NUCLEAR PHYSICS

Challenging **MCQ** questions by The Physics Cafe

Compiled and selected by The Physics Cafe

1 **(a)** Thoron is a radioactive gas. The variation with time *t* of the detected count rate *C* from a sample of the gas is shown in Fig. 6.1

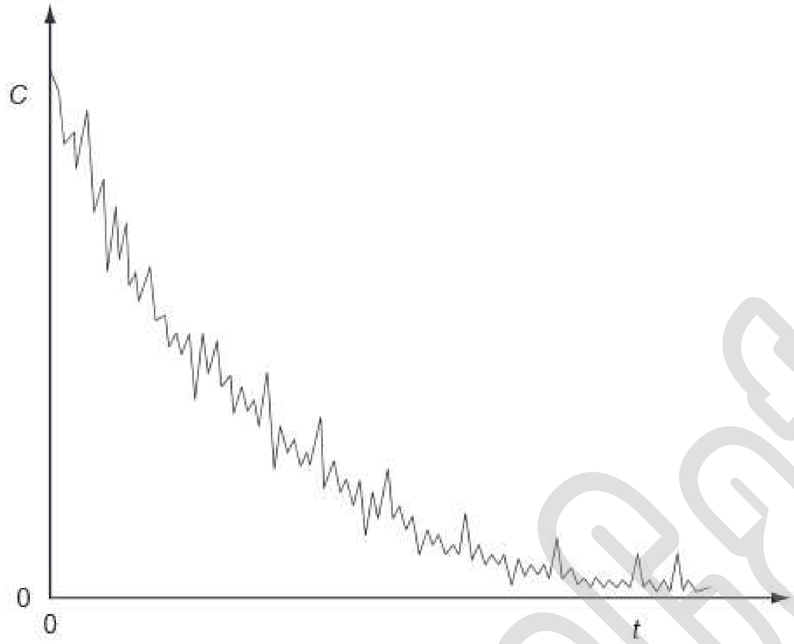

Fig 6.1

(i) Radioactive decay is said to be a *random* and *spontaneous* process.

State the feature of Fig 6.1 which indicates that the process is *random*.

....

....

.... [1]

....

(ii) A second similar sample of thoron is prepared but it is at a much higher temperature. The variation with time of the count rate for this second sample is determined.

State the expected feature of the decay curve for the second sample, with reference to Fig 6.1 that suggests that radioactive decay is a spontaneous process.

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....

.... [1]

....

(b) In order to identify the radioactive particles emitted by a given sample of radioactive isotope, a student set up the apparatus as illustrated in Fig 6.2 and vary the thickness of Al sheets used. The separation from the window of the detector from the shielding is about 6 cm.

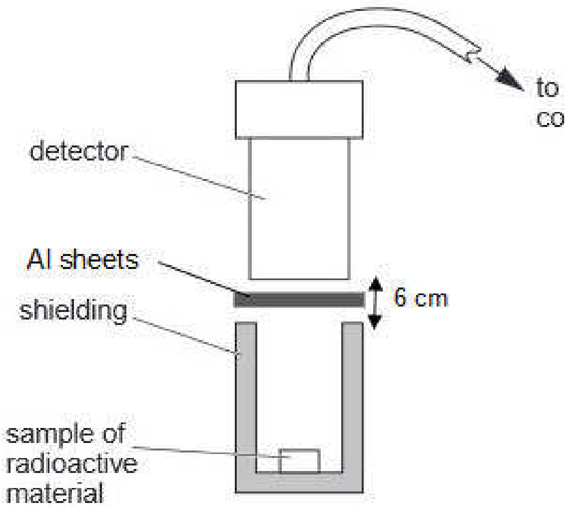

Fig 6.2

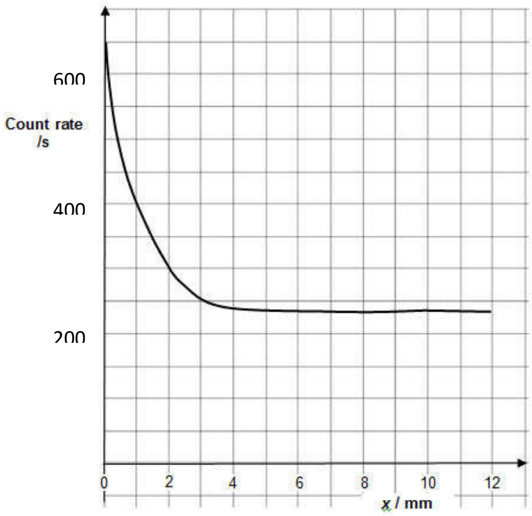

Fig 6.3

Fig 6.3 is the best fit line showing the variation of the count rate with the thickness *x* of Al sheets used.

The count rate plotted in Fig 6.3 is after accounting for background count.

(i) Explain why this experiment cannot provide evidence to show the presence of alpha particles.

....

.... [1]

....

(ii) Indicate the evidence from Fig 6.3 that indicates the presence of

1. *beta* particles

....

.... [1]

....

2. *gamma* particles

....

.... [1]

....

(c) A point source of alpha particles $^{241}_{95}Am$ with decay constant 4.80 x 10-11 s-1 is mounted 7.0 cm in front of a Geiger Muller(GM) tube whose mica window has a receiving area of 3.0 cm2, as shown in Fig 4. The whole setup is enclosed in a vacuum enclosure.

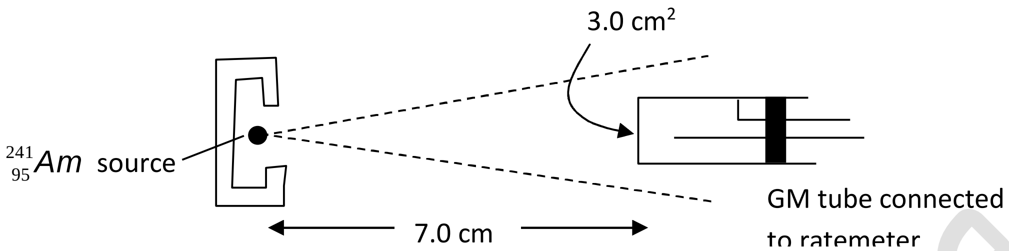

Fig 4

The counter linked to the GM tube records 5.4 x 10^4 counts per minute.

(i) Show that the activity of the source is 18.5 x 10^4 s^{-1}

[1]

(ii) Hence determine the number of $^{241}_{95}Am$ atoms in the source.

Number of atoms = …………… [1]

Ans

6(a)(i) Count rate flunctuates / curve not smooth

(ii) The new graph should give the same half-life.

(b)(i) Alpha particle is **stopped in air**, hence cannot be detected.

(ii)1. As thickness of Al sheets increases, the count rate **decreases rapidly** as beta particles are stopped by mm of Al.

(ii)2. The count rate became a **constant** for thickness beyond 3 mm. This indicates presence of gamma particles as they are not stopped by mm of Al.

(c)(i)

Total disintegrations $= 4\pi(7)^2[\frac{5.4x10^4/60}{3}]$

$= 184725.6\ s^{-1}$

$= 18.5 \times 10^4\ s^{-1}$

(ii) $A = \lambda N$

$184725.6 = 4.80 \times 10^{-11}\ N$

Hence $N = 3.85 \times 10^{15}$

2 **(a)** The equation for a typical fusion reaction for two ${}^{2}_{1}H$ nuclei is:

$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n $$

Data: rest mass of ${}^{2}_{1}H$ nucleus = 2.01355*u*

rest mass of neutron = 1.00867*u*

rest mass of proton = 1.00728*u*

rest mass of electron = 0.00055*u*

(i) Show that the binding energy per nucleon for the ${}^{2}_{1}H$ nucleus is 1.12 MeV.

[2]

(ii) Given that the binding energy per nucleon for the ${}^{3}_{2}\text{He}$ nucleus is 2.57 MeV, calculate the energy released during the reaction.

energy released = ... MeV [1]

(iii) Explain why a release of energy occurs in a nuclear reaction when there is an increase in the binding energy.

....

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.... [2]

(iv) State the form of energy released from the reaction in **(iii)**.

.... [1]

(b) **(i)** Define the *half-life* for a radioactive nuclide.

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.... [1]

(ii) A small quantity of solution containing a radioactive nuclide of half-life 15 hours and initial activity 1.5 microcurie is injected into the blood of a patient. A 1.0 cm^3 sample of the patient's blood taken after 6.0 hours show an activity of 326 disintegrations per minute.

Assuming the radioactive nuclide is distributed uniformly in the patient's blood, calculate the total volume of blood in the patient's body.

(1 microcurie = 3.7×10^4 disintegrations per second)

volume = ... cm^3 [3]

Ans	**(a)(i)**	Mass defect = 1.00867u + 1.00728u – 2.01355u = 0.0024u	**[1] mass defect**
		Binding energy = (0.0024)(1.66 × 10^{-27})(3.00 × 10^{8})^2 = 3.59 × 10^{-13} J = 2.24 MeV	
		Binding energy per nucleon = $\frac{2.24}{2}$	**[1] wkg**
		= 1.12 MeV.	
	(ii)	Energy released = increase in binding energy = (3)(2.57) – (2)(2)(1.12) = **3.23 MeV**	**[1] ans**
	(iii)	The binding energies of the products are larger than the binding energies of the reactants	
		By the **conservation of nucleon number**, the **products have a higher binding energy per nucleon.**	
		OR The energy released from the formation of the products is larger than the energy needed to break the reactants into its individual nucleons.	**[1]**
		The **difference in binding energy** between the products and the reactants is the **energy released.**	**[1]**
	(iv)	**Kinetic energy**	**[1]**
	(b)(i)	**Half-life** of a radioactive nuclide is defined as the **average time taken for half of the original number of radioactive nuclei** in a sample to decay.	**[1] defn**
	(ii)	A_o = (1.5)(3.7 × 10^4) = 55500 Bq	
		$\ln A = \ln A_o - \lambda t$	**[1] *A***
		Final activity = (55500) $\left(\frac{1}{2}\right)^{\frac{6}{15}}$ = 42100 Bq	**[1] wkg**
		1 cm^3 has activity $\frac{326}{60}$ = 5.43 Bq	**[1] ans**
		Therefore volume of blood = $\frac{42100}{5.43}$ = 7750 cm^3	

3 **(a)** Explain what is meant by the *binding energy per nucleon* of a nucleus.

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(b) Fig. 5.1 shows the variation with nucleon number *A* of the binding energy *B.E.* per nucleon of nuclei.

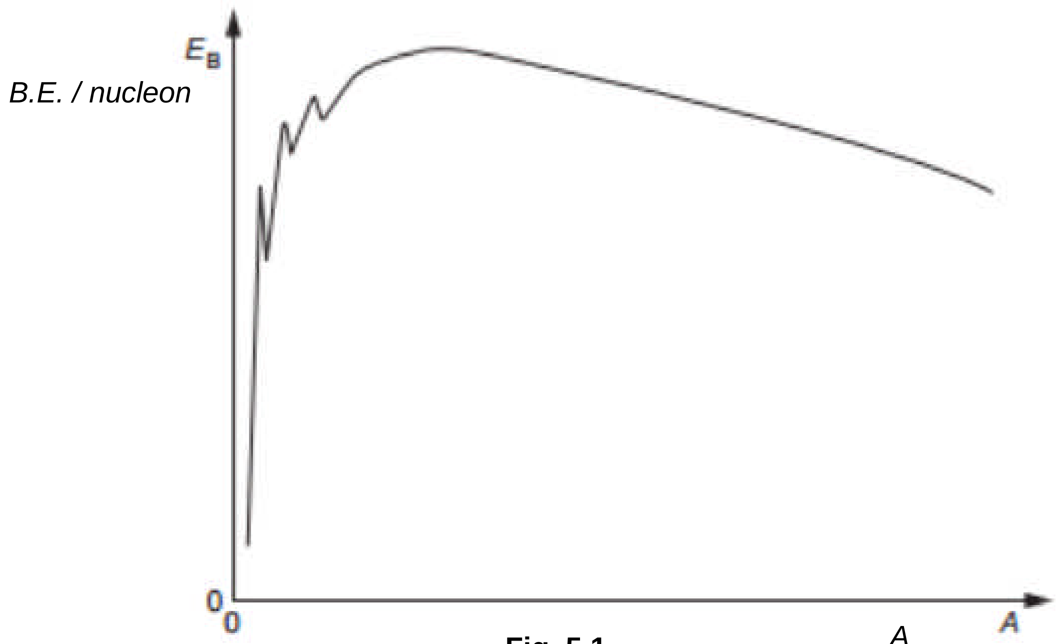

Fig. 5.1

An example of a nuclear fission is shown below.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + \ldots\ldots\ldots\ldots$$

(i) Complete the above equation. [1]

(ii) On Fig. 5.1, label the approximate positions of

$^{235}_{92}\mathrm{U}$ with the symbol *U*

$^{141}_{56}\mathrm{Ba}$ with the symbol *Ba* and

$^{92}_{36}\mathrm{Kr}$ with the symbol *Kr*. [1]

(iii) Although the neutron that is absorbed by a stationary uranium nucleus has negligible kinetic energy, explain why this nuclear fission is still possible.

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(c) Fig. 5.2 shows values of mass and binding energy per nucleon of some nuclei and particles.

	Mass / u	***B.E.* per nucleon / MeV**
$^{235}_{92}U$	235.123	
$^{141}_{56}Ba$	140.912	8.24
$^{92}_{36}Kr$	91.913	8.56
$^{1}_{1}p$	1.007	
$^{1}_{0}n$	1.009	

Fig. 5.2

(i) By performing suitable calculations, complete the table in Fig. 5.2 for the values of the binding energy per nucleon for $^{235}_{92}U$, $^{1}_{1}p$ and $^{1}_{0}n$.

(ii)

energy released = …………………… MeV

(iii) Suggest what form(s) of energy could be released.

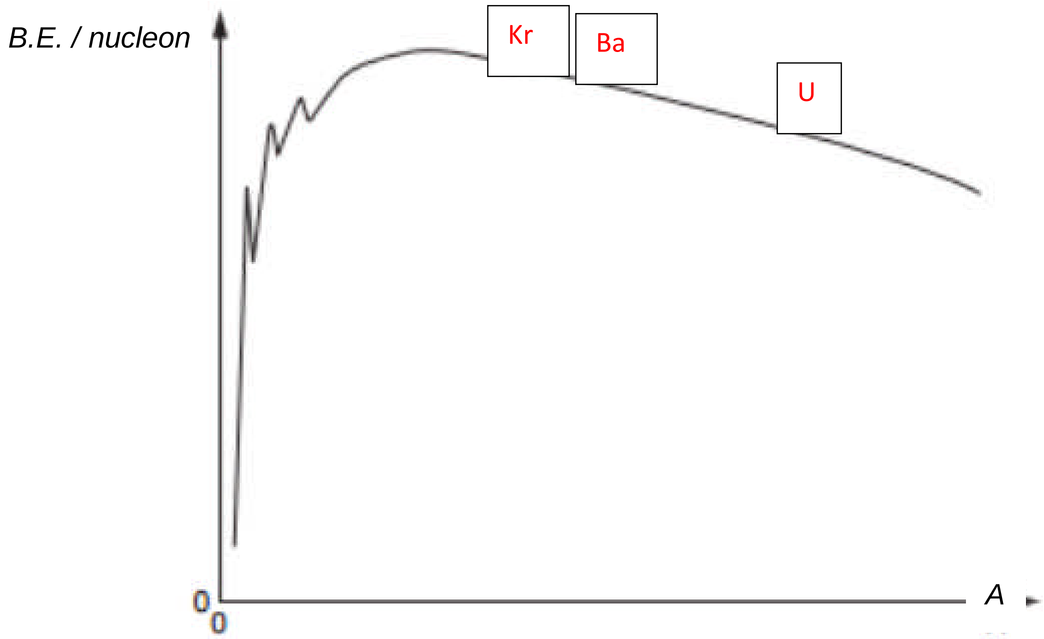
……………………………………………………………………………………………

Ans **(a)** work done on the nucleus to separate it into its constituent neutrons and protons to infinity divided by the number of nucleons

(b) (i)

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}n + \text{energy (or gamma)}$$

(ii)



(iii) Fission involves breaking down a less stable to more stable nuclei.
BE/ nucleon indicates stability.

and since BE/nucleon of Ba and Kr > Be/nucleon of U,
implies U is less stable than Ba and Kr, hence fission can occur.

(c) (i)

	Mass / u	*B.E.* per nucleon / MeV
$^{235}_{92}\mathrm{U}$	235.123	7.18
$^{141}_{56}\mathrm{Ba}$	140.912	8.24
$^{92}_{36}\mathrm{Kr}$	91.913	8.56
$^{1}_{1}\mathrm{p}$	1.007	0
(T	1.009	0

For uranium: BE per nucleon
= {(92x1.007)+(143x1.009) – 235.123}(1.66x10^{-27})(3x10^{8})^{2} / 235
= 1.149 x 10^{-12} J
= 7.18 MeV
BE of proton = BE of neutron = 0

(iii) Energy released = BE of products – BE of reactants
= (8.24x141)+(8.56x92) – (7.18x235)
= 262 MeV
Or use energy released = (mass $_{\text{reactants}}$ – mass $_{\text{products}}$) c^{2}
= 235.123 – 140.912 – 91.913 – 2(1.009)
= 0.28 u = 261 MeV

(iv) Gamma radiation and kinetic energy of products.