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

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

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

11-9 TOTAL BINDING ENERGY $\approx Z m_p c^2 + N m_N c^2 - M_A c^2$

(a) ^9Be $M_A = 9.0121 u$

$m_p = 1.00783 u$ $Z = 4$

$m_N = 1.00867 u$ $N = 9 - 4 = 5$

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

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

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

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

$BE_{TOT} = [6(1.00783) + 7(1.00867) - 13.00336] uc^2$

$\boxed{BE_{TOT} = 97.2 MeV}$ * BOOK HAS INCORRECT ANSWER

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

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

$BE_{TOT} = [26(1.00783) + 31(1.00867) - 56.935] uc^2$

$\boxed{BE_{TOT} = 502 MeV}$

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

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

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

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

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

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

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

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

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

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

11-35 $F_c = \frac{ke^2}{d^2}$ NUCLEAR DIAMETER OF CARBON $= 2R = 2(1.2 fm) 13^{1/3} = 5.64 fm$

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

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

POTENTIAL $U = F \cdot d$

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

$$U_g = -5.9 \cdot 10^{-36} N \cdot 5.64 fm \cdot (1.602 \cdot 10^{-19} J/eV)^{-1} = 2 \cdot 10^{-37} MeV$$

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

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

11-47 (a) $R[cm] = (.31)(5)^{3/2} cm = \boxed{3.46 cm}$

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

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

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

12-36

(a) FIND NET REACTION FOR (1) $2\,{}^1H \rightarrow {}^2H + \beta^+ + \nu$

(2) ${}^1H + {}^2H \rightarrow {}^3He + \gamma$

(3) $2\,{}^3He \rightarrow {}^4He + 2\,{}^1H$

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

SO WE NEED TO MULTIPLY THE 1ST TWO REACTIONS BY 2 AND THEN SUM:

FOR THE REACTION $2\times(1) + 2\times(2) + (3)$

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

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

CANCELING TERMS THAT APPEAR IN BOTH:

$4\,{}^1H \rightarrow {}^4He + 2\nu + 2\gamma + 2\beta^+$ AS REQUIRED.

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

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

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

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

NET REACTION: $4\,{}^1H \rightarrow {}^4He + 2\beta^+ + 2\nu + \gamma$ AS REQUIRED.

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

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

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

$E_{\beta^+} = (.511\text{ MeV})$ (SAME AS ELECTRON)

PRECISE ANSWER DEPENDS ON VALUES YOU USE FOR THE MASSES.

$E_\gamma = 4(938.78\text{ MeV}) - 3728.4\text{ MeV} - 2(.511\text{ MeV}) = \boxed{25\text{ MeV}}$ ←

COUNTING THE ADDITIONAL ENERGY RELEASED GIVES 26.72 MeV.

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

RATE OF p CONSUMPTION $= \frac{2.49\cdot 10^{45}\text{ eV/s}}{26.7\cdot 10^6\text{ eV}}\cdot 4p = \boxed{3.74\cdot 10^{38}\text{ p/s}}$

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

OF SECONDS TO CONSUME ALL p $= \frac{\#\text{ OF } p}{\text{RATE}} = \frac{6\cdot 10^{56}\,p}{\cdot 10^{38}\,p/s} = \boxed{2\cdot 10^{13}\text{ seconds}}$

(MORE THAN 10 billion YEARS)

13-47 (a) INITIALLY HAVE NO KINETIC ENERGY, SO $E_i = m_\Lambda c^2 = 1116\ \text{MeV}$

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

$\therefore E_i = E_f$ REQUIRES $1116\text{MeV} = KE_f + 1077.9\text{MeV}$
$\Rightarrow \boxed{KE_f = 38.1\text{MeV}}$

(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) $t_2 = \frac{x}{u_2}$, $t_1 = \frac{x}{u_1}$

$$\Delta t = t_2 - t_1 = \frac{x}{u_2} - \frac{x}{u_1} = x\left(\frac{u_1}{u_1u_2} - \frac{u_2}{u_1u_2}\right) = x\left(\frac{u_1-u_2}{u_1u_2}\right)$$

$u_1, u_2 \approx c^2$ SO $u_1u_2 \approx c^2 \Rightarrow \Delta t \approx \frac{x\Delta u}{c^2}$ QED.

(b) $E = \frac{m_0c^2}{\sqrt{1-u^2/c^2}}$ (2-10) REARRANGING, $1 - \frac{u^2}{c^2} = \left(\frac{m_0c^2}{E}\right)^2$

OR $\frac{u}{c} = \sqrt{1-\left(\frac{m_0c^2}{E}\right)^2}$ SINCE $E \gg m_0c^2$, CAN TAYLOR EXPAND $\left(\frac{m_0c^2}{E}\right)^2$ AROUND ZERO.

LET $x \equiv \left(\frac{m_0c^2}{E}\right)^2$. THEN $\frac{u}{c} = \sqrt{1-x} \approx 1 + \frac{1}{2}x + \cdots$

SO $\frac{u}{c} \approx 1 + \frac{1}{2}\left(\frac{m_0c^2}{E}\right)^2$ QED.

#11

(DINE SPECIAL)

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

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

$R_W \ll R_N$

#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, $B_{NET}=0$), THEN CONSERVATION OF BARYON NUMBER WOULD HAVE TO BE VIOLATED IN ORDER TO PRODUCE THE UNIVERSE WE SEE TODAY.

13-2

(a) $E_{\gamma\,min}$ = REST ENERGY OF Λ^+, π^-

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

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

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

13-8

(a) $n \to p + \bar{e} + \bar{\nu}_e$ LEPTONS PRODUCED BUT NO PHOTONS: WEAK

(b) $\pi^0 \to \gamma + \gamma$ PHOTONS PRODUCED: EM

(c) $\Delta^+ \to \pi^0 + p$ HYPERCHARGE CONSERVED: STRONG

(d) $\pi^+ \to \mu^+ + \nu_\mu$ 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.

$$u_1 - u_2 \approx c\left[-\frac{1}{2}\left(\frac{m_1c^2}{E_1}\right)^2 + \frac{1}{2}\left[\frac{m_2c^2}{E_2}\right]^2\right] = \frac{(2.4\,eV)^2}{2}\left[\frac{-1}{(20MeV)^2} + \frac{1}{(5MeV)^2}\right]$$

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

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

FOR $m_0c^2 = 40eV$, WE GET

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

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