IB$_2$

Physics SL

Tot : / 32 marks

Thursday 22 september 2022

* ANSWERS *

Problem 1

[/10 marks]

(a) Describe the phenomenon of natural radioactive decay. *[3]*

Radioactive decay is a random and spontaneous process which involve unstable nucei emitting radioactive particles.

Notice : By this process, energy is released and the total biending energy *increases* !

External links

Essential concepts(carleton.edu)

Radioactive Decay Wikipedia

(b) A nucleus of americium-241 (Am-241) decays into a nucleus of neptunium-237 (Np-237) in the following reaction.

$$^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{X}\mathrm{Np} + {}^{4}_{2}\alpha$$

(i) State the value of X. *[1]*

$x = 93$

(ii) Explain in terms of mass why energy is released in the reaction in (b). *[2]*

As the decay releases energy, there is a mass defect Δm (that is a consequence of Einstein formula : $E = \Delta m\ c^2$)

Notice :Experiments into nuclear structure have found that the total mass of a nucleus is **less** than the sum of the masses of its constituent nucleons

(this question continues next page)

(iii) Define *binding energy* of a nucleus. *[1]*

Binding energy can be defined as
1: The minimum energy needed to break a nucleus up into its constituent nucleons,
2: The energy released when a nucleus forms from constituent nucleons.

Notice : IB's markshemes give preference to the first definition.

(iv) The following data are available.

Nuclide	**Binding energy per nucleon / MeV**
americium-241	7.54
neptunium-237	7.58
helium-4	7.07

Determine the energy released in the reaction in (b). *[3]*

$E = (237 \times 7.58 + 4 \times 7.07) - 241 \times 7.54$

$= (1796.5 + 28.3) - 1817 = 7.6\,\text{Mev}$

Notice : Suppose the mass defect would be asked (as a next question)

E=Δmc^2 first method : $\Delta m = \frac{7.6 \times 10^6 \times 1.602 \cdot 10^{-19}}{(3 \cdot 10^8)^2}$ in Kg

second method : $\Delta m =$ 7.6 Mev / 931.5MeV c^{-2} in u

(see booklet page 1)

Problem 2 [/ 10 marks]

(ii) The mass of a nucleus of plutonium $\left({}^{239}_{94}\text{Pu}\right)$ is 238.990396u. Deduce that the binding energy per nucleon for plutonium is 7.6MeV. *[3]*

Mass of a nucleus of ^{239}PU $= 238.990396 \times 1.661 \times 10^{-27} = 3.9696305 \cdot 10^{-25}$kg

$\Delta m = 3.9696305 \cdot 10^{-25} - (94 \times 1.673 \times 10^{-27}\,\text{kg} + 145 \times 1.675 \times 10^{-27}\,\text{kg})$

$= (3.9696305 - 4.00137)10^{-25}\text{kg} \quad = -3.17410^{-27}\text{kg}$

then $\text{E}_{\text{bind}} = 3.17410^{-27} \times (3.10^8)^2 = 2.857 \cdot 10^{-10} J \Rightarrow \frac{\text{E}_{\text{bind}}}{\text{nucl}} = \frac{2.857 \cdot 10^{-10}}{239} = 1.196 \cdot 10^{-12} J/\text{nucl}$

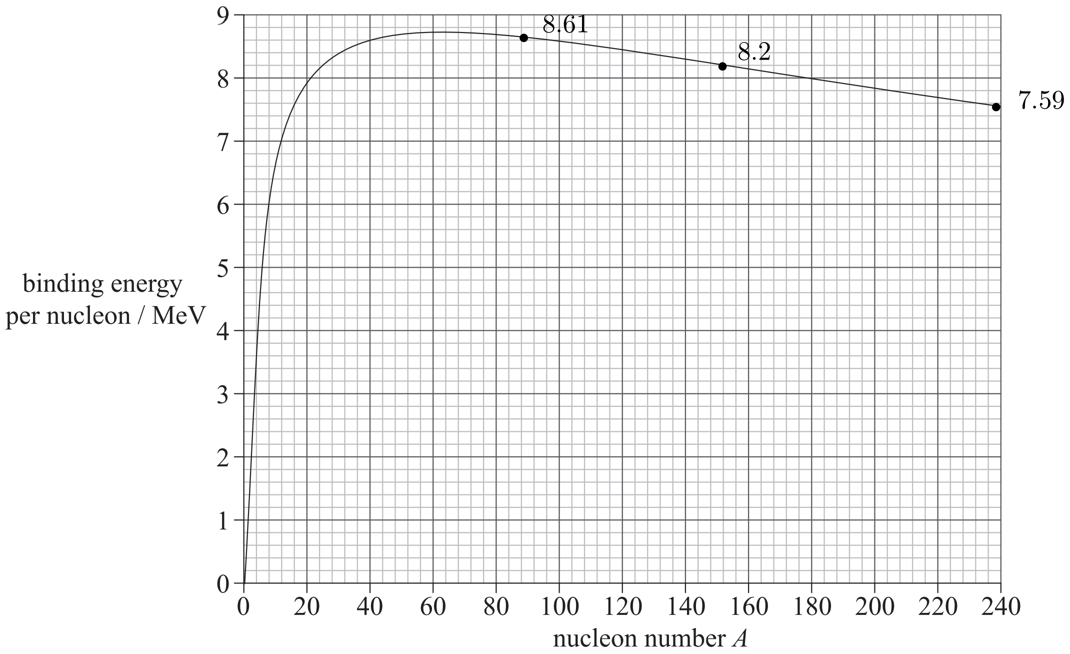
$= \frac{1.196 \cdot 10^{-12}}{1.6 \cdot 10^{-19}} J/\text{nucl} \cong 0.75 \cdot 10^7 J/\text{nucl} = \boxed{7.5\text{Mev/nucl}}$

Short way : $\Delta m = 238.990396 - (94 \times 1.007276 + 145 \times 1.008665) = -1.949973u$

$1.949973u = 1.949973 \times 931.5\text{MeV}\,c^{-2} = 1816.4\text{MeV}\,c^{-2} \Rightarrow \text{E}_{\text{bind}} = 1816.4\text{MeV} = \boxed{7.6\text{Mev/nucl}}$

(this question continues next page)

(b) The graph shows the variation with nucleon number A of the binding energy per nucleon.



Plutonium $\left({}^{239}_{94}\mathrm{Pu}\right)$ undergoes nuclear fission according to the reaction given below.

$$ {}^{239}_{94}\mathrm{Pu} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{91}_{38}\mathrm{Sr} + {}^{146}_{56}\mathrm{Ba} + x\,{}^{1}_{0}\mathrm{n} $$

(i) Calculate the number x of neutrons produced. *[1]*

$x = 3$

(ii) Use the graph to estimate the energy released in this reaction. *[2]*

$239 \times 7.59 - (91 \times 8.61 + 146 \times 8.2) = 1814 - 1980.7 \cong 894$ Mev

(this question continues next page)

(c) Stable nuclei with a mass number greater than about 20, contain more neutrons than protons. By reference to the properties of the nuclear force and of the electrostatic force, suggest an explanation for this observation. *[4]*

facts:

the electric force acts on protons, the strong nuclear force acts on nucleons;

the electric force is repulsive/tends to split the nucleus;

the nuclear force is attractive/binds the nucleons;

but:

the electric force is long range whereas the nuclear force is short range;

so :

so adding more neutrons (compared to protons) contributes to binding and does not add to tendency to split the nucleus.

Problem 3 [/ 8 marks]

Let us consider a sample 1.0 kg of strontium-94 (Sr-94).

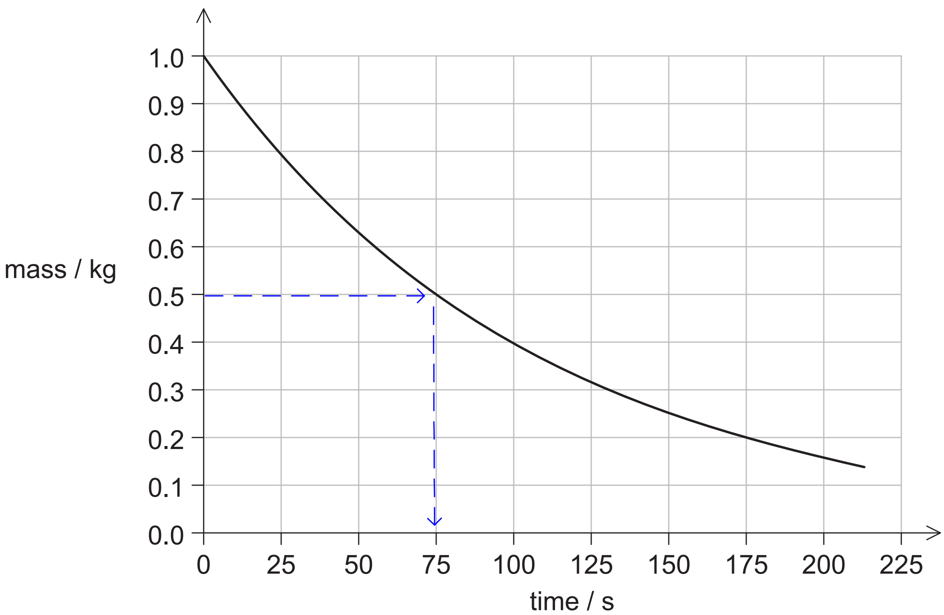
Sr-94 is radioactive and undergoes beta-minus decay into a daughter nuclide X.

The reaction for this decay is

$$^{94}_{38}\mathrm{Sr} \rightarrow \,^{\boxed{94}}_{\boxed{39}}\mathrm{X} + \boxed{^{0}_{-1}\beta} + \boxed{^{0}_{0}\bar{\nu}}$$

1) complete the reaction (providing the missing information) [4]

The graph shows the variation with time of the mass of Sr-94 remaining in the samp



2)

(ii) State the half-life of Sr-94.

$\boxed{T_{\frac{1}{2}} = 75s}$

(iii) Calculate the mass of Sr-94 remaining in the sample after 10 minutes.

$10\text{ min} = \frac{600}{75} = 8T_{\frac{1}{2}}$

then after 10min : $\boxed{(\frac{1}{2})^8 = 0.0093\,\text{Kg (or } 3.9\text{g) of Sr}}$

Four paper1 questions [/ 4 marks]

Q1

A detector, placed close to a radioactive source, detects an activity of 260 Bq. The average background activity at this location is 20 Bq. The radioactive nuclide has a half-life of 9 hours.

What activity is detected after 36 hours?

A. 15 Bq

(B.) 16 Bq

C. 20 Bq

D. 35 Bq

Q2

Which of the following statements best describes the **random** nature of radioactive decay?

A. The decaying nucleus emits either an α-particle, or a β-particle or a γ-ray photon.

B. The type of radiation emitted by the decaying nucleus cannot be predicted.

(C.) The time at which a particular nucleus will decay cannot be predicted.

D. The decay of a nucleus is unaffected by environmental conditions.

Q3

A freshly prepared sample contains 4.0 μg of iodine-131. After 24 days, 0.5 μg of iodine-131 remain. The best estimate of the half-life of iodine-131 is

(A.) 8 days.

B. 12 days.

C. 24 days.

D. 72 days.

Q4

The average binding energy per nucleon of the $^{15}_{8}O$ nucleus is 7.5 MeV. What is the total energy required to separate the nucleons of one nucleus of $^{15}_{8}O$?

A. 53 MeV

(B.) 60 MeV

C. 113 MeV

D. 173 MeV