1 An ancient sealed flask contains a liquid, assumed to be water. An archaeologist asks a scientist to determine the volume of liquid in the flask without opening the flask. The scientist decides to use a radioactive isotope of sodium ($^{24}_{11}Na$) that decays with a half-life of 14.8 h.

(a) She first mixes a compound that contains 3.0×10^{-10} g of sodium-24 with 1500 cm^3 of water. She then injects 15 cm^3 of the solution into the flask through the seal.
Show that initially about 7.5×10^{10} atoms of sodium-24 are injected into the flask.

(1)

(b) Show that the initial activity of the solution that is injected into the flask is about 1×10^6 Bq.

activity = ______________Bq

(3)

(c) She waits for 3.5 h to allow the injected solution to mix thoroughly with the liquid in the flask. She then extracts 15 cm^3 of the liquid from the flask and measures its activity which is found to be 3600 Bq.

Calculate the total activity of the sodium-24 in the flask after 3.5 h and hence determine the volume of liquid in the flask.

(3)

(d) The archaeologist obtained an estimate of the volume knowing that similar empty flasks have an average mass of 1.5 kg and that mass of the flask and liquid was 5.2 kg. Compare the estimate that the archaeologist could obtain from these masses with the volume calculated in part 4.3 and account for any difference.

____

____

____

____

(2)

(Total 9 marks)

2 The isotope of uranium, $^{238}_{92}U$, decays into a stable isotope of lead, $^{206}_{82}Pb$, by means of a series of α and β^- decays.

(a) In this series of decays, α decay occurs 8 times and β^- decay occurs n times.
Calculate n.

answer = ____________________

(1)

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

____

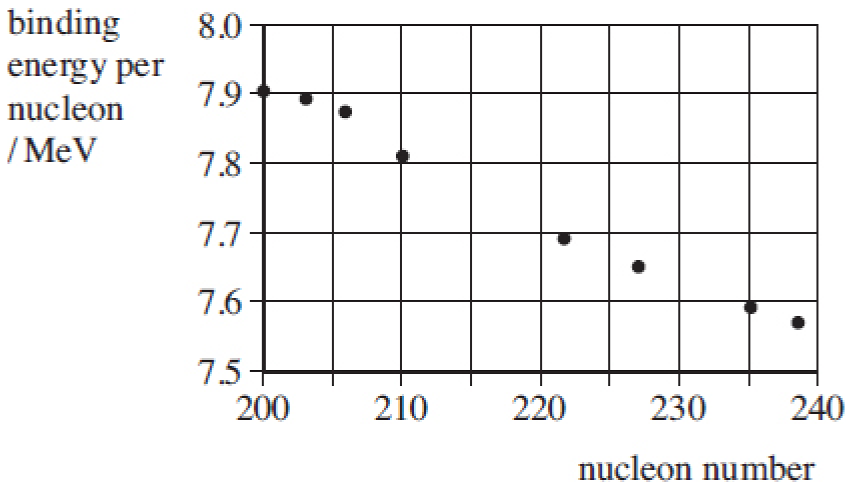
____

____

(2)

(ii) **Figure 1** shows the binding energy per nucleon for some stable nuclides.

Figure 1



Use **Figure 1** to estimate the binding energy, in MeV, of the $^{206}_{82}Pb$ nucleus.

answer = ____________________ MeV

(1)

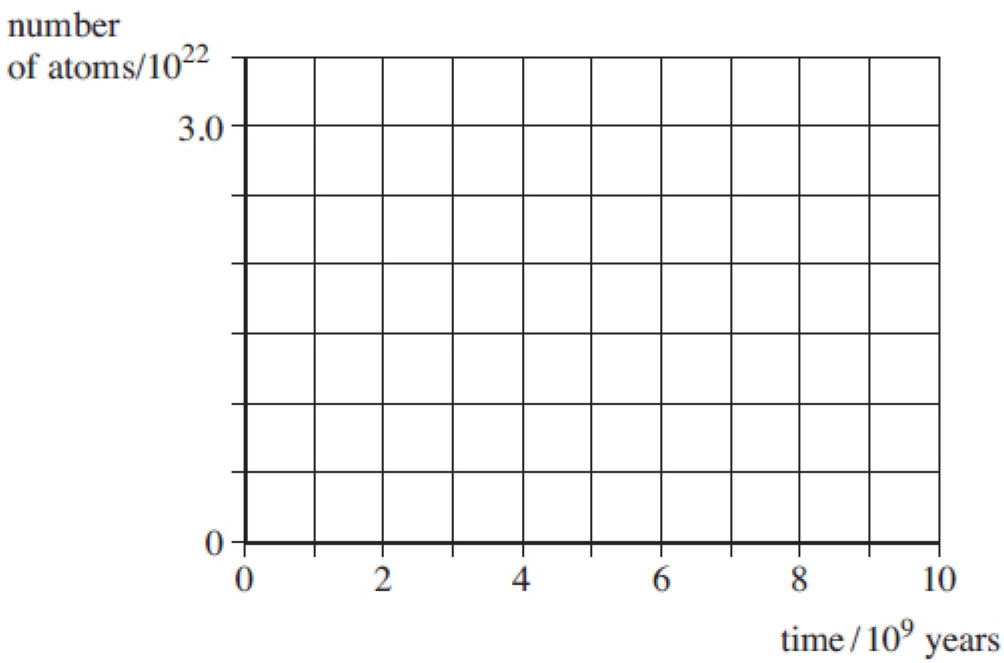
(c) The half-life of $^{238}_{92}U$ is 4.5×10^9 years, which is much larger than all the other half-lives of the decays in the series.

A rock sample when formed originally contained 3.0×10^{22} atoms of $^{238}_{92}U$ and no $^{206}_{82}Pb$ atoms.

At any given time most of the atoms are either $^{238}_{92}U$ or $^{206}_{82}Pb$ with a negligible number of atoms in other forms in the decay series.

(i) Sketch on **Figure 2** graphs to show how the number of $^{238}_{92}U$ atoms and the number of $^{206}_{82}Pb$ atoms in the rock sample vary over a period of 1.0×10^{10} years from its formation.
Label your graphs U and Pb.

Figure 2



(2)

(ii) A certain time, *t*, after its formation the sample contained twice as many $^{238}_{92}U$ atoms as $^{206}_{82}Pb$ atoms.
Show that the number of $^{238}_{92}U$ atoms in the rock sample at time *t* was 2.0×10^{22}.

(1)

(ii) Calculate t in years.

answer = ____________________ years

(3)

(Total 10 marks)

3 (a) In a radioactivity experiment, background radiation is taken into account when taking corrected count rate readings in a laboratory. One source of background radiation is the rocks on which the laboratory is built. Give **two** other sources of background radiation.

source 1 ____

source 2 ____

(1)

(b) A γ ray detector with a cross-sectional area of 1.5×10^{-3} m^2 when facing the source is placed 0.18 m from the source.
A corrected count rate of 0.62 counts s^{-1} is recorded.

(i) Assume the source emits γ rays uniformly in all directions.
Show that the ratio

$$\frac{\text{number of } \gamma \text{ photons incident on detector}}{\text{number of } \gamma \text{ photons produced by source}}$$

is about 4×10^{-3}.

(2)

(ii) The γ ray detector detects 1 in 400 of the γ photons incident on the facing surface of the detector.
Calculate the activity of the source. State an appropriate unit.

answer = ____________________ unit ___________

(3)

(c) Calculate the corrected count rate when the detector is moved 0.10 m further from the source.

answer = ____________________ counts s^{-1}

(3)

(Total 9 marks)

4 The fissile isotope of uranium, $^{233}_{92}U$, has been used in some nuclear reactors. It is normally produced by neutron irradiation of thorium-232. An irradiated thorium nucleus emits a β^- particle to become an isotope of protactinium.

This isotope of protactinium may undergo β^- decay to become $^{233}_{92}U$.

(a) Complete the following equation to show the β^- decay of protactinium.

$$^{......}_{......}Pa \rightarrow {}^{233}_{92}U + \beta^- + \;......\;.$$

(2)

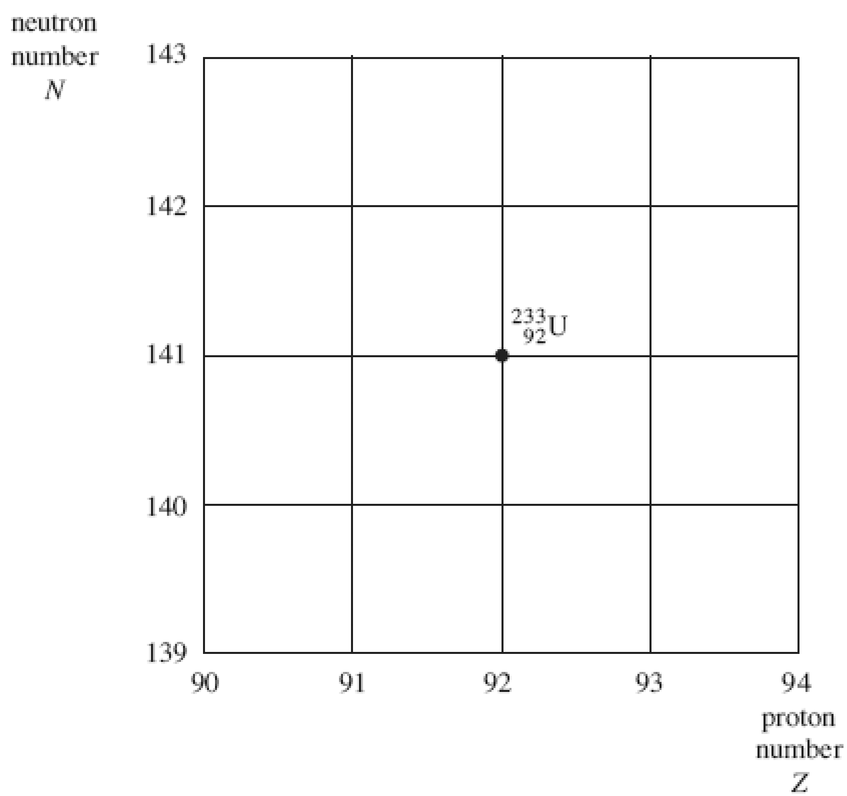
(b) Two other nuclei, **P** and **Q**, can also decay into $^{233}_{92}U$.

P decays by β^{+} decay to produce $^{233}_{92}U$.

Q decays by α emission to produce $^{233}_{92}U$.

The figure below shows a grid of neutron number against proton number with the position of the $^{233}_{92}U$ isotope shown.

On the grid label the positions of the nuclei **P** and **Q**.



(2)

(c) A typical fission reaction in the reactor is represented by

$$^{233}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{91}_{36}\text{Kr} + ^{139}_{56}\text{Ba} + x \text{ neutrons}$$

(i) Calculate the number of neutrons, x.

answer = ______________________neutrons

(1)

(ii) Calculate the energy released, in MeV, in the fission reaction above.

mass of neutron = 1.00867 u

mass of $^{233}_{92}\text{U}$ nucleus = 232.98915 u

mass of $^{91}_{36}\text{Kr}$ nucleus = 90.90368 u

mass of $^{139}_{56}\text{Ba}$ nucleus = 138.87810 u

answer = ______________________MeV

(3)

(Total 8 marks)

5 The first artificially produced isotope, phosphorus $^{30}_{15}P$, was formed by bombarding an aluminium isotope, $^{27}_{13}Al$, with an *α* particle.

(a) Complete the following nuclear equation by identifying the missing particle.

$$^{27}_{13}\text{Al} + \alpha \rightarrow {}^{30}_{15}\text{P} + \ldots\ldots\ldots$$

(1)

(b) For the reaction to take place the α particle must come within a distance, *d*, from the centre of the aluminium nucleus. Calculate *d* if the nuclear reaction occurs when the α particle is given an initial kinetic energy of at least 2.18×10^{-12} J.

The electrostatic potential energy between two point charges Q_1 and Q_2 is equal to $\frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$ where *r* is the separation of the charges and ε_0 is the permittivity of free space.

answer = ______________________ m

(3)
(Total 4 marks)

6 The age of an ancient boat may be determined by comparing the radioactive decay of $^{14}_{6}C$ from living wood with that of wood taken from the ancient boat.
A sample of 3.00×10^{23} atoms of carbon is removed for investigation from a block of living wood. In living wood one in 10^{12} of the carbon atoms is of the radioactive isotope $^{14}_{6}C$, which has a *decay constant* of 3.84×10^{-12} s^{-1}.

(a) What is meant by the decay constant?

____

____

____

(1)

(b) Calculate the half-life of $^{14}_{6}C$ in years, giving your answer to an appropriate number of significant figures.

1 year = 3.15×10^7 s

answer = ______________________ years

(3)

(c) Show that the rate of decay of the $^{14}_{6}C$ atoms in the living wood sample is 1.15 Bq.

(2)

(d) A sample of 3.00×10^{23} atoms of carbon is removed from a piece of wood taken

from the ancient boat. The rate of decay due to the $^{14}_{6}C$ atoms in this sample is 0.65 Bq. Calculate the age of the ancient boat in years.

answer = ______________________ years

(3)

(e) Give **two** reasons why it is difficult to obtain a reliable age of the ancient boat from the carbon dating described.

____

____

____

____

____

____

(2)

(Total 11 marks)

7 (a) Describe the changes made inside a nuclear reactor to reduce its power output and explain the process involved.

____

____

____

____

(2)

(b) State the main source of the highly radioactive waste from a nuclear reactor.

____

____

(1)

(c) In a nuclear reactor, neutrons are released with high energies. The first few collisions of a neutron with the moderator transfer sufficient energy to excite nuclei of the moderator.

(i) Describe and explain the nature of the radiation that may be emitted from an excited nucleus of the moderator.

____

____

____

____

(2)

(ii) The subsequent collisions of a neutron with the moderator are elastic.

Describe what happens to the neutrons as a result of these subsequent collisions with the moderator.

____

____

____

____

(2)

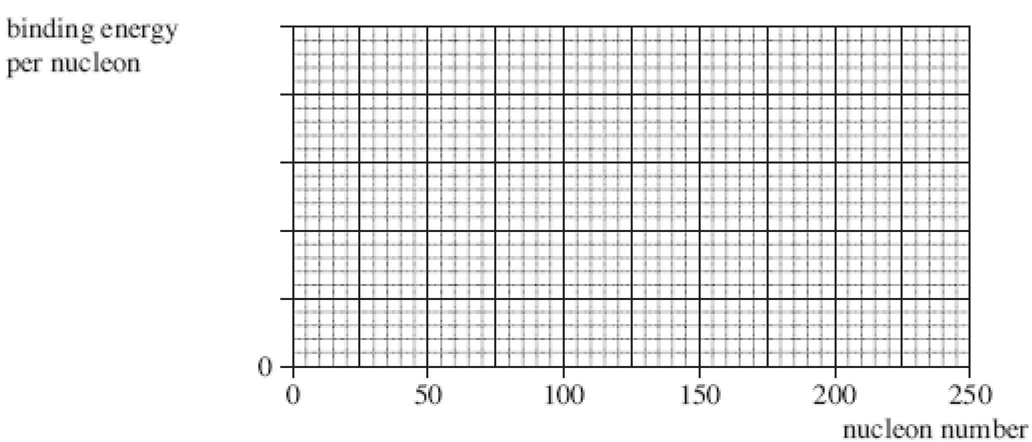
(Total 7 marks)

8 Complete the following equation showing the β^+ decay of carbon-11.

$$^{11}_{6}\mathrm{C} \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{B} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{+} + {}^{\cdots\cdots}_{\cdots\cdots}\ \cdots\cdots$$

(Total 3 marks)

9 (a) Sketch a graph of binding energy per nucleon against nucleon number for the naturally occurring nuclides on the axes given in the figure below. Add values and a unit to the binding energy per nucleon axis.



(4)

(b) Use the graph to explain how energy is released when some nuclides undergo fission and when other nuclides undergo fusion.

____

____

____

____

____

____

(3)

(Total 7 marks)

10 A nuclide of manganese $\left({}^{52}_{25}\mathrm{Mn}\right)$ undergoes beta^{+} decay to form a nuclide of chromium (Cr).

(a) Complete the equation for this decay process.

$$^{52}_{25}\mathrm{Mn} \rightarrow {}^{\cdots}_{24}\mathrm{Cr} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{+} + {}^{\cdots\cdots}_{\cdots\cdots}$$

(2)

(b) State the name of the exchange particle involved in this beta^{+} decay.

____

(1)

(Total 3 marks)

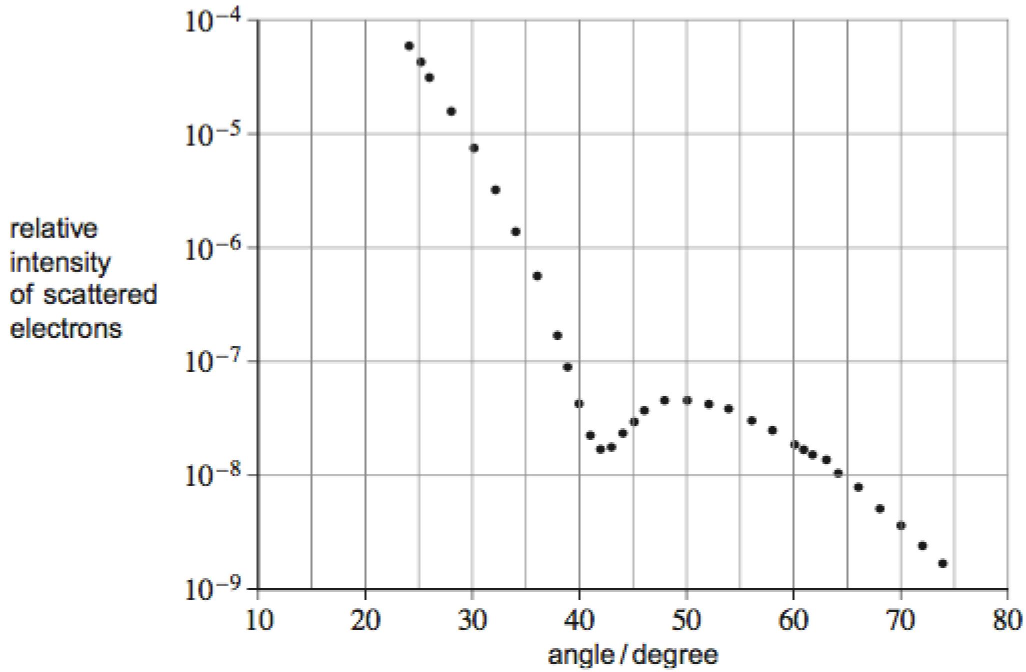
11 (a) The radius of a nucleus may be determined by electron diffraction. In an electron diffraction experiment a beam of electrons is fired at oxygen-16 nuclei. Each electron has an energy of 5.94×10^{-11} J.

The approximation, momentum = $\frac{\text{energy}}{\text{speed of light}}$ can be used for electrons at this energy.

(i) Show that the de Broglie wavelength λ of each electron in the beam is about 3.3×10^{-15} m.

(2)

(ii) The graph shows how the relative intensity of the scattered electrons varies with angle due to diffraction by the oxygen-16 nuclei. The angle is measured from the original direction of the beam.



The angle θ of the first minimum in the electron-diffraction pattern is given by

$$\sin\theta = \frac{0.61\lambda}{\text{nuclear radius}}$$

Calculate the radius of an oxygen-16 nucleus using information from the graph.

radius = ____________________ m

(1)

(b) Rutherford used the scattering of α particles to provide evidence for the structure of the atom.

(i) Sketch a labelled diagram showing the experimental arrangement of the apparatus used by Rutherford.

(2)

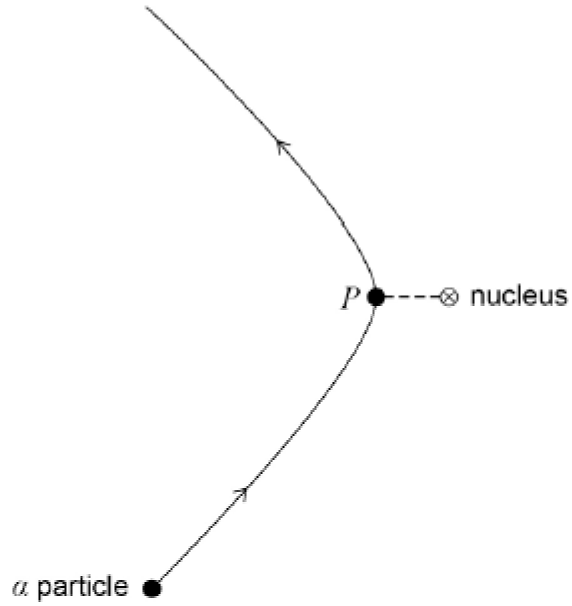
(ii) State and explain the results of the scattering experiment.
Your answer should include the following:

- the main observations
- the significance of each observation
- how the observtions placed an upper limit on the nuclear radius.

The quality of your written communication will be assessed in your answer.

(6)
(Total 11 marks)

12 The diagram shows the path of an α particle deflected by the nucleus of an atom. Point P on the path is the point of closest approach of the α particle to the nucleus.



Which of the following statements about the α particle on this path is correct?

A Its acceleration is zero at P. ☐

B Its kinetic energy is greatest at P. ☐

C Its potential energy is least at P. ☐

D Its speed is least at P. ☐

(Total 1 mark)

13 Which of the following best describes the decay constant for a radioisotope?

A The reciprocal of the half-life of the radioisotope. ☐

B The rate of decay of the radioisotope. ☐

C The constant of proportionality which links half-life to the rate of decay of nuclei. ☐

D The constant of proportionality which links rate of decay to the number of undecayed nuclei. ☐

(Total 1 mark)

14 Which of the following is equal to $\frac{\text{radius of a nucleus of } ^{125}_{51}\text{Sb}}{\text{radius of a nucleus of } ^{64}_{30}\text{Zn}}$??

A 1.19 ☐

B 1.25 ☐

C 1.33 ☐

D 1.40 ☐

(Total 1 mark)

15 After 64 days the activity of a radioactive nuclide has fallen to one sixteenth of its original value.
The half-life of the radioactive nuclide is

A 2 days. ☐

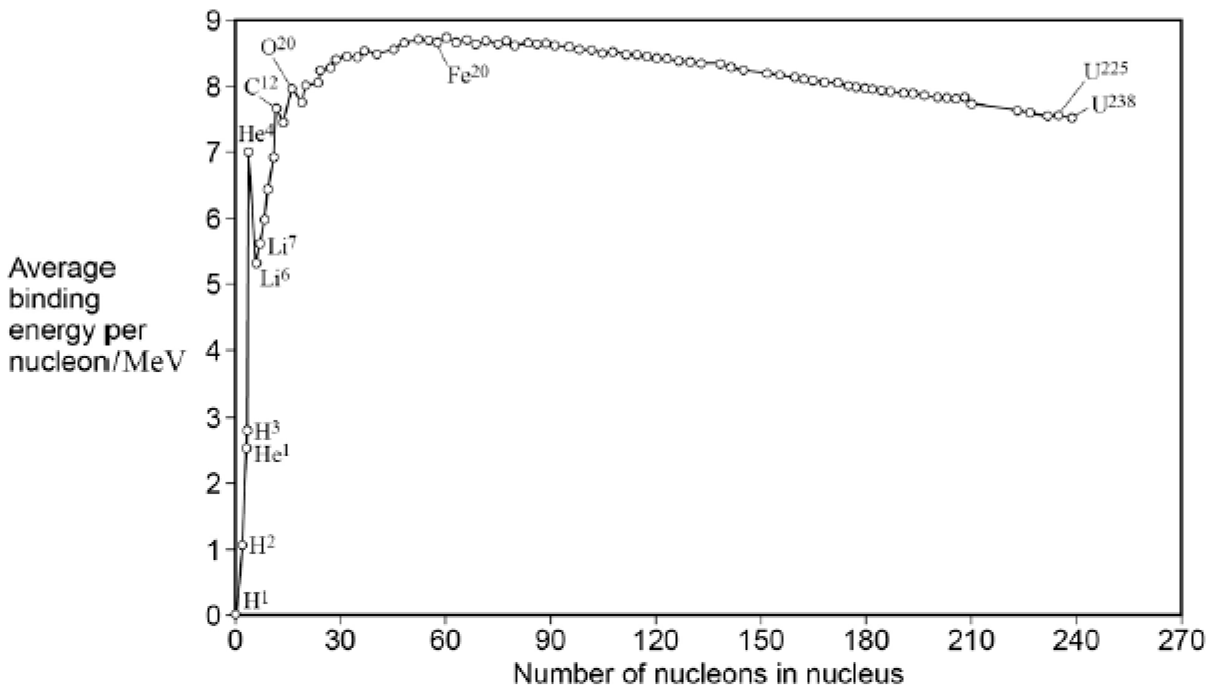
B 4 days. ☐

C 8 days. ☐

D 16 days. ☐

(Total 1 mark)

16 The graph shows how the binding energy per nucleon varies with the nucleon number for stable nuclei.



What is the approximate total binding energy for a nucleus of $^{184}_{74}W$?

A 1.28 pJ

B 94.7 pJ

C 103 pJ

D 230 pJ

(Total 1 mark)

Mark schemes

1 (a) $(3.0 \times 10^{-10}/24) \times 6.02 \times 10^{23}$ seen✓

(7.52×10^{10})

1

(b) Decay constant = $(0.69 / 14.8\ h^{-1})$ or $1.3 \times 10^{-5}\ s^{-1}$✓

$A = 1.30 \times 10^{-5} \times 7.5 \times 10^{10}$ ✓

9.75×10^{5} Bq ✓

Allow 2 or 3 sf

Allow use of $A = \lambda N$ with an incorrectly calculated decay constant

3

(c) Activity 3.5 h later should be $A = 9.8 \times 10^{5}\ e^{-0.0466 \times 3.5}$ ✓

8.33×10^{5} Bq✓

Volume of liquid = $(8.33 \times 10^{5} / 3600) \times 15 = 3470\ cm^{3}$✓

3

(d) Estimate gives 3700 compared with 3500✓

Flask has more mass than average / liquid is not water✓

2

[9]

2 (a) $({}^{206}_{76}X \rightarrow {}^{206}_{82}Pb + \beta \times {}^{0}_{-1}\beta + \beta \times \overline{v_e})$

$\beta = 6$ ✓

1

(b) (i) the energy **required** to split up the nucleus ✓

into its individual neutrons and protons/nucleons ✓

(or the energy **released** to form/hold the nucleus ✓

from its individual neutrons and protons/nucleons ✓)

2

(ii) $7.88 \times 206 = 1620$ MeV ✓ (allow 1600-1640 MeV)

1

(c) (i) U, a graph starting at 3×10^{22} showing exponential fall passing through

0.75×10^{22} near 9×10^9 years ✓

Pb, inverted graph of the above so that the graphs cross at 1.5×10^{22} near 4.5×10^9 years ✓

2

(ii) (*u* represents the number of uranium atoms then)

$$\frac{u}{3 \times 10^{22} - u} = 2$$

$u = 6 \times 10^{22} - 2u$ ✓

$u = 2 \times 10^{22}$ atoms

1

(iii) (use of $N = N_o e^{-\lambda t}$)

$2 \times 10^{22} = 3 \times 10^{22} \times e^{-\lambda t}$ ✓

$t = \ln 1.5 / \lambda$

(use of $\lambda = \ln 2 / t_{1/2}$)

$\lambda = \ln 2 / 4.5 \times 10^9 = 1.54 \times 10^{-10}$ ✓

$t = 2.6 \times 10^9$ years ✓(or 2.7×10^9 years)

3

[10]

3 (a) any 2 from:

the sun, cosmic rays, radon (in atmosphere), nuclear fallout (from previous weapon testing), any radioactive leak (may be given by name of incident) nuclear waste, carbon-14 ✓

1

(b) (i) (ratio of area of detector to surface area of sphere)

$$\text{ratio} = \frac{0.0015}{4\pi(0.18)^2}$$ ✓

0.0037 ✓ (0.00368)

2

(ii) activity = 0.62/(0.00368 × 1/400) give first mark if either factor is used.

67000 ✓ Bq accept s^{-1} or decay/photons/disintegrations s^{-1} but not counts s^{-1} ✓ (67400 Bq)

3

(c) (use of the inverse square law)

$$\frac{I_1}{I_2} = \left(\frac{r_2}{r_1}\right)^2$$ or calculating k = 0.020 from $I = k/x^2$ ✓

$$I_2 = 0.62 \times \left(\frac{0.18}{0.28}\right)^2$$ ✓ 0.26 counts s^{-1} ✓(allow 0.24-0.26)

3

[9]

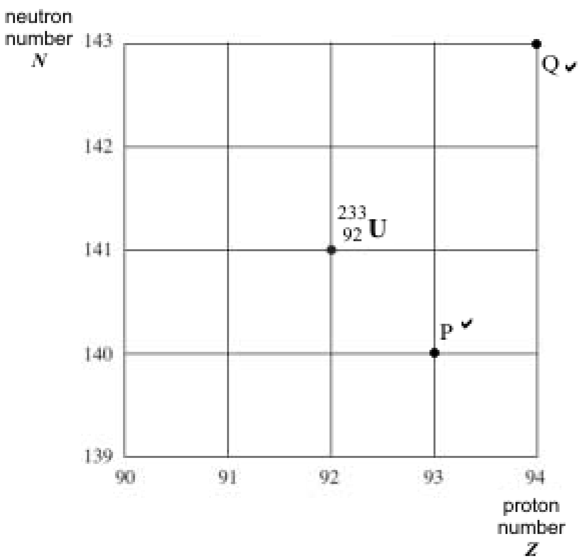
4

(a) $^{231}_{91}Pa$ ✓

anti (electron) neutrino ✓

2

(b)



2

(c) (i) $x = 4$ ✓

1

(ii) mass defect = [(232.98915 + 1.00867) –
(90.90368 + 138.87810 + 4 × 1.00867)] u ✓

= 0.18136 u ✓

3

energy released (= 0.18136 × 931) = 169 (MeV) ✓

[8]

5 (a) $^{27}_{13}Al + \alpha \rightarrow ^{30}_{15}P + ^{(1)}_{(0)}n$ ✓

1

(b) kinetic energy lost by the α particle approaching the nucleus is equal to the potential energy gain ✓

$$2.18 \times 10^{-12} = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{13 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19}}{r}$$ ✓

$r = 2.75 \times 10^{-15}$ (m) ✓

3

[4]

6 (a) probability of decay per unit time/given time period

or fraction of atoms decaying per second

or the rate of radioactive decay is proportional to the number of (unstable) nuclei

and nuclear decay constant is the constant of proportionality **(1)**

1

(b) use of $T_{\frac{1}{2}} = \frac{ln2}{\lambda}$

$T_{\frac{1}{2}} = \ln2/3.84 \times 10^{-12}$ s **(1)** (1.805×10^{11} s)

$= (1.805 \times 10^{11}/3.15 \times 10^{7}) = 5730$ y **(1)**

answer given to 3 sf **(1)**

3

(c) number of nuclei = $N = 3.00 \times 10^{23} \times 1/10^{12}$ **(1)**

(= 3.00×10^{11} nuclei)

(using $\frac{\Delta N}{\Delta t} = -\lambda N$)

rate of decay = $3.84 \times 10^{-12} \times 3.00 \times 10^{11}$ **(1)**

(= 1.15 Bq)

2

(d) ($N = N_0e^{-\lambda t}$ and activity is proportional to the number of nuclei A µ N use of $A = A_0e^{-\lambda t}$)

$0.65 = 1.15 \times e^{-3.84\times10^{-12}t}$ **(1)**

$$t = \frac{\ln\left(\frac{1.15}{0.65}\right)}{3.84\times10^{-12}} \text{ or } \frac{\ln\left(\frac{0.651}{1.15}\right)}{-3.84\times10^{-12}}$$

$t = 4720\ y$ **(1)**

3

(e) the boat may have been made with the wood some time after the tree was cut down

the background activity is high compared to the observed count rates

the count rates are low or sample size/mass is small or there is statistical variation in the recorded results

possible contamination

uncertainty in the ratio of carbon-14 in carbon thousands of years ago

*any two **(1)(1)***

2

[11]

7 (a) insert control rods (further) into the nuclear core / reactor ✓

a change must be implied for 2 marks
marks by use of (further) or (more)

allow answers that discuss shut down as well as power reduction

which will absorb (more) neutrons (reducing further fission reactions) ✓

If a statement is made that is wrong but not asked for limit the score to 1 mark (e.g. wrong reference to moderator)

2

(b) fission fragments / daughter products or <u>spent / used</u> fuel / uranium rods (allow) plutonium (produced from U-238) ✓

not uranium on its own

1

(c) (i) γ (electromagnetic radiation is emitted) ✓

A reference to α or β loses this first mark

as the energy gaps are large (in a nucleus) as the nucleus de-excites down discrete energy levels to allow the nucleus to get to the ground level / state ✓
mark for reason

2nd mark must imply energy levels or states

2

(ii) momentum / kinetic energy is transferred (to the moderator atoms)
or
a neutron slows down / loses kinetic energy (with each collision) ✓

(eventually) reaching speeds associated with thermal random motion or reaches speeds which can cause fission (owtte) ✓

2

[7]

8 boron numbers correct: A = 11; Z = 5

B1

β^+ correct: A = 0; Z = (+)1

B1

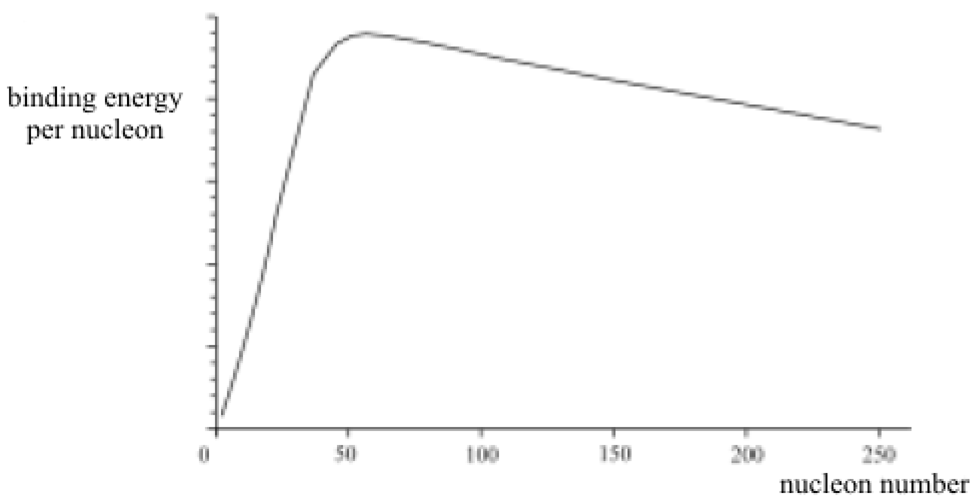
v_e (not anti neutrino) with numbers correct: 0,0

B1

3

[3]

9 (a)



peak 8.7 (accept 8.0 – 9.2)

in MeV ✓

(or peak 1.4×10^{-12} accept $1.3 - 1.5 \times 10^{-12}$ in J ✓)

at nucleon number 50 – 60 ✓ accept 50 – 75

sharp rise from origin and moderate fall not below 2/3 of peak height ✓

4

(b) energy is released/made available when binding energy **per nucleon** is increased ✓

in fission a (large) nucleus splits and in fusion (small) nuclei join ✓

the most stable nuclei are at a peak

fusion occurs to the left of peak and fission to the right ✓

max 3

[7]

10 (a) correct numbers for beta+ (0, (+)1) and chromium (52)

B1

(electron) neutrino with correct numbers (0,0)

B1

2

(b) W^+/W/(intermediate vector) boson (not Z boson)

B1

1

[3]

11 (a) (i) momentum (= E/c)

$= 5.94 \times 10^{-11} / 3.00 \times 10^{8} = 2.0 \times 10^{-19}$ (kg m s^{-1})

(= 1.98×10^{-19} kg m s^{-1})

Or evidence of use of $E = hc / \lambda$ ✓

$\lambda = (h / mv = 6.63 \times 10^{-34} / 1.98 \times 10^{-19}) = 3.35 \times 10^{-15}$ (m) ✓

(allowable range 3.32×10^{-15} - 3.37×10^{-15} m)

3.348×10^{-15} m alone may score 1 mark

A completed calculation to at least 3 sf must be seen for 2nd mark

2

(ii) nuclear radius = $0.61 \lambda / \sin \theta = 0.61 \times 3.35 \times 10^{-15} / \sin 42°$

$= 3.1 \times 10^{-15}$ (m) ✓ (allow $2.95 – 3.1 \times 10^{-15}$ m which is a range incorporating 3.32×10^{-15} - 3.37×10^{-15} m and 42° – 43°)

(The answer must be to 2 sf or better

note 3.3×10^{-15} , 42° gives 3.008×10^{-15} m i.e. 3.0×10^{-15})

1

(b) (i) diagram to show a labelled α source, foil target and detector (which is not simply a forward facing screen so there must be some indication it can move around the target e.g. a curved arrow / positioned at an angle / or screen curved round target or detectors shown in at least two positions) ✓

with evacuated vessel or an item to collimate the beam ✓ (the evacuated vessel does not have to be drawn so a simple label of 'in a vacuum' will gain the mark.) (A tube or a plate(s) must be drawn with a collimator label or a label on an emergent alpha beam from the drawn item (which is distinct from the source) will gain a mark)

'detector' has alternatives e.g. fluorescent screen / scintillator / zinc sulphide

2

(ii) The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).

Descriptor

High Level – Good to Excellent

Both observations should be given ie most α particles pass straight through the foil and that some α's are backscattered. Again both of these must be explained. Additionally one approach to finding the upper limit to the radius must be given and interpreted.

The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.

6 marks = all 3 bullet points covered in full.

5 marks = Same as 6 marks but one explanation is omitted or poorly expressed

5 - 6

Intermediate Level – Modest to Adequate

Both observations should be given ie most α particles pass straight through the foil and that some α's are backscattered. Both of these observations can be explained or one of them explained along with the observation necessary to obtain the upper limit to the nuclear radius but without the explanation of how to use the data.

The grammar and spelling may have a few shortcomings but the ideas must be clear.

4 marks = for first two bullet points covered in full.

Alternatively both observations given but only one explained along with an observation necessary to find the upper limit to the nuclear radius.

3 marks = for both observations given but only one explained

3 - 4

Low Level – Poor to Limited

Any two observations or interpretations but an interpretation must come with the appropriate observation.

There may be many grammatical and spelling errors and the information may be poorly organised.

2 marks for two observations or one observation along with its interpretation.

1 mark = Any observation..

1 - 2

The description expected in a competent answer should include:

1. most α particles pass straight through
2. which suggests an atom is composed of mainly open space
3. α particles can be backscattered or scattered by more than 90°
4. which suggests

i. they have collided with something more massive than themselves (using momentum considerations)

ii. they have been repelled by a concentrated positive charge (using coulomb repulsion)

these together suggest a 'solar system' configuration for the atom.

5. Consider the proportion of α's passing straight through the foil, i.e. how much of the straight through beam is stopped by the foil.

Or

Appreciate that scattering of α's close to 180° takes place which means the α's have not touched the nuclear surface.

6. First alternative data can be related to how much of the beam is intercepted by nuclei. Using the number of atomic layers / thickness of foil and the nuclear cross-sectional area the upper limit to the radius may be found

Or If second alternative is used some detail is needed to gain this point.

Either a discussion of the loss KE = gain PE to find upper limit to the radius

Or the idea that backscattering is not observed / falls off if the alpha comes close to the nucleus because the strong nuclear force (SNF) takes over and so provides an upper limit to the radius.

(owtte)

Do not award 'large space between atoms'.

The question is a QWC and not all the points are expected to be given as detailed on the left. This check list gives a brief idea of the main parts expected.

(note the pairing of 1 and 2, 3 and 4, 5 and 6 where the second of each pair cannot be given in isolation but the first of each pair does not have to perfect)

If it is obvious the candidate is talking about an alpha particle but calls it something different do not over penalise. E.g. miss out a pairing of marks then mark as if alpha)

Quick check list.

1. Most alpha's go straight on

2. Because an atom has mainly empty space

3. A few alpha's are backscattered

4. Because of nuclear positive charge or large nuclear mass

5. Method suggested to find R (drop in straight on beam Or backscattering means α's have not touched nucleus)

6. Some detail such as ref. to (nuclear) area <u>and</u> (foil) thickness Or alpha KE to PE giving r Or if α's touch surface SNF stops scattering.

[11]

12 D

[1]

13 D

[1]

14 B

[1]

15 D

[1]

16 D

[1]

Examiner reports

2 Even though part (a) needed a little thought almost all students obtained the correct answer. By contrast part (b)(i) was simply a factual recall question, which was answered poorly by a significant minority. The main error was for students not to state the energy needs to be given out or is required, when a nucleus was formed or broken up. It was common to see written, ‘The energy to keep the nucleus together’. In part (b)(ii) a majority of students simply read the value from the graph and gave an answer near 7.88 MeV without appreciating the ‘per nucleon’ on the y-axis of the graph. Part (c)(i) was done well by most students. Some students missed marks due to a lack of care in choosing specific coordinates for the graphs to pass through. Most students made a good attempt at part (c)(ii). Part (c)(iii) was more difficult and only the better student could correctly combine the two equations required to answer the question. A common mistake made by a few students who looked as if they were going to get the correct answer was for them to confuse the time units they were using. These students obtained the correct answer but then multiplied it by 60×60×24×365.

3 A majority of students could not give two clear specific sources of background radiation. The answers given in response to question part (a) were all too often of a general nature and too vague to be worthy of a mark. For example, ‘power stations’ or ‘the air’. The answers needed to be clearer statements like, ‘radioactive material leaked from a power station, or radon gas in the atmosphere. As only one mark was being awarded only one detailed source gained the mark provided the second point was in some way appropriate even if poorly stated. Part (b)(i) was a very good discriminator. More able students realised that a comparison of areas was required to answer the question. Part (b)(ii) was also a good discriminator. Only the top 20% of students used the detection efficiency factor as well as the fraction of gamma rays hitting the detector to obtain the correct answer. Most used only the 1/400 detection efficiency. Students were more successful in choosing the correct unit. Part (c) was interesting in that students either attempted the question successfully or they left this section blank.

4 The more able candidates successfully negotiated the majority of this question but the less able found many pit-falls.

In part (a) most obtained the first mark but then did not obtain the anti-neutrino.

For part (b) some candidates did not identify the position of P. Position Q was easier for students to identify.

A majority of candidates could balance the number of neutrons in part (c)(i) to obtain the correct answer $x = 4$. Those that guessed the answer almost always gave the answer $x = 3$.

Part (c)(ii) was very discriminating. Less able candidates did not know how to balance the energies and only scored marks on the conversion from u to MeV. Some did not go directly from u to MeV and gave many lines of calculation. If correctly performed, they still got the mark for the conversion, but they had many opportunities to show errors and so tended to be less successful and missed the mark.

5 Part (a) was very straightforward for most candidates but less than half could tackle part (b) effectively.

Problems were seen at every stage. Some had no idea what was happening at all; some used the wrong charge on the aluminium nucleus and used 27 × 1.6 × 10.19 C; and some even changed the equation given in the question to the Coulomb law of force equation by introducing a squared term for the separation.

6 Less than half the candidates could explain the meaning of the decay constant. By contrast almost all candidates could find the half-life in part (b) and a majority could answer part (c). Some candidates did not gain credit because they conveniently removed 10^{12} in their calculation without showing the division. So lines like, 1.15×10^{12} Bq = 1.15 Bq, were seen. Most candidates who tackled part (d) using the exponential decay of the activity equation got full marks. Only a few candidates could not rearrange the equation. By contrast almost all candidates who tried to use the exponential decay in the number of nuclei got confused. Most had numbers of nuclei on one side of the equation but activity on the other.

Part (e) did discriminate but only between scoring zero marks or one mark. Very few candidates attempted two reasons. Most acceptable answers to this question were difficult for the candidate to express. For example, in question (d) it states that the decay rate due to carbon-14 is 0.65 Bq, indicating it is a corrected count rate. So an answer to part (e) like, 'the background can effect the result', is not acceptable. This is not the same as saying it is difficult to obtain the results for the sample activity because the background activity is high in comparison. This example is also ambiguous in that it suggests the surroundings can influence the rate of decay. Another answer that was not acceptable was, 'radioactive decay is random so it's bound to give false values'. To gain a mark following this line of thought it was necessary to refer to its effect on the statistics. The most common answers that candidates found easy to express included the following; the tree died well before the boat was made; or the boat was repaired later in its life with fresh wood; or that carbon based microbes died in the wood when the boat was rotting at the end of its useful life.

7 Most candidates were fully aware of the function of the control rods in absorbing excess neutrons and scored well in part (a). Some candidates said too much by explaining the role of the control rods to absorb neutrons and the moderator to slow neutrons down but then did not make it clear which reduced the power. The weaker candidates talked about control rods controlling the reactions without any further explanation.

Part (b) was answered well by most but it was common to give the answer fuel rods rather than spent fuel rods.

In (c)(i) the most common answer was 'gamma rays' but very few then went on to discuss energy levels. Some of those that did then spoilt their answer by referring to changing electron levels.

Part (c)(ii) was a very good question to distinguish between the weak and strong candidates. The weaker candidates focussed on the wording in question concerning elastic collisions. They interpreted this to mean the neutrons maintain their kinetic energy or momentum during all subsequent collisions.

8 The majority of students got most of the data correct. A few had no idea of the nature of the reaction involved. Misidentification of the electron neutrino was quite common from those who made minor errors.

9 Part (a) gave a much greater spread of marks than expected. About one third of candidates did not attempt to place a unit on the y-scale and less able candidates also could not recall the correct shape of the graph. At the top end, candidates allowed the graph to fall too steeply as the nucleon number increased and/or they had the peak in the wrong position. Only the more able candidates knew the height of the peak.

In part (b) only the more able candidates could use the idea of .binding energy. in a coherent manner. Less able candidates did not really make any significant points that were worthy of marks. On a marking point, although the question starts with ‘use the graph..’ it was possible to score full marks without reference to the graph, as we allowed a reference to high and low nucleon numbers as being equivalent to being either side of the peak.

10 Surprisingly, few candidates achieved full marks in part (a). The most common error was to include the (electron) antineutrino instead of the (electron) neutrino.

Part (b) was poorly answered; many candidates had no idea of the exchange particle involved in β^+ decay. Common errors included gluon, neutron, pion and weak force.

11 (a) (i) Most students could manipulate the equations to obtain the de Broglie wavelength, usually by calculating the momentum first in a two stage process. The most common error was to fail to show a completed evaluation to 3 significant figures. In many cases the equations and substitutions would be shown but followed by a jump to the answer given in the question. It is important for students to give answers to a ‘show that’ question to at least one more significant figure than the quoted answer as evidence of the correct calculation being carried out.

(ii) The use and rearrangement of the equation was done well by almost all students. It was choosing the correct angle from figure 1 which caused difficulties for some. Many chose to use 24 degrees, which is where the graph data began. Others were unable to correctly establish the 1st interference minimum to a reasonable precision.

(b) (i) Many of the diagrams were very rough and sketchy but were clear enough to show the main features. Most showed the basic purpose of the apparatus and included a source of a beam of alpha particles colliding with a gold film. Some students failed to score marks because of their lack of labels and many did not have a detector that surrounded or could move round the target area. A significant majority of all students did not indicate that the experiment should take place in a vacuum or the alpha particles need to be collimated.

(ii) In the extended response question many students showed the ability to give a good account of the main observations made by Rutherford and his team during the scattering experiment. Many students went on to explain the significance of each observation and how it refined the model of the atom, therefore securing an intermediate level mark. Fewer students were able to produce a high level response and explain, in sufficient detail, a method by which the scattering experiment results can be used to place an upper limit upon the nuclear radius. Those that had difficulty with the question fell into different groups. Some seemed to make a simple slip by discussing the scattering of electrons but gave descriptions that fit with alpha particles. Others went on to discuss electron diffraction and threw a little of everything into the mix. Another group of students had difficulty in knowing what the observations were. Many of these discussed the experiment by considering how close to the nucleus an alpha particle passed by and what path it would follow which they took as the observation, so they did not approach the task by considering the results of an experiment first. Another group failed to relate interpretations to observations and these students simply made a list of observations and a separate list of unrelated facts about atoms. Many of the moderate ability students were side tracked into discussing what Rutherford expected to see that was consistent with the 'plum pudding model'. There was nothing wrong with this as an introduction to an answer but in many cases it took up more than half the answer space even though it was not asked for in the question. The main issue in the interpretations was how the idea that atoms consisted of mainly open space was stated. 'There is lots of space between atom', the nucleus is mainly open space' and 'an atom is mainly made from air' and similar statements were seen. A minority of students showed how the results lead to an upper limit to the nuclear radius. The most successful were those that considered the least distance of approach with a head on collision. In the analysis however, it was common for the expression for the force between the nucleus and the alpha particle to be mistaken for the expression for potential energy. Most students that attempted to place an upper limit to the radius by considering how alpha particles are obstructed by the area of the nuclei failed to consider the thickness of the foil. It was a common misconception that a gold foil is one atom thick.