(Question B1 continued)

Part 2 Radioactivity and nuclear energy levels

(a) Define the following terms.

(i) *Radioactive half-life* ($T_{\frac{1}{2}}$) *[1]*

time it take for half of the nuclei to decay (transmutate)

(ii) *Decay constant* (λ) *[1]*

The probability that a nucleus will decay in unit time

(b) Deduce that the relationship between $T_{\frac{1}{2}}$ and λ is *[2]*

$$\lambda T_{\frac{1}{2}} = \ln 2.$$

$N = N_0 e^{-\lambda t}$ $N = \frac{N_0}{2}$ $t = T_{1/2}$

$\frac{N_0}{2} = N_0 e^{-\lambda \tau}$

$\ln \frac{1}{2} = -\lambda \tau$

$\ln 2 = \lambda \tau$ QED.

(This question continues on the following page)

(Question B1, part 2 continued)

Thorium-227 (Th-227) undergoes α-decay with a half-life of 18 days to form radium-223 (Ra-223). A sample of Th-227 has an initial activity of 3.2×10^5 Bq.

(c) Determine, the activity of the remaining thorium after 50 days. *[2]*

$\lambda = \frac{\ln 2}{18(24)(3600)} = 4.46\times10^{-7}\ s^{-1}$

$R = R_0 e^{-\lambda t} = (3.2\times10^5\ Bq)\exp(-4.46\times10^{-7}\ s^{-1})(50)(24)(3600)$

$R = 4.7\times10^4\ Bq$

In the decay of a Th-227 nucleus, a γ-ray photon is also emitted.

(d) (i) Use the following data to deduce that the energy of the γ-ray photon is 0.667 MeV. *[3]*

mass of Th-227 nucleus	= 227.0278 u
mass of Ra-223 nucleus	= 223.0186 u
mass of helium nucleus	= 4.0026 u
energy of α-particle emitted	= 5.481 MeV
unified atomic mass unit (u)	= 931.5 MeV c^{-2}

You may assume that the Th-227 nucleus is stationary before decay and that the Ra-223 nucleus has negligible kinetic energy.

$227.0278\ u - (223.0186\ u + 4.0026\ u)$

$= 0.0066\ u\ (931.5\ MeV c^{-2})$

$= 6.1479\ MeV c^{-2} - 5.481\ MeV$

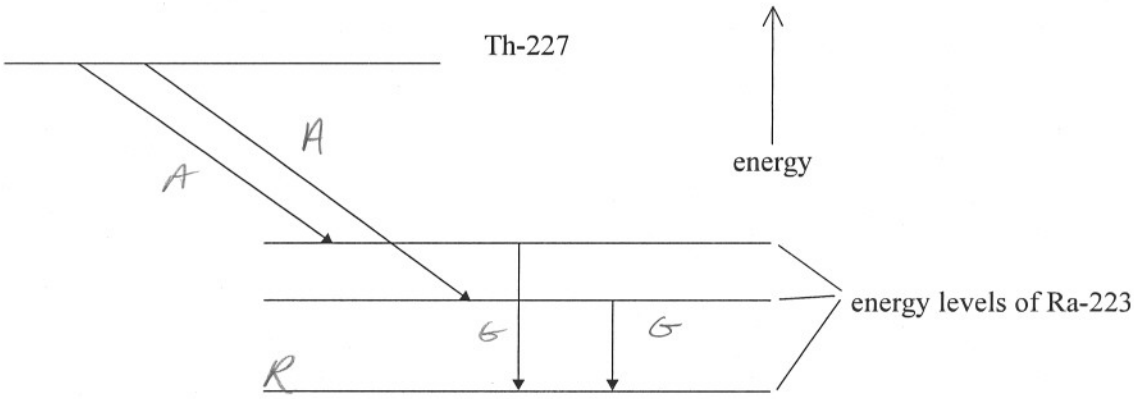
$= 0.667\ MeV$

(ii) Calculate the frequency of the γ-ray photon. *[3]*

(This question continues on the following page)

(Question B1, part 2 continued)

Although in the decay of a Th-227 nucleus, an α-particle and a γ-ray photon are emitted, they may have different energies to those in (d) (i). However, all the α-particles emitted in the decay of Th-227 have discrete energies as do the associated γ-ray photons. This provides evidence for the existence of nuclear energy levels. The diagram below represents some of the energy levels of a nucleus of Ra-223 relative to Th-227.



(e) On the diagram above label

(i) the arrows associated with α-particles (with the letter A). *[1]*

(ii) the arrows associated with γ-ray photons (with the letter G). *[1]*

(iii) the ground state energy level of Ra-223 (with the letter R). *[1]*

(f) Use data from (d), to suggest a value for the energy difference between the ground states of a nucleus of Th-227 and the ground state of a nucleus of Ra-223. *[1]*

6.148 MeV