THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS3050 NUCLEAR PHYSICS

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Question 1 [15 marks]

A Σ^0 particle, at rest, decays into a Λ^0 and a gamma-ray $\Sigma^0 \rightarrow \Lambda^0 + \gamma$. The rest-masses of the Σ^0 and the Λ^0 are 1193 MeV/c^2 and 1116 MeV/c^2, respectively. Determine the energy of the gamma-ray produced. [Hint: it's not a simple case of E = 1193 – 1116 = 77 MeV].

Question 2 [10 marks]

Beryllium has only one stable isotope ${}^{9}_{4}Be$. When a 50 MeV proton strikes a beryllium target it is found that a high energy neutron is emitted from the target.

(i) Use the conservation laws appropriate to nuclear reactions to determine the residual nucleus in the reaction which produces the neutrons. Write down the full nuclear reaction.

(ii) Determine the Q of the reaction and so estimate the energy of the neutrons emitted in the forward direction i.e. the same direction of propagation as the incident protons.

Question 3 [5 marks]

Estimate the ratio of the surface energy term per nucleon for ${}^{40}Ca$ to that of ${}^{208}Pb$.

Question 4 [10 marks]

Recent news articles about 'table-top cold fusion' claim that neutrons are produced via the reaction $d + d \rightarrow n + X$ where X is a nucleus in its ground state.

(i) Identify X.

(ii) How much energy is released in this reaction ?

Q1 $\Sigma^0 \rightarrow \Lambda^0 + \gamma$

Conserve momentum $P_{\Lambda^0} = P_\gamma = E_\gamma / c$

$\therefore K_{\Lambda^0} = \frac{P_{\Lambda^0}^2}{2M_{\Lambda^0}} = \frac{E_\gamma^2}{2M_{\Lambda^0}c^2}$ non-relativistic

conserve energy

$$M_{\Sigma^0}c^2 = M_{\Lambda^0}c^2 + K_{\Lambda^0} + E_\gamma$$

$$1193 = 1116 + \frac{E_\gamma^2}{(2 \times 1116)} + E_\gamma \quad \text{in MeV}$$

$$\rightarrow E_\gamma^2 + 2232 E_\gamma - 171864 = 0$$

$$\rightarrow E_\gamma = 74.51 \text{ MeV}$$

Q2 (i) $p + {}^9_4Be \rightarrow n + {}^A_ZX$

conserve charge $1 + 4 \rightarrow Z = 5 \therefore$ Boron
" mass $1 + 9 \rightarrow 1 + A \therefore A = 9$

$$\Rightarrow {}^9_5B$$

Q2 (ii)

$$\text{At. Mass } {}^{9}_{4}Be = 9.012182\ u$$

$$\text{" " } {}^{9}_{5}B = 9.013329\ u$$

$$M_p = 1.00727647\ u$$

$$M_n = 1.00866501\ u$$

$$M_e = 5.485803 \times 10^{-4}\ u$$

$$Q = (M_i - M_f)c^2$$

$$= \left\{ \text{At. Mass}({}^{9}_{4}Be) - 4M_e + M_p - \left[\text{At. Mass}({}^{9}_{5}B) - 5M_e + M_n \right] \right\} \cdot c^2$$

$$= \left\{ 9.012182 + 1.00727647 - 9.013329 - 1.00866501 + (5.485803 \times 10^{-4}) \right\} c^2$$

$$= -0.001987\ u \cdot c^2$$

$$= -0.001987 \times 931.502 = -1.85\ \text{MeV}$$

$Q < 0$ so energy is absorbed

$$K_p = 50\ \text{MeV}$$

$$\therefore K_n = 50 - 1.85 = 48.15\ \text{MeV}$$

Q3 Surface energy term $= -a_s A^{2/3}$ nucleus

$= -a_s A^{2/3}/A$ per nucleon

$= -a_s/A^{1/3}$

$\Rightarrow$ ratio $^{40}Ca / ^{208}Pb$

$= \left(\frac{208}{40}\right)^{1/3} = 1.73$

Q4 (i) $d + d \rightarrow n + {}^{A}_{Z}X$

charge $1+1 \rightarrow 0 + Z \therefore Z = 2 \therefore$ Helium

mass $2+2 \rightarrow 1 + A \therefore A = 3$

$\therefore {}^{3}_{2}He$

(ii) $M_d = 2.01355321\ u$

$M_n = 1.00866501\ u$

At. Mass $({}^{3}_{2}He) = 3.016029\ u$

$M_e = 5.485803 \times 10^{-4}\ u$

$Q = (2 \times M_d) - [M_n + At.M({}^{3}_{2}He) - 2M_e] \cdot c^2$

$= +0.003510\ u$

$\times 931.502\ MeV/c^2 \longrightarrow 3.27\ MeV$