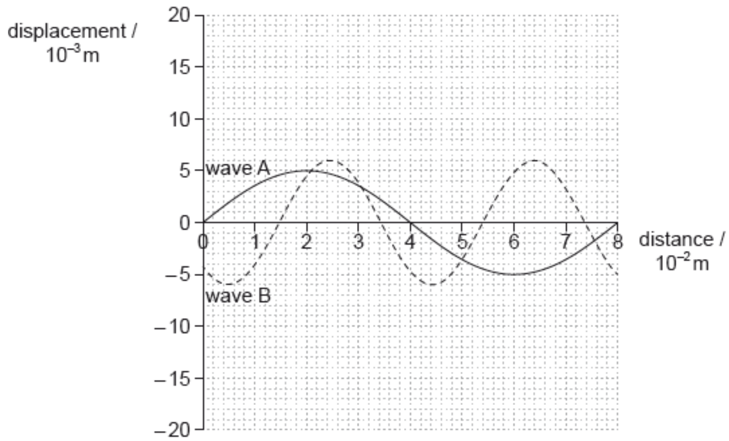
6 half-lives occurred;

9600 years;

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

Part 2 Waves

Two waves, A and B, are travelling in opposite directions in a tank of water. The graph shows the variation of displacement of the water surface with distance along the wave at a particular instant.



10f. State the amplitude of wave A. *[1 mark]*

Markscheme

5 mm ***or*** 5.0 mm; *units are required*

Allow other units, eg: 5/5.0 $\times$ 10^{-3} m.

10g. Wave A has a frequency of 9.0 Hz. Calculate the velocity of wave A. *[2 marks]*

Markscheme

wavelength $= 8.0 \text{ cm}$ ***or*** 8 cm; *(accept clear substitution in MP2 for this mark)*

$v = (f\lambda =)\ 9 \times 8 = 72 \text{ cm s}^{-1}$; *units are required*

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

10h. Deduce the frequency of wave B. *[3 marks]*

Markscheme

wavelength $= 3.9 \text{ (cm)}$; *(accept answers in the range of 3.8 to 4.0 (cm))*

frequency $= \left(\frac{72}{3.9} =\right)\ 18$;

Hz ***or*** s^{-1};

*Award **[3]** for a bald correct answer that includes unit.*

10i. State what is meant by the principle of superposition of waves. *[2 marks]*

Markscheme

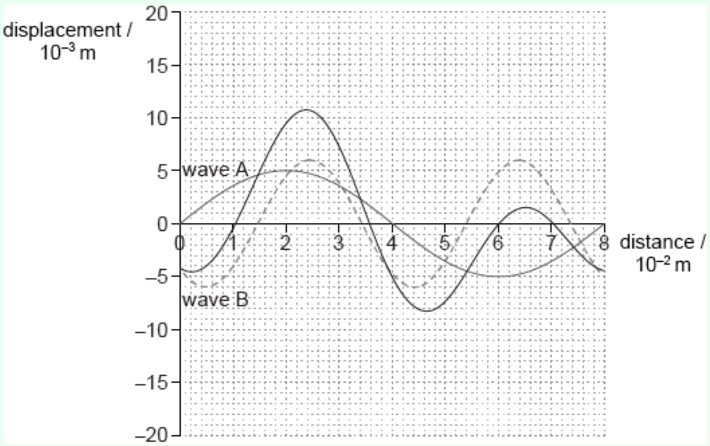
when two or more waves (of the same nature) meet/interfere / *OWTTE*;

the resultant displacement is the (vector) sum of their individual displacements; } *(do not allow constructive or destructive interference as answer to this point)*

Do not accept "amplitude" for "displacement" anywhere in answer.

10j. On the graph opposite, sketch the wave that results from the superposition of wave A and wave B at that instant. *[3 marks]*

Markscheme



start and end points correct (equal B) and crossing points on distance axis correct $(1, 3.6, 6, 7)$;

peaks and troughs at $(2.4, 11)$ $(4.6, -8)$ $(6.5, 1.5)$;

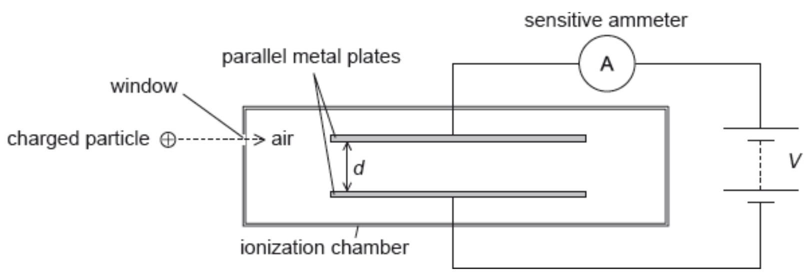
general shape correct as in example; } *(maximum and minimum must be alternating +/–)*

All tolerances ± 1 square.

This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about waves.

Part 1 Electric fields and radioactive decay

An ionization chamber is a device which can be used to detect charged particles.



The charged particles enter the chamber through a thin window. They then ionize the air between the parallel metal plates. A high potential difference across the plates creates an electric field that causes the ions to move towards the plates. Charge now flows around the circuit and a current is detected by the sensitive ammeter.

11a. On the diagram, draw the shape of the electric field between the plates. *[2 marks]*

Markscheme

minimum of three lines equally spaced and distributed, perpendicular to the plates and downwards; edge effect shown; } *(condone lines that do not touch plates)*

The separation of the plates *d* is 12 mm and the potential difference V between the plates is 5.2 kV. An ionized air molecule M with charge $+2e$ is produced when a charged particle collides with an air molecule.

11b. Calculate the electric field strength between the plates. *[1 mark]*

Markscheme

$4.3 \times 10^5\ (\mathrm{NC^{-1}})$

11c. Determine the change in the electric potential energy of M as it moves from the positive to the negative plate. *[3 marks]*

Markscheme

$\Delta E_\mathrm{P} = q\Delta V$ ***or*** $3.2 \times 10^{-19} \times 5.2 \times 10^3$;

$1.7 \times 10^{-15}\ (\mathrm{J})$;

negative/loss;

Radium-226 $\left({}^{226}_{88}\mathrm{Ra}\right)$ decays into an isotope of radon (Rn) by the emission of an alpha particle and a gamma-ray photon. The alpha particle may be detected using the ionization chamber but the gamma-ray photon is unlikely to be detected.

11d. Construct the nuclear equation for the decay of radium-226. *[2 marks]*

$${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{\dots\dots}_{\dots\dots}\mathrm{Rn} + {}^{\dots\dots}_{\dots\dots}\mathrm{He} + {}^{0}_{0}\gamma$$

Markscheme

$\left({}^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma\right)$

${}^{222}_{86}\mathrm{Rn}$ ***or*** ${}^{4}_{2}\mathrm{He}$;

numbers balance top and bottom on right-hand side;

11e. Radium-226 has a half-life of 1600 years. Determine the time, in years, it takes for the activity of radium-226 to fall to 5% of its original activity. *[3 marks]*

Markscheme

$\lambda = \frac{\ln 2}{1600} = 4.33 \times 10^{-4}\ (\mathrm{yr^{-1}})$;

$0.05 = \mathrm{e}^{-\lambda t}$;

6900 (years);

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

*Award **[2 max]** for 2.18 × 10^11 (s).*

*Award **[1 max]** to a candidate who identifies time as about 4.3 half-lives but cannot get further or gives an approximate reasoned answer.*

*However award **[3]** if number n of half-lives is calculated from 0.05 = 2^{-n} (= 4.32 usually from use of $\log_2$ working) and time shown.*

In beta minus (β^-) decay a d quark decays into a u quark, an electron and an electron antineutrino.

12a. Show that lepton number is conserved in this decay. *[1 mark]*

Markscheme

«lepton number on» LHS = 0 and «lepton number on» RHS = 0 +1−1
OR
quarks have no/0/zero lepton number and the lepton number for electron and the antineutrino cancel

12b. A nucleus of phosphorus-32 $\left({}^{32}_{15}\mathrm{P}\right)$ decays by beta minus (β^-) decay into a nucleus of sulfur-32 $\left({}^{32}_{16}\mathrm{S}\right)$. The binding energy per nucleon of ${}^{32}_{15}\mathrm{P}$ is 8.398 MeV and for ${}^{32}_{16}\mathrm{S}$ it is 8.450 MeV. *[3 marks]*

(i) State what is meant by the binding energy of a nucleus.

(ii) Determine the energy released in this decay.

Markscheme

(i)
energy released when a nucleus forms from constituent nucleons
OR
minimum energy needed/work done to break a nucleus up into its constituent nucleons

Do not allow reference to "atom".

*Award **[0]** for "energy to assemble nucleus".*

Do not allow "particles", "constituents" or "components" for "nucleons".

(ii)
«energy/mass difference =» 8.450 – 8.398 «= 0.052 MeV»

Q = 1.7 ***or*** 1.66 ***or*** 1.664 MeV
OR
2.66×10^{-13} J

12c. Quarks were hypothesized long before their existence was experimentally verified. Discuss the reasons why physicists developed a theory that involved quarks. *[3 marks]*

Markscheme

quark theory is simpler ***OR*** Occam's razor example ***OR*** simple model explains complex observations

quotes experiment that led to quark theory, eg deep inelastic scattering or electron scattering

model incorporates strong/weak interactions/forces between protons and neutrons

model incorporates conservation rules

model explains differences between neutrons and protons ***OR*** explains decay of neutron to proton

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This question is in two parts. **Part 1** is about renewable energy. **Part 2** is about nuclear energy and radioactivity.

Part 1 Renewable energy

A small coastal community decides to use a wind farm consisting of five identical wind turbines to generate part of its energy. At the proposed site, the average wind speed is 8.5ms^{-1} and the density of air is 1.3kgm^{-3}. The maximum power required from the wind farm is 0.75 MW. Each turbine has an efficiency of 30%.

13a. (i) Determine the diameter that will be required for the turbine blades to achieve the maximum power of 0.75 MW. *[8 marks]*

(ii) State **one** reason why, in practice, a diameter larger than your answer to (a)(i) is required.

(iii) Outline why the individual turbines should not be placed close to each other.

(iv) Some members of the community propose that the wind farm should be located at sea rather than on land. Evaluate this proposal.

Markscheme

(i) total wind power required $= \frac{750000}{0.3}$;

maximum wind power required per turbine, $P = \frac{750000}{5 \times 0.3} (= 500\text{kW})$;

$d = \left(\frac{8P}{\rho \pi v^3} =\right)^{\frac{1}{2}} 40(\text{m})$

*Award **[1 max]** for an answer of 48.9 (m) as it indicates 5 and 0.3 ignored.*
*Award **[2 max]** for 22 (m) as it indicates 0.3 ignored.*
*Award **[2 max]** for 89 (m) as it indicates 5 ignored.*

(ii) not all kinetic energy can be extracted from wind / losses in cables to community / turbine rotation may be cut off/"feathered" at high or low wind speeds;
Do not allow "wind speed varies" as question gives the average speed.

(iii) less kinetic energy available / wind speed less for turbines behind; turbulence/wake effect; *(do not allow "turbines stacked too close")*

(iv) *implications:* average wind speeds are greater / more space available;
limitations: installation/maintenance cost / difficulty of access / wave damage;
*Must see one each for **[2]**.*

13b. Currently, a nearby coal-fired power station generates energy for the community. Less coal will be burnt at the power station if the wind farm is constructed. *[7 marks]*

(i) The energy density of coal is 35 MJ kg^{-1}. Estimate the minimum mass of coal that can be saved every hour when the wind farm is producing its full output.

(ii) One advantage of the reduction in coal consumption is that less carbon dioxide will be released into the atmosphere. State **one** other advantage and **one** disadvantage of constructing the wind farm.

(iii) Suggest the likely effect on the Earth's temperature of a reduction in the concentration of atmospheric greenhouse gases.

Markscheme

(i) mass of coal per second (=0.0214 kg);
77.1 (kg);
or
energy saved per hour=0.75×3600 (=2700MJh^{-1}) ;

mass of coal saved $= \left(\frac{2700}{35} =\right) 77.1(\text{kg})$;

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

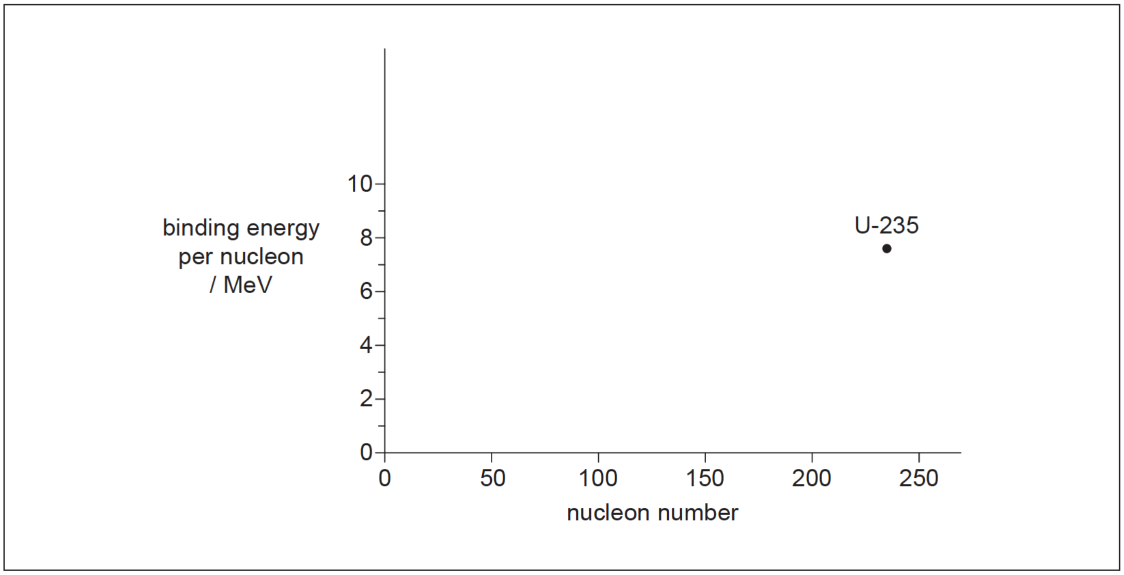
(ii) *advantage:*
energy is free (apart from maintenance and start-up costs) / energy is renewable / sufficient for small community with predominance of wind / supplies energy to remote community / independent of national grid / any other reasonable advantage;
Answer must focus on wind farm not coal disadvantages.

disadvantage:
wind energy is variable/unpredictable / noise pollution / killing birds/bats / large open areas required / visual pollution / ecological issues / need to provide new infrastructure;

(iii) greenhouse gas molecules are excited by/absorbed by/resonate as a result of infrared radiations; { (must refer to infrared not "heat")
this radiation is re-emitted in all directions;
less greenhouse gas means less infrared/heat returned to Earth; { (consideration of return direction is essential for mark)
temperature falls (to reach new equilibrium);

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.



13c. State what is meant by the binding energy of a nucleus. *[1 mark]*

Markscheme

energy released when a nucleus forms from constituent nucleons / (minimum) energy needed/work done to break a nucleus up into its constituent nucleons;

*Award **[0]** for energy to assemble nucleus.*

Do not allow "particles" or "components" for "nucleons".

Do not accept "energy that binds nucleons together" OWTTE.

13d. (i) On the axes, sketch a graph showing the variation of nucleon number with the binding energy per nucleon. *[5 marks]*

(ii) Explain, with reference to your graph, why energy is released during fission of U-235.

Markscheme

(i) generally correct shape with maximum shown, trending down to U-235;
maximum shown somewhere between 40 and 70;
*Award **[0]** for straight line with positive gradient from origin.*
*Award **[1]** if maximum position correct but graph begins to rise or flatlines beyond or around U-235.*

(ii) identifies fission as occurring at high nucleon number / at right-hand side of graph;
fission means that large nucleus splits into two (or more) smaller nuclei/nuclei to left of fissioning nucleus (on graph);
(graph shows that) fission products have higher (average) binding energy per nucleon than U-235;
energy released related to difference between initial and final binding energy;
*Award **[2 max]** if no reference to graph.*

13e. 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) Define the term *radioactive half-life*.

(iii) 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. Calculate the initial mass of the U-235 if the rock sample was formed 2.1×10^{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) time taken for number of unstable nuclei/(radio)activity to halve;
Accept atom/isotope.
Do not accept mass/molecule/amount/substance.

(iii) three half-lives identified;
45 (mg);
*Award **[2]** for bald correct answer.*

Part 2 Radioactivity

Radium-224 $\left({}^{224}_{88}\mathrm{RA}\right)$ is a radioactive nuclide that decays to form radon-220. Radon-220 is itself radioactive and undergoes a further decay. The table shows the series of radioactive nuclides that are formed as the decays proceed. The series ends with a stable isotope of lead.

Parent nuclide	Emitter	Half-life	Daughter nuclide(s)
radium-224	alpha	3.64 days	radon-220 (Rn)
radon-220	alpha	55 seconds	polonium-216 (Po)
polonium-216	alpha	0.15 seconds	lead-212 (Pb)
lead-212	beta	10.6 hours	bismuth-212 (Bi)
bismuth-212	beta alpha	60.6 minutes	polonium-212 thallium (Tl)
polonium-212	alpha	3.0×10^{-7} seconds	lead-208 (stable)
thallium	beta	3.1 minutes	lead-208 (stable)

14a. For the final thallium nuclide, identify the *[2 marks]*

(i) nucleon number.

(ii) proton number.

Markscheme

(i) 208;

(ii) 81;

14b. Radon-220 is a radioactive gas. It is released by rocks such as granite. In some parts of the world, houses are built from materials containing granite. Explain why it is unlikely that radon-220 will build up in sufficient quantity to be harmful in these houses. *[2 marks]*

Markscheme

because the half-life is (only) 55 s;
radon is produced slowly but decays quickly (so cannot build up);

14c. (i) Calculate, in hour^{-1}, the decay constant of lead-212. *[6 marks]*

(ii) In a pure sample of lead-212 at one instant, 8.0 × 10^{-3} kg of the lead-212 is present. Calculate the mass of lead-212 that remains after a period of 35 hours.

(iii) A sample of pure radium begins to decay by the series shown in the table. At one instant, a mass of 8.0 × 10^{-3} kg of lead-212 is present in the sample. Suggest why, after 35 hours, there will be a greater mass of lead-212 present in the sample than the value you calculated in (h)(ii).

Markscheme

(i) $\left(\lambda = \frac{\text{In2}}{\text{T}_{\frac{1}{2}}} = \frac{0.693}{10.6} = \right) 6.5 \times 10^{-2}\text{hour}^{-1}$

(ii) use of λ from (h)(i);
correct substitution into N = N0e−λt ;
8.0 to 8.3 × 10–4 kg;

(iii) the rate of decay/activity of polonium/radium;
is greater than the rate of decay/activity of lead;

This question is about radioactive decay.

A nucleus of an iodine isotope, I-131, undergoes radioactive decay to form a nucleus of the nuclide xenon-131. Xe-131 is stable.

15a. Explain what is meant by an isotope. *[2 marks]*

Markscheme

same number of protons / atoms of the same element;

different number of neutrons;

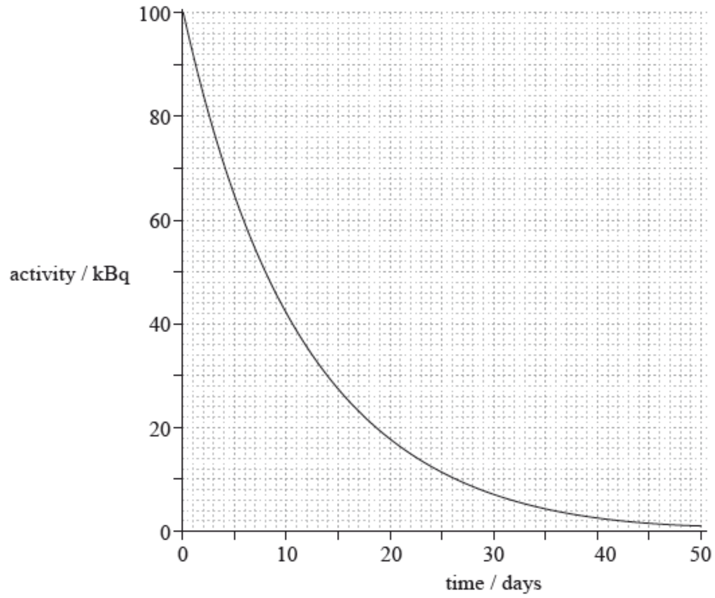
15b. Identify the missing entries to complete the nuclear reaction for the decay of I-131. *[1 mark]*

$${}^{131}_{53}\text{I} \rightarrow {}^{131}_{\ldots\ldots}\text{Xe} + \beta^{-} + \ldots\ldots\ldots\ldots\ldots$$

Markscheme

54 and antineutrino/
$\bar{\nu}$; *(both needed)*

The initial activity of a sample of I-131 is 100 kBq. The subsequent variation of the activity of the sample with time is shown in the graph.



15c. The I-131 can be used for a medical application but only when the activity lies within the range of $(20 \pm 10)\ \text{kBq}$. Determine an estimate for the time during which the iodine can be used. *[2 marks]*

Markscheme

range is 14 to 26 ***or*** 14 to 27;

12 ***or*** 13 days;

*Award **[2]** if marking points added to the graph.*

15d. A different isotope has half the initial activity and double the half-life of I-131. On the graph in (c), sketch the variation of activity with time for this isotope. *[2 marks]*

Markscheme

starts at 50 kBq and approximately exponential decay curve;

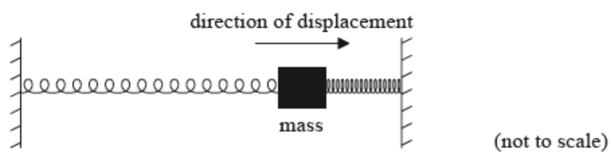
half-life is $\sim 16\ \text{days}$ / line passes through $[16,\ 25]$ to within a small square;

This question is in **two** parts. **Part 1** is about the oscillation of a mass. **Part 2** is about nuclear fission.

Part 1 Oscillation of a mass

A mass of 0.80 kg rests on a frictionless surface and is connected to two identical springs both of which are fixed at their other ends. A force of 0.030 N is required to extend or compress each spring by 1.0 mm. When the mass is at rest in the centre of the arrangement, the springs are not extended.

The mass is displaced to the right by 60 mm and released.



16a. Determine the acceleration of the mass at the moment of release. *[3 marks]*

Markscheme

force of 1.8 N for each spring so total force is 3.6 N;

acceleration $= \frac{3.6}{0.8} = 4.5\ \mathrm{ms}^{-2}$; *(allow ECF from first marking point)*

to left/towards equilibrium position / negative sign seen in answer;

16b. Outline why the mass subsequently performs simple harmonic motion (SHM). *[2 marks]*

Markscheme

force/acceleration is in opposite direction to displacement/towards equilibrium position;

and is proportional to displacement;

16c. Calculate the period of oscillation of the mass. *[2 marks]*

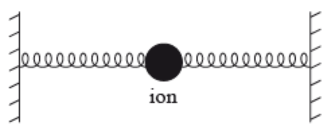
Markscheme

$\omega = \left(\sqrt{\left(\frac{a}{x}\right)} =\right) \sqrt{\frac{4.5}{60\times10^{-3}}} (= 8.66\ \mathrm{rad\,s^{-1}})$;

$T = 0.73\ \mathrm{s}$;

Watch out for ECF from (a)(i) eg award ***[2]*** *for* $T = 1.0\ s$ *for* $a = 2.25\ \mathrm{m\,s^{-2}}$.

The motion of an ion in a crystal lattice can be modelled using the mass–spring arrangement. The inter-atomic forces may be modelled as forces due to springs as in the arrangement shown.



The frequency of vibration of a particular ion is $7\times10^{12}\ \mathrm{Hz}$ and the mass of the ion is $5\times10^{-26}\ \mathrm{kg}$. The amplitude of vibration of the ion is $1\times10^{-11}\ \mathrm{m}$.

16d. Estimate the maximum kinetic energy of the ion. *[2 marks]*

Markscheme

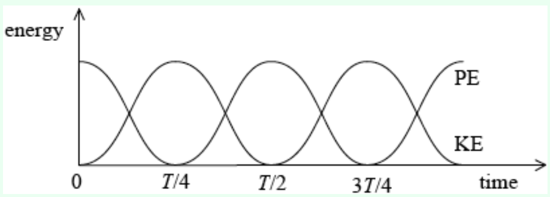
$\omega = 2\pi\times7\times10^{12} (= 4.4\times10^{13} Hz)$;

$5\times10^{-21}\ \mathrm{J}$;

Allow answers in the range of 4.8 to $4.9\times10^{-21}\ \mathrm{J}$ *if 2 sig figs or more are used.*

16e. On the axes, draw a graph to show the variation with time of the kinetic energy of mass and the elastic potential energy stored in the springs. You should add appropriate values to the axes, showing the variation over one period. *[3 marks]*

Markscheme



KE and PE curves labelled – very roughly $\cos^2$ and $\sin^2$ shapes; } *(allow reversal of curve labels)*

KE and PE curves in anti-phase and of equal amplitude;

at least one period shown;

either $E_{\max}$ marked correctly on energy axis, or T marked correctly on time axis;

16f. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). *[1 mark]*

Markscheme

$7.0 \times 10^{12}\ \mathrm{Hz}$ is equivalent to wavelength of $4.3 \times 10^{-5}\ \mathrm{m}$;

Part 2 Nuclear fission

A reaction that takes place in the core of a particular nuclear reactor is as shown.

$$ {}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \to {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3{}^{1}_{0}\mathrm{n} $$

In the nuclear reactor, 9.5×10^{19} fissions take place every second. Each fission gives rise to 200 MeV of energy that is available for conversion to electrical energy. The overall efficiency of the nuclear power station is 32%.

16g. Determine the mass of U-235 that undergoes fission in the reactor every day. *[3 marks]*

Markscheme

number of fissions in one day $= 9.5 \times 10^{19} \times 24 \times 3600\ (= 8.2 \times 10^{24})$;

mass of uranium atom $= 235 \times 1.661 \times 10^{-27}\ (= 3.9 \times 10^{-25}\ \mathrm{kg})$;

mass of uranium in one day $(= 8.2 \times 10^{24} \times 3.9 \times 10^{-25}) = 3.2\ \mathrm{kg}$;

16h. Calculate the power output of the nuclear power station. *[2 marks]*

Markscheme

energy per fission $= 200 \times 10^6 \times 1.6 \times 10^{-19}$ $(= 3.2 \times 10^{-11}\ \text{J})$;

power output $= (9.5 \times 10^{19} \times 3.2 \times 10^{-11} \times 0.32 =)\ 9.7 \times 10^8\ \text{W}$;

*Award **[1]** for an answer of* $6.1 \times 10^{27}\ \text{eVs}^{-1}$.

In addition to the U-235, the nuclear reactor contains a moderator and control rods. Explain the function of the

16i. moderator. *[3 marks]*

Markscheme

neutrons have to be slowed down (before next fission);

because the probability of fission is (much) greater (with neutrons of thermal energy);

neutrons collide with/transfer energy to atoms/molecules (of the moderator);

16j. control rods. *[2 marks]*

Markscheme

have high neutron capture cross-section/good at absorbing neutrons;

(remove neutrons from the reaction) thus controlling the rate of nuclear reaction;

This question is about nuclear reactions.

A reaction that takes place in the core of a particular nuclear reactor is as shown.

$$^{235}_{92}\text{U} + \text{X} \rightarrow ^{144}_{56}\text{Ba} + ^{89}_{36}\text{Kr} + 3\text{X}$$

17a. State the nature of X. *[1 mark]*

Markscheme

neutron / ^1_0n;

17b. State **one** form of energy that is instantaneously released in the reaction. *[1 mark]*

Markscheme

kinetic energy / gamma radiation / binding energy;

In the nuclear reactor, 9.5×10^{19} fissions take place every second. Each fission gives rise to 200 MeV of energy that is available for conversion to electrical energy. The overall efficiency of the nuclear power station is 32%.

17c. Determine the mass of U-235 that undergoes fission in the reactor every day. *[3 marks]*

Markscheme

number of fissions in one day $= 9.5 \times 10^{19} \times 24 \times 3600\ (= 8.2 \times 10^{24})$;

mass of uranium atom $= 235 \times 1.661 \times 10^{-27}\ (= 3.9 \times 10^{-25}\ \text{kg})$;

mass of uranium in one day $(= 8.2 \times 10^{24} \times 3.9 \times 10^{-25}) = 3.2\ \text{kg}$;

17d. Calculate the power output of the nuclear power station. *[2 marks]*

Markscheme

energy per fission $= 200 \times 10^{6} \times 1.6 \times 10^{-19}\ (= 3.2 \times 10^{-11}\ \text{J})$;

power output $= (9.5 \times 10^{19} \times 3.2 \times 10^{-11} \times 0.32 =)\ 9.7 \times 10^{8}\ \text{W}$;

*Award **[1]** for an answer of* $6.1 \times 10^{27}\ \text{eVs}^{-1}$.

17e. In addition to the U-235, the nuclear reactor contains graphite that acts as a moderator. Explain the function of the moderator. *[3 marks]*

Markscheme

neutrons have to be slowed down (before next fission);

because the probability of fission is (much) greater (with neutrons of thermal energy);

neutrons collide with/transfer energy to atoms/molecules (of the moderator);

17f. Outline how energy released in the nuclear reactor is transformed to electrical energy. *[3 marks]*

Markscheme

kinetic energy of neutrons/thermal energy of core is transferred into thermal energy

of the coolant (and elsewhere);

(thermal energy) is converted into kinetic energy in moving steam;

(kinetic energy of steam) is transferred into (rotational) kinetic energy of turbine;

(kinetic energy of turbine) is transferred into electrical energy by dynamo/generator;

This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about thermal energy transfer.

Part 1 Nuclear reactions

18a. (i) Define the term *unified atomic mass unit.* *[2 marks]*

(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in MeVc^{-2}.

Markscheme

one twelfth of the mass of a carbon-12 atom/
$^{12}_{6}\text{C}$;
Do not allow nucleus.

255.09×931.5 = 237600(MeVc−2);
Award [1] for a bald correct answer.

18b. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), a nucleus of potassium (K-40) and a proton are produced. *[6 marks]*

$$^{40}_{20}\mathrm{Ca} + \mathrm{X} \rightarrow {}^{40}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{p}$$

The following data are available for the reaction.

Particle	Rest mass / MeV c^{-2}
calcium-40	37 214.694
X	939.565
potassium-40	37 216.560
proton	938.272

(i) Identify particle X.

(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton.

Markscheme

(i) neutron/$^{1}_{0}\mathrm{n}$;

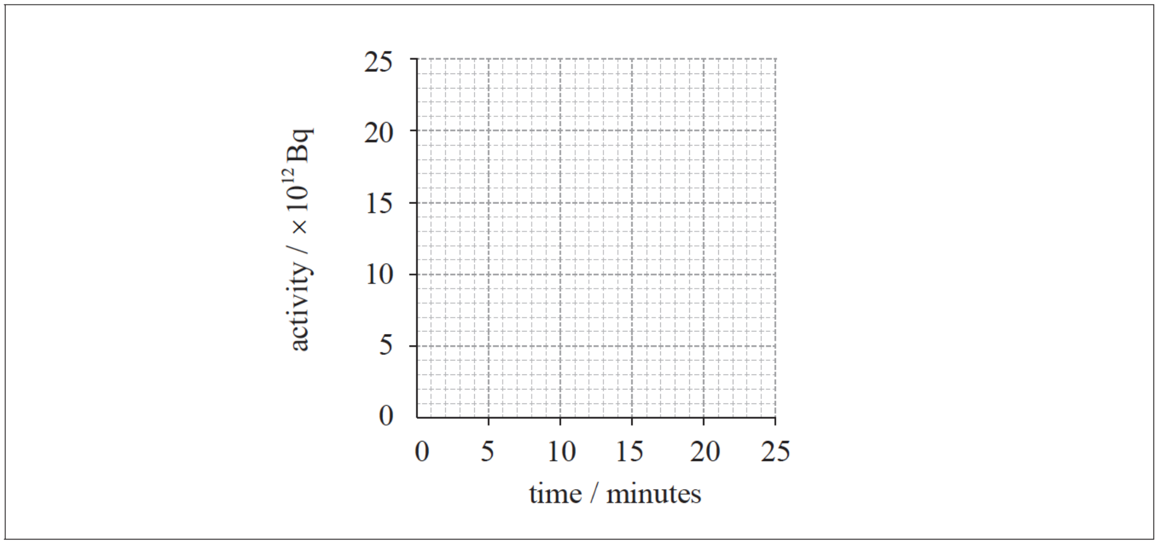
(ii) the (rest) mass of the products is greater than that of the reactants;
energy must be given to supply this extra mass;

(iii) $\Delta m = [37216.560 + 938.272] - [37214.694 + 939.565] = 0.573\ (\mathrm{MeVc}^{-2})$;
energy required for reaction=0.573(MeV);
kinetic energy=(8.326-0.573=)7.753(MeV);
*Award **[3]** for a bald correct answer.*

18c. Potassium-38 decays with a half-life of eight minutes. *[5 marks]*

(i) Define the term *radioactive half-life*.

(ii) A sample of potassium-38 has an initial activity of 24×10^{12} Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample.

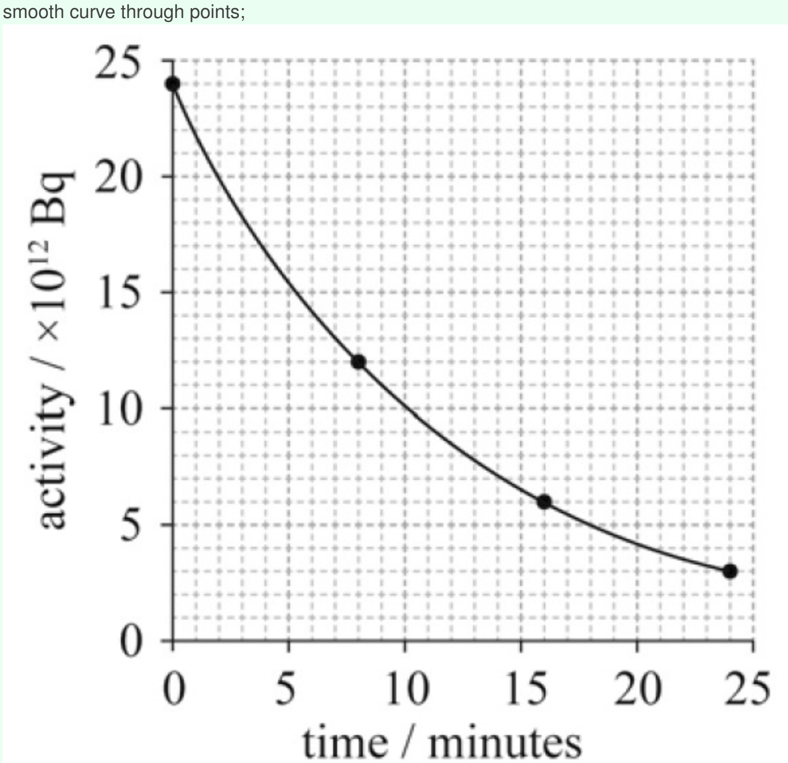


(iii) Determine the activity of the sample after 2 hours.

Markscheme

(i) time for the activity of a sample to halve / time for half the radioactive nuclei to decay;

(ii) four data points (0, 24) (8, 12) (16, 6) (24, 3) correct;
smooth curve through points;



(iii) 2 hours (=120 minutes)=15 half-lives;
activity=$\frac{24 \times 10^{12}}{2^{15}} = 7.3 \times 10^{8}\,(\mathrm{Bq})$;

or

$\lambda = \frac{\ln 2}{8}; \left(A = A_0 e^{-\lambda t} \text{method}\right);$

=7.3×10^{8}(Bq)

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

Part 2 Thermal energy transfer

18d. (i) Define the *specific latent heat* of fusion of a substance. *[5 marks]*

(ii) Explain, in terms of the molecular model of matter, the relative magnitudes of the specific latent heat of vaporization of water and the specific latent heat of fusion of water.

Markscheme

(i) the energy (absorbed/released) when a unit mass/one kg;
of liquid freezes (to become solid) at constant temperature / of solid melts (to become liquid) at constant temperature;

(ii) potential energy changes during changes of state / bonds are weakened/broken during changes of state;
potential energy change is greater for vaporization than fusion / more energy is required to break bonds than to weaken them;
SLH vaporization is greater than SLH fusion;
Only award third marking point if first marking point or second marking point is awarded.

18e. A piece of ice is placed into a beaker of water and melts completely. *[5 marks]*

The following data are available.

Initial mass of ice = 0.020 kg
Initial mass of water = 0.25 kg
Initial temperature of ice = 0°C
Initial temperature of water = 80°C
Specific latent heat of fusion of ice = 3.3×10^{5}J kg^{-1}
Specific heat capacity of water = 4200 J $kg^{-1}K^{-1}$

(i) Determine the final temperature of the water.

(ii) State **two** assumptions that you made in your answer to part (f)(i).

Markscheme

(i) use of $\Delta Q = mc\Delta T$ and *mL*;
$0.020 \times 3.3 \times 10^{5} + 0.020 \times 4200 \times (T - 0) = 0.25 \times 4200 \times (80 - T)$;
T=68(°C);
*Allow **[3]** for a bald correct answer.*
*Award **[2]** for an answer of T=74°(C) (missed melted ice changing temperature).*

(ii) no energy given off to the surroundings/environment;
no energy absorbed by beaker;
no evaporation of water;

This question is about binding energy and mass defect.

19a. State what is meant by mass defect. *[1 mark]*

Markscheme

difference between mass of a nucleus and the sum of mass of nucleons/ constituents/particles;

19b. (i) Data for this question is given below. *[6 marks]*

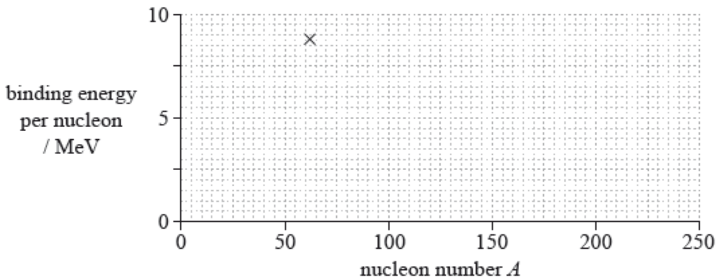
Binding energy per nucleon for deuterium $\left({}^2_1\text{H}\right)$ is 1.1 MeV.

Binding energy per nucleon for helium-3 $\left({}^3_2\text{He}\right)$ is 2.6 MeV.

Using the data, calculate the energy change in the following reaction.

$${}^2_1\text{H} + {}^1_1\text{H} \rightarrow {}^3_2\text{He} + \gamma$$

(ii) The cross on the grid shows the binding energy per nucleon and nucleon number *A* of the nuclide nickel-62.



On the grid, sketch a graph to show how the average binding energy per nucleon varies with nucleon number *A*.

(iii) State and explain, with reference to your sketch graph, whether energy is released **or** absorbed in the reaction in (b)(i).

Markscheme

(i) binding energy of left-hand side $= 1.11 \times 2$ and binding energy of right-hand side $= 3 \times 2.6$; } *(both needed) (allow ECF)*

energy release $= 5.58\ (\text{MeV})$; *(ignore sign)*

(ii) line goes through Ni point and nickel is the maximum ± 2 small squares horizontally; } *(allow Fe-56 as maximum – this is just outside the range allowed)*

line starts at 0, downward trend for *A* after 62, trend after nickel less steep than before;

Line must go through part of the X to award first marking point.

Line must not flatten out to award second marking point.

Allow smooth curve for low A.

Allow incorrect variations at low A.

(iii) nucleus produced in the reaction is higher up the curve than the reactants / *OWTTE*; } *(must see reference to graph)*

reference to binding energy/other valid reason results in energy release;

*Award **[0]** for a bald correct answer.*

*Award **[0]** for any discussion of fission.*