1 (a) Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\mathrm{Co}$.

nuclear mass of $^{59}_{27}\mathrm{Co}$ = 58.93320 u

mass in u is

proton rest mass(equivalent to 1.00728u)
neutron rest mass(equivalent to 1.00867u)
1u is equivalent to 931.5MeV

$27 \times 1.00728 + 32 \times 1.00867$

$= 59.474\,u$

$B.E = 59.474u - 58.93320\,u = 0.5408\,u$

See YouTube walkthrough

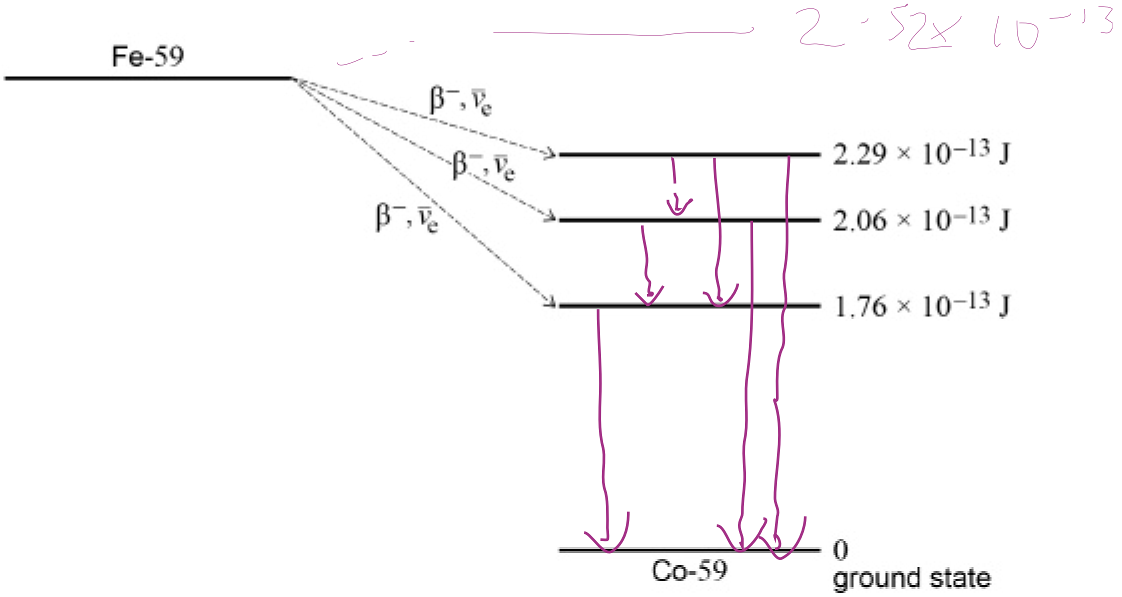
binding energy = 503.8 MeV

(3)

(b) A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown below. The energies of the excited states are shown relative to the ground state.



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

$2.52 \times 10^{-13} - 1.76 \times 10^{-13} = 0.76 \times 10^{-13}$

$\frac{0.76 \times 10^{-13}}{e^-} =$

maximum kinetic energy = 0.475 MeV

(2)

(c) Following the production of excited states of ${}^{59}_{27}\mathrm{Co}$, γ-radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

maximum number = 6

(1)

(d) Calculate the longest wavelength of the emitted γ-radiation.

$c = f\lambda$

$E = hf \Rightarrow E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$

So smallest drop

2.3×10^{-14}

Longest wavelength = 8.6×10^{-12} m

(3)

(Total 9 marks)

2 The isotope of uranium, $^{238}_{92}\mathrm{U}$, decays into a stable isotope of lead, $^{206}_{82}\mathrm{Pb}$, 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*.

$$^{238}_{92}U \rightarrow {}^{206}_{82}Pb + 8\,{}^{4}_{2}He + {}^{0}_{-6}X$$

$\therefore 6$

answer = ______________________

(1)

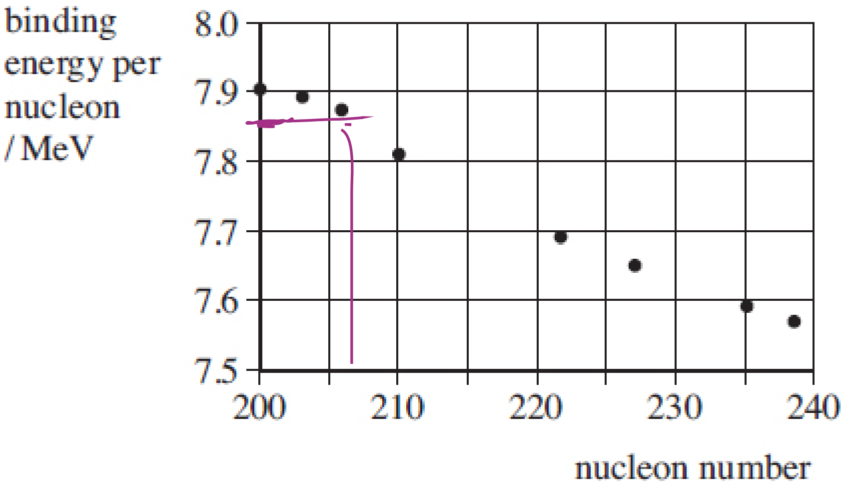
(b) (i) Explain what is meant by the binding energy of a nucleus.

energy required to break it apart into separate nucleons

(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 $^{206}_{82}\text{Pb}$ nucleus.

7.85 MeV × 206

answer = 1617 = 1620 (3sf) MeV

(1)

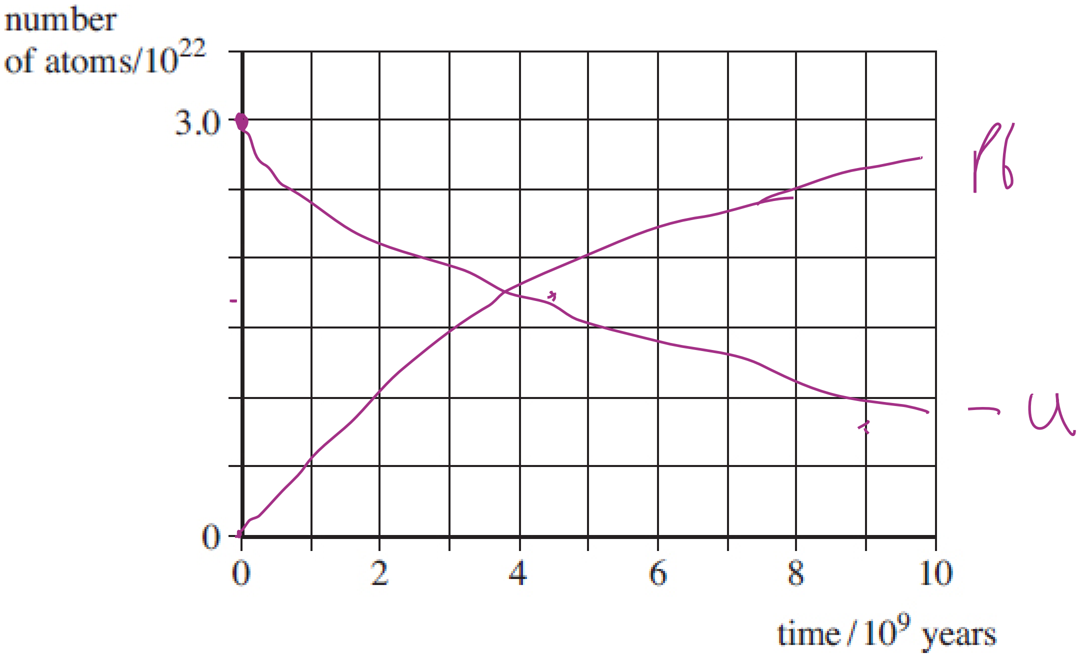
(c) The half-life of $^{238}_{92}\text{U}$ is 4.5 × 10^9 years, which is much larger than all the other half-lives of the decays in the series.

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

At any given time most of the atoms are either $^{238}_{92}\text{U}$ or $^{206}_{82}\text{Pb}$ 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 $^{238}_{92}\text{U}$ atoms and the number of $^{206}_{82}\text{Pb}$ 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 $^{238}_{92}\text{U}$ atoms as $^{206}_{82}\text{Pb}$ atoms.
Show that the number of $^{238}_{92}\text{U}$ atoms in the rock sample at time *t* was 2.0 × 10^{22}.

3×10^{22} split into $\frac{1}{3}$'s

(1)

(ii) Calculate *t* in years.

answer = ____________________ years

(3)

(Total 10 marks)

3 (a) (i) Sketch a graph to show how the neutron number, N, varies with the proton number, Z, for naturally occurring stable nuclei over the range Z = 0 to Z = 90. Show values of N and Z on the axes of your graph and draw the N = Z line.

(ii) On your graph mark points, one for each, to indicate the position of an unstable nuclide which would be likely to be

an α emitter, labelling it A,

a β^- emitter, labelling it B.

(5)

(b) State the changes in N and Z which are produced in the emission of

(i) an α particle,

____

____

(ii) a β^- particle.

____

____

(2)

(c) The results of electron scattering experiments using different target elements show that

$$R = r_0 A^{\frac{1}{3}}$$

where A is the nucleon number and r_0 is a constant.

Use this equation to show that the density of a nucleus is independent of its mass.

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(3)

(Total 10 marks)

4 (a) (i) Explain why, despite the electrostatic repulsion between protons, the nuclei of most atoms of low nucleon number are stable.

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(ii) Suggest why stable nuclei of higher nucleon number have greater numbers of neutrons than protons.

____

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____

(iii) All nuclei have approximately the same density. State and explain what this suggests about the nature of the strong nuclear force.

____

____

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____

____

(6)

(b) (i) Compare the electrostatic repulsion and the gravitational attraction between a pair of protons the centres of which are separated by 1.2×10^{-15} m.

proton charge = 1.6×10^{-19} C
proton mass = 1.7×10^{-27} kg
gravitational constant = 6.7×10^{-11} N m^{2} kg^{-2}
permittivity of free space = 8.9×10^{-12} F m^{-1}

(ii) Comment on the relative roles of gravitational attraction and electrostatic repulsion in nuclear structure.

____

____

(5)

(Total 11 marks)

Mark schemes

1

(a) (using mass defect = Δm = Z m_p + N m_n – M_{Co})

Δm = 27 × 1.00728 + 32 × 1.00867 – 58.93320 (u) ✓

Δm = 0.5408 (u) ✓

Binding Energy = 0.5408 × 931.5 = 503.8 (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.

Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0.

If subtraction is the wrong way round lose 1 mark.

Data may come from rest mass eg m_n =939.551 MeV or 1.675 × 10^{-27} kg or 1.00867 u.

So if kg route used Δm = 8.83 × 10^{-28} kg BE = 7.95 × 10^{-28} J and 497 Mev.

Conversion mark (2nd) may come from a wrong value worked through. 0.47(5)

3

(b) (2.52 – 1.76) × 10^{-13} = 7.6 × 10^{-14} J ✓

7.6 × 10^{-14} / 1.60 × 10^{-13} = 0.47 or 0.48 MeV ✓(0.475 MeV)

Correct answer scores both marks.

2

(c) 6 (specific wavelengths)

1

(d) (longest wavelength = lowest frequency = smallest energy)

(2.29 × 10^{-13} – 2.06 × 10^{-13}) = 2.3 × 10^{-14} (J) ✓

λ (= $h\,c\,/\,E$) = 6.63 × 10^{-34} × 3.00 × 10^{8} / 2.3 × 10^{-14} ✓

λ = 8.6 - 8.7 × 10^{-12} (m) ✓ (8.6478 × 10^{-12} m)

Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state.

The allowed energy gaps for CE are:

2.29, 2.06, 1.76, 0.53, 0.30 all × 10^{-13}

Note substitution rather than calculation gains mark.

The final mark must be as shown here and not from a CE above.

3

[9]

2

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

β = 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 × 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 $\lambda = \ln 2 / t_{1/2}$)

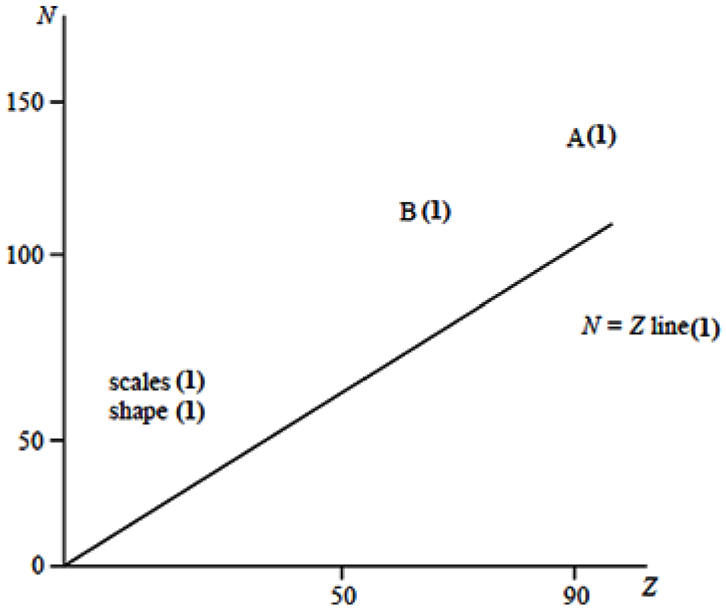
$\lambda = \ln 2 / 4.5 \times 10^{9} = 1.54 \times 10^{-10}$ ✓

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

3

[10]

3 (a)



(5)

(b) (i) α emitter: $N \downarrow 2$, $Z \downarrow 2$ **(1)**

(ii) β^- emitter: $N \downarrow 1$, $Z \uparrow 1$ **(1)**

(2)

(c) density = $\frac{\text{mass}}{\text{volume}}$ **(1)**

mass $\propto A$

volume $\propto R^3$ and $R \propto A^{\frac{1}{3}}$ hence volume $\propto A$ **(1)**

hence density = $\frac{\text{mass}}{\text{volume}}$ is independent of A **(1)**

(3)

[10]

4 (a) (i) strong nuclear force acts on all nucleons/both forces act on protons/mention of gluons as force carrier

B1

strong nuclear force > electrostatic repulsion

B1

(ii) neutrons spread the protons out/neutrons reduce electrostatic repulsion

B1

(iii) strong nuclear force has short range

M1

if snf fell off more gradually bigger nuclei would have lower densities/…more rapidly still higher densities

A1

strong nuclear force acts on all nucleons

M1

attractive nature of snf means all nucleons in contact/close packed

A1

strong nuclear force becomes repulsive at very small separations

M1

prevents nuclei from becoming denser

A1

needs minimum of two M1s to score all three here

max 6

(b) (i) $F_E \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ or $F_E \propto k \frac{Q_1 Q_2}{r^2}$ with *k* defined

C1

1.59×10^{2}N

A1

$F_G = G\frac{m_1 m_2}{r^2}$

C1

1.3×10^{-34}N

A1

(ii) can ignore gravitation when considering nuclear forces **or**
gravitational force is much weaker than electrostatic force **not** e.c.f.

B1

5

[11]