Nuclear Reactions + Energies

A Physics

1. Americium-241 (Am) has an atomic no. of 95, and is used in smoke detectors. It decays, emitting α-radiation, into neptunium (Np)

(a) Can you write the nuclear equation? (2)

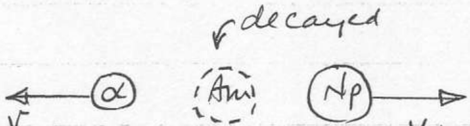
(b) "The mass defect of the decay is 0.00589 u."
What does this statement mean? (2)

(c) How much energy is released in the decay of one Am-243 nucleus? (2)

(d) What form does this released energy take? (1)

(e) What is the source of this energy? (2)

(f) The α and Np nuclei fly apart from each other, along a straight line – why is this? (2)



(g) Can you show that the ratio of velocities, V_α / V_{Np} is about 59:1? (2)

(h) The velocity of the Np nuclei is 2.73×10^5 m/s.
Calculate the <u>K.E.</u> of the α particles (3)

(i) Use the information and answer in part (h) to calculate the energy released in 1 decay – and compare this with your answer to (c). (3.)

(j) Can you show that given the masses of α and Np nuclei the ratio of K.E.s, K.E.(α)/K.E.(Np) must be about 59:1? (2)
(your answer to (g) – if you could do it – will help you!)

(k) A typical smoke detector contains 5 mg of Americium, which has a half life of 458 years.
Calculate the no. of Am nuclei present, and ... (2)

(l) Calculate the no. of He nuclei (α – that is!) emitted /sec. (2)

Data
- speed of light $c = 3 \times 10^8$ m/s
- 1 atomic mass unit $= 1.66 \times 10^{-27}$ kg
- Stella Artois – too much for me.
- Avogadro's No. $N_A = 6 \times 10^{23}$ /mole.

TRN

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Nuclear Reactions + Energies — Answers — A Physics

1\. a) Nuc. equation ... $^{241}_{95}Am \longrightarrow {}^{237}_{93}Np$ (1) $+ {}^{4}_{2}He$ (1) ← or α (2

b) There is a loss of mass (1) of 0·00589 atomic mass units .... or 9.7774×10^{-30} kg (1) (2

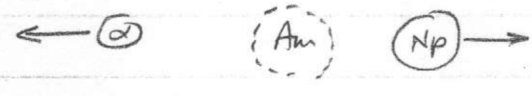
c) use $E = mc^2 = 9.7774 \times 10^{-30}$ (1) $\times (3 \times 10^8)^2$

$= \underline{8.7997 \times 10^{-13}\ J}$ (1) (2

d) Kinetic ! (particles just move – it's not heat yet !) (1

e) the loss / difference (1) in mass (1) Am to Np. (2

f) initial system (Am) has zero momentum (1)
the final system (α + Np) must also have zero momentum (1) – so they must move apart along the same straight line. (2



g) total $p = mv = 0 = m_\alpha v_\alpha = m_{Np} v_{Np}$ (1)

so $v_\alpha / v_{Np} = m_{Np} / m_\alpha = 237/4 = 59.25$ (1) (2

h) If $v_{Np} = 2.73 \times 10^5$ m/s then $v_\alpha = 59 \times 2.73 \times 10^5 = \underline{1.62 \times 10^7 \text{ m/s}}$ (1)

so $KE_\alpha = \frac{1}{2} m_\alpha v_\alpha^2$ (1) $= \frac{1}{2} \times (4 \times 1.66 \times 10^{-27}) \times (1.62 \times 10^7)^2$

$= \underline{8.71 \times 10^{-13}\ J}$ (1) (3

i) Energy released in 1 decay $= KE_\alpha + KE_{Np}$ (1)

$KE_\alpha = 8.71 \times 10^{-13}$ J

$KE_{Np} = \frac{1}{2} \times (237 \times 1.66 \times 10^{-27}) \times (2.73 \times 10^5)^2$

$= 1.466 \times 10^{-14}$ J (1)

Total energy $= 8.71 \times 10^{-13} + 1.47 \times 10^{-14} = 8.85 \times 10^{-13}$ J (1)

This is close enough to the answer to (c) to be taken as the same.

j) $K.E._\alpha / K.E._{Np} = \dfrac{\cancel{\frac{1}{2}} m_\alpha v_\alpha^2}{\cancel{\frac{1}{2}} m_{Np} v_{Np}^2}$ but $m_{Np} = 59 \times m_\alpha$ and $v_\alpha = 59 \times v_{Np}$

so K.E. ratio $= \dfrac{\cancel{m_\alpha} \times (59 \times \cancel{v_{Np}}) \times (59 \times \cancel{v_{Np}})}{(59 \times \cancel{m_\alpha}) \times \cancel{v_{Np}} \times \cancel{v_{Np}}} = \dfrac{59 \times 59}{59} = 59$! (2)

k) rel. atomic mass of Am = 241 ... so 241 g = 1 mole = 6×10^{23} nuclei

so 5 mg $= 5 \times 10^{-3}$ g $= 5 \times 10^{-3} \times 6 \times 10^{23} = \underline{3 \times 10^{21} \text{ nuclei}}$ (2

l) use $A = -\lambda N$ — $N = 3 \times 10^{21}$ nuclei

$\ln 2 = T_{1/2} \text{(sec)} \times \lambda \text{(sec}^{-1}\text{)}$

so $\lambda = \dfrac{\ln 2}{T_{1/2}} = \dfrac{\ln 2}{458 \times 365 \times 24 \times 60 \times 60} = 4.8 \times 10^{-11}$ (1) (s^{-1})

(y) (d) (h) (m) (s)

so $A = 4.8 \times 10^{-11} \times 3 \times 10^{21}$

$= \underline{1.44 \times 10^{11}}$ (1) decays/sec (Bq)