

$$\boxed{11-8} \quad R = R_0 A^{1/3} [\text{fm}] = 1.2 \text{ fm} \cdot A^{1/3}$$

$$\rho = \frac{\text{mass}}{\text{volume}} \approx \frac{A \cdot u}{\frac{4}{3} \pi R^3} = \frac{3 A u}{4 \pi (1.2 \text{ fm})^3 A}$$

$$= \frac{3 (1.66 \cdot 10^{-27} \text{ kg})}{4 \pi (1.2 \cdot 10^{-15} \text{ m})^3} = \boxed{2.29 \cdot 10^{17} \frac{\text{kg}}{\text{m}^3}}$$

$$\boxed{11-9} \quad \text{TOTAL BINDING ENERGY} = Z m_p c^2 + N m_n c^2 - M_A c^2$$

$$(a) \quad {}^9\text{Be} \quad M_A = 9.0121 \text{ u}$$

$$m_p = 1.00783 \text{ u}$$

$$Z = 4$$

$$m_n = 1.00867 \text{ u}$$

$$N = 9 - 4 = 5$$

$$\text{B.E.}_{\text{TOT}} = [4(1.00783) + 5(1.00867) - 9.012] \text{ u} c^2$$

$$u = 931.49 \text{ MeV}/c^2 \Rightarrow \boxed{\text{BE}_{\text{TOT}} = 58.3 \text{ MeV}}$$

$$\text{PER NUCLEON: } 58.3 \text{ MeV}/9 = \boxed{6.5 \text{ MeV}}$$

$$(b) \quad {}^{13}\text{C} \quad M_A = 13.00336 \text{ u}, \quad Z = 6, \quad N = 7$$

$$\text{BE}_{\text{TOT}} = [6(1.00783) + 7(1.00867) - 13.00336] \text{ u} c^2$$

$$\boxed{\text{BE}_{\text{TOT}} = 97.2 \text{ MeV}} \quad * \text{BOOK HAS INCORRECT ANSWER}$$

$$\text{PER NUCLEON: } 97.2 \text{ MeV}/13 = \boxed{7.5 \text{ MeV}}$$

$$(c) \quad M_A = 56.935 \text{ u} \quad {}^{57}\text{Fe} \quad Z = 26, \quad N = 57 - 26 = 31$$

$$\text{BE}_{\text{TOT}} = [26(1.00783) + 31(1.00867) - 56.935] \text{ u} c^2$$

$$\boxed{\text{BE}_{\text{TOT}} = 502 \text{ MeV}}$$

$$\text{PER NUCLEON} = \frac{502 \text{ MeV}}{57} = \boxed{8.8 \text{ MeV}}$$

11-15 (a) AT $t=0$, $R=R_0=4000$

$$\Rightarrow R(t) = 4000 e^{-\lambda t}$$

$$R(t=10s) = 4000 e^{-\lambda(10\text{sec})} \stackrel{\text{set}}{=} 1000$$

$$\Rightarrow e^{-\lambda(10\text{sec})} = .25$$

$$-\lambda(10s) = \ln .25$$

$$\lambda = \frac{\ln 4}{10s} = .139 \frac{\text{decays}}{\text{sec}}$$

$$t_{1/2} = \frac{\ln 2}{\lambda} = \boxed{5 \text{ sec}}$$

(b) AFTER 20 sec, 2 HALF LIVES HAVE ELAPSED FROM $t=10\text{sec}$

$$1000 \frac{\text{counts}}{\text{sec}} \cdot \frac{1}{2} \cdot \frac{1}{2} = \boxed{250 \frac{\text{counts}}{\text{sec}}}$$

11-35

$$F_c = \frac{ke^2}{d^2}$$

NUCLEAR DIAMETER OF CARBON

$$= 2R = 2(1.2 \text{ fm}) 13^{1/3} = 5.64 \text{ fm}$$

$$\Rightarrow F_c = \frac{(8.98 \cdot 10^9 \text{ Nm}^2/\text{C}^2)(1.602 \cdot 10^{-19} \text{ C})^2}{(5.64 \cdot 10^{-15} \text{ m})^2} = 7.3 \text{ N}$$

$$F_g = -\frac{Gm_p^2}{d^2} \quad m_p = 1.67 \cdot 10^{-27} \text{ kg} \quad = -5.9 \cdot 10^{-36} \text{ N}$$

POTENTIAL $U = F \cdot d$

$$U_c = 7.3 \text{ N} \cdot 5.64 \text{ fm} \cdot (1.602 \cdot 10^{-19} \text{ J/eV})^{-1} = .25 \text{ MeV}$$

$$U_g = -5.29 \cdot 10^{-36} \text{ N} \cdot 5.64 \text{ fm} \cdot (1.602 \cdot 10^{-19} \text{ J/eV})^{-1} = 2 \cdot 10^{-37} \text{ MeV}$$

$$U_{\text{NUCLEAR}} = 50 \text{ MeV (GIVEN)}$$

$$\text{THUS, } |U_{\text{NUCLEAR}}| > |U_c| \gg |U_g|$$

11-47

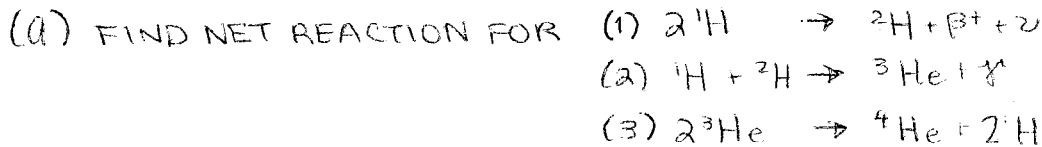
(a) $R[\text{cm}] = (.317)(5)^{3/2} \text{ cm} = \boxed{3.46 \text{ cm}}$

(b) $R[\text{cm}] \cdot \rho[\text{g/cm}^3] = 3.46 \text{ cm} \cdot 1.29 \cdot 10^{-39} / \text{cm}^3 = \boxed{4.47 \cdot 10^{-39} \frac{\text{g}}{\text{cm}^3}}$

(c) $R[\text{g/cm}^2] = R[\text{cm}] \cdot \rho[\text{g/cm}^3]$

$$\Rightarrow R[\text{cm}] = \frac{R[\text{g/cm}^2]}{\rho} = \frac{4.47 \cdot 10^{-39} / \text{cm}^2}{2.70 \text{ g/cm}^3} = \boxed{1.65 \text{ cm}}$$

12-36



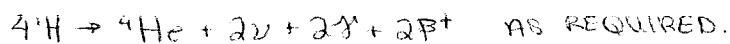
WE WANT TO OBTAIN $4^1\text{H} \rightarrow ^4\text{He} + 2\nu + 2\gamma + 2\beta^+$ (ERROR IN TEXT)

SO WE NEED TO MULTIPLY THE 1ST TWO REACTIONS BY 2 AND THEN SUM:
FOR THE REACTION $2 \times (1) + 2 \times (2) + (3)$

$$\text{PARTICLES IN} = 2 \cdot 2^1\text{H} + 2^1\text{H} + 2^2\text{H} + 2^3\text{He}$$

$$\text{PARTICLES OUT} = 2^2\text{H} + 2\beta^+ + 2\nu + 2^3\text{He} + 2\gamma + ^4\text{He} + 2^1\text{H}$$

CANCELING TERMS THAT APPEAR IN BOTH:

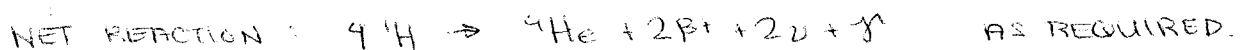


NOW CONSIDER REACTION (4) $^1\text{H} + ^3\text{He} \rightarrow ^4\text{He} + \beta^+ + \nu$ INSTEAD OF (3).

THIS TIME WE GET THE REQUIRED ANSWER BY ADDING (1)+(2)+(4)

$$\text{PARTICLES IN} = ^1\text{H} + ^3\text{He} + 2^1\text{H} + ^1\text{H} + ^2\text{H}$$

$$\text{PARTICLES OUT} = ^2\text{H} + \beta^+ + \nu + ^3\text{He} + \gamma + ^4\text{He} + \beta^+ + \nu$$



(b) ENERGY OF $\gamma = 4E_{^1\text{H}} - \{E_{^4\text{He}} + 2E_{\beta^+}\}$

$$E_{^1\text{H}} = (1.00783 \text{ u})c^2 = 938.78 \text{ MeV}$$

$$E_{^4\text{He}} = (4.0026 \text{ u})c^2 = 3728.4 \text{ MeV}$$

$$E_{\beta^+} = (0.511 \text{ MeV}) \quad (\text{SAME AS ELECTRON})$$

PRECISE ANSWER
DEPENDS ON
VALUES YOU USE
FOR THE MASSES.

$$E_{\gamma} = 4(938.78 \text{ MeV}) - 3728.4 \text{ MeV} - 2(0.511 \text{ MeV}) = \boxed{25 \text{ MeV}} \quad \leftarrow$$

COUNTING THE ADDITIONAL ENERGY RELEASED GIVES 26.72 MeV.

(c) $P = 4 \cdot 10^{26} \frac{\text{J}}{\text{s}} \cdot \frac{1 \text{ eV}}{1.602 \cdot 10^{-19} \text{ J}} = 2.49 \cdot 10^{45} \text{ eV/s}$

$$\text{RATE OF } p \text{ CONSUMPTION} = \frac{2.49 \cdot 10^{45} \text{ eV/s}}{26.7 \cdot 10^6 \text{ eV}} \cdot 4p = \boxed{3.74 \cdot 10^{35} \text{ p/s}}$$

$$\# \text{ OF } p = \frac{10^{30} \text{ kg}}{1.67 \cdot 10^{-27} \text{ kg}} = \boxed{6 \cdot 10^{56} \text{ PROTONS}}$$

$$\# \text{ OF SECONDS TO CONSUME ALL } p = \frac{\# \text{ OF } p}{\text{RATE}} = \frac{6 \cdot 10^{56} \text{ p}}{10^{35} \text{ p/s}} = \boxed{2 \cdot 10^{21} \text{ seconds}}$$

(MORE THAN 10 billion years)

13-47 (a) INITIALLY HAVE NO KINETIC ENERGY,
SO $E_i = m_p c^2 = 938 \text{ MeV}$

$$\begin{aligned} \text{FINAL REST ENERGY} &= m_p c^2 + m_{\pi^-} c^2 \\ &= 938.3 \text{ MeV} + 139.6 \text{ MeV} = 1077.9 \text{ MeV} \end{aligned}$$

$$\therefore E_i = E_f \text{ REQUIRES } 938 \text{ MeV} = KE_f + 1077.9 \text{ MeV}$$

$$\Rightarrow \boxed{KE_f = 38.1 \text{ MeV}}$$

(b) CONSERVATION OF MOMENTUM GIVES

$$m_{\pi} |v_{\pi}| = m_p |v_p| \quad \text{OR} \quad \frac{m_p}{m_{\pi}} = \left| \frac{v_{\pi}}{v_p} \right|$$

$$\frac{KE_{\pi}}{KE_p} = \left(\frac{m_{\pi}}{m_p} \right) \frac{v_{\pi}^2}{v_p^2} = \frac{v_{\pi}}{v_p} = \frac{938.3}{139.6} = \boxed{6.72}$$

(c) $KE_p + KE_{\pi} = 38.1 \text{ MeV}$, $KE_{\pi} = 6.72 KE_p$

$$\Rightarrow KE_p (1 + 6.72) = 38.1 \text{ MeV}$$

$$KE_{\pi} = 6.72 KE_p$$

$$\boxed{\begin{aligned} KE_p &= 4.94 \text{ MeV} \\ KE_{\pi} &= 33.2 \text{ MeV} \end{aligned}}$$

13-49 (a) $t_2 = \frac{x}{u_2}$, $t_1 = \frac{x}{u_1}$

$$\Delta t = t_2 - t_1 = \frac{x}{u_2} - \frac{x}{u_1} = x \left(\frac{u_1}{u_1 u_2} - \frac{u_2}{u_1 u_2} \right) = x \left(\frac{u_1 - u_2}{u_1 u_2} \right)$$

$$u_1, u_2 \approx c^2 \text{ SO } u_1 u_2 \approx c^2 \Rightarrow \Delta t \approx \frac{x \Delta u}{c^2} \quad \text{QED.}$$

(b) $E = \frac{m_0 c^2}{\sqrt{1 - u^2/c^2}}$ (2-10) REARRANGING, $1 - \frac{u^2}{c^2} = \left(\frac{m_0 c^2}{E} \right)^2$

$$\text{OR } \frac{u}{c} = \sqrt{1 - \left(\frac{m_0 c^2}{E} \right)^2} \quad \text{SINCE } E \gg m_0 c^2, \text{ CAN TAYLOR EXPAND } \left(\frac{m_0 c^2}{E} \right)^2 \text{ AROUND ZERO.}$$

$$\text{LET } X \equiv \left(\frac{m_0 c^2}{E} \right)^2. \text{ THEN } \frac{u}{c} = \sqrt{1 - X} \approx 1 + \frac{1}{2} X + \dots$$

$$\text{SO } \frac{u}{c} \approx 1 + \frac{1}{2} \left(\frac{m_0 c^2}{E} \right)^2 \quad \text{QED.}$$

#11

(DINE SPECIAL)

$$R_W \approx \frac{\hbar c}{mc^2} = \frac{(197.3 \text{ nm eV})}{91 \cdot 10^9 \text{ eV}} = 2.1 \cdot 10^{-9} \text{ nm} = \boxed{2.1 \cdot 10^{-18} \text{ m}}$$

COMPARE TO RANGE OF NUCLEAR FORCE: $R_N = 1.4 \cdot 10^{-18} \text{ m}$:
 $R_W < R_N$

#12

(DINE SPECIAL)

FROM THE INFORMATION GIVEN,
 TOTAL BARYON NUMBER MUST BE A
 LARGE POSITIVE NUMBER, SINCE

P AND n HAVE $B=+1$ AND \bar{p}, \bar{n} HAVE $B=-1$.
 IF THE UNIVERSE HAS EVER CONTAINED NO BARYONS
 (IE, $B_{\text{NET}} = 0$), THEN CONSERVATION OF BARYON NUMBER
 WOULD HAVE TO BE VIOLATED IN ORDER TO PRODUCE
 THE UNIVERSE WE SEE TODAY.

#13-2

(a) $E_{\gamma \text{ min}} = \text{REST ENERGY OF } \Delta^+ \pi^-$

$$= m_{\Delta} c^2 + m_{\pi} c^2 = 2285 \text{ MeV} + 139.6 \text{ MeV} = \boxed{2424 \text{ MeV}}$$

$$(b) \gamma \rightarrow p + \bar{p} \quad E_{\gamma \text{ min}} = 2(938.3 \text{ MeV}) = \boxed{1877 \text{ MeV}}$$

$$(c) \gamma \rightarrow \mu + \mu^+ \quad E_{\gamma \text{ min}} = 2(105.7 \text{ MeV}) = \boxed{211.4 \text{ MeV}}$$

#13-8

(a) $n \rightarrow p + \bar{e} + \bar{\nu}_e$ LEPTONS PRODUCED BUT NO PHOTONS: WEAK(b) $\pi^0 \rightarrow \gamma + \gamma$ PHOTONS PRODUCED: EM(c) $\Delta^+ \rightarrow \pi^0 + p$ HYPERCHARGE CONSERVED: STRONG(d) $\pi^+ \rightarrow \mu^+ + \nu_{\mu}$ LEPTONS BUT NO PHOTONS: WEAK

#13-14

(a) RIGHT SIDE: $L_e = -2$ LEFT SIDE: $L_e = 0$ LEPTON NUMBER(b) $m_p + m_{\pi^-} > m_n$: ENERGY CONSERVATION VIOLATED(c) MUST HAVE 2 PHOTONS TO CONSERVE MOMENTUM

(d) NO VIOLATIONS

(e) RIGHT SIDE: $L_e = -1$, LEFT SIDE: $L_e = +1$ LEPTON NUMBER(f) NO BARYONS ON RIGHT HAND SIDE: BARYON NUMBER

13-49 cont'd

(c) WARNING : ANSWERS MAY DIFFER ACCORDING TO LEVEL OF PRECISION USED IN CALCULATIONS.

$$u_1 - u_2 = c \left[-\frac{1}{2} \left(\frac{m_1 c^2}{E_1} \right)^2 + \frac{1}{2} \left[\frac{m_2 c^2}{E_2} \right]^2 \right] = \frac{(2.4 \text{ eV})^2}{2} \left[\frac{-1}{(20 \text{ MeV})^2} + \frac{1}{(5 \text{ MeV})^2} \right]$$

$$= c \frac{(2.4 \text{ eV})^2}{2} (3.75 \cdot 10^{-14} \text{ eV}) = 1.08 \cdot 10^{-13} c$$

$$\Delta t \approx \frac{\lambda \Delta u}{c^2} = \frac{(170,000 \text{ c} \cdot \text{yr}) (1.08 \cdot 10^{-13} c)}{c^2} = 1.8 \cdot 10^{-8} \text{ yr} \approx \boxed{.6 \text{ sec}}$$

FOR $m_0 c^2 = 40 \text{ eV}$, WE GET

$$\Delta u = \frac{(40 \text{ eV})^2}{2} \left[\frac{-1}{(20 \text{ MeV})^2} + \frac{1}{(5 \text{ MeV})^2} \right] = 3 \cdot 10^{-11} c$$

$$\Delta t \approx \frac{170,000 \text{ c} \cdot \text{yr}}{c^2} \cdot (3 \cdot 10^{-11} c) = 5.1 \cdot 10^{-6} \text{ yr} \approx \boxed{160 \text{ sec}}$$