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

\[ C = \frac{\text{mass}}{\text{volume}} = \frac{A \cdot u}{\frac{4}{3} \pi R^3} = \frac{3 A u}{4 \pi (1.2 \text{ fm})^3} \]

\[ = \frac{3 \times (1.66 \times 10^{-27} \text{ kg})}{4 \pi (1.2 \times 10^{-15} \text{ m})^3} = \frac{2.29 \times 10^{17} \text{ kg}}{\text{m}^3} \]

11-9 \hspace{1cm} \text{TOTAL BINDING ENERGY} = Z m_p c^2 + N m_n c^2 - M_A c^2

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

\[ m_p = 1.00783 \text{ u} \quad Z = 4 \]

\[ m_n = 1.00867 \text{ u} \quad N = 9 - 4 = 5 \]

\[ \text{B.E. tot} = [4(1.00783) + 5(1.00867) - 9.0121] uc^2 \]

\[ u = 931.49 \text{ MeV/c}^2 \]

\[ \text{BE tot} = 58.3 \text{ MeV} \]

\[ \text{PER NUCLEON:} \quad \frac{58.3 \text{ MeV}}{9} = 6.5 \text{ MeV} \]

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

\[ \text{BE tot} = 6(1.00783) + 7(1.00867) - 13.00336 \text{ uc}^2 \]

\[ \text{BE tot} = 97.2 \text{ MeV} \]

\[ \text{PER NUCLEON:} \quad \frac{97.2 \text{ MeV}}{13} = 7.5 \text{ MeV} \]

(c) \[ ^{56}\text{Fe} \quad Z = 26, \quad N = 57 - 26 = 31 \]

\[ \text{BE tot} = 26(1.00783) + 31(1.00867) - 56.935 \text{ uc}^2 \]

\[ \text{BE tot} = 502 \text{ MeV} \]

\[ \text{PER NUCLEON:} \quad \frac{502 \text{ MeV}}{57} = 8.8 \text{ MeV} \]
11.15 (a) At t = 0, R = R₀ = 4000

\[ R(t) = 4000 e^{-\lambda t} \]

\[ \ln(1000) = 1000 \]

\[ e^{-\lambda (10 \text{ sec})} = 0.25 \]

\[ -\lambda (10 \text{ sec}) = \ln 0.25 \]

\[ \lambda = \frac{\ln 4}{10 \text{ sec}} = 0.139 \text{ decays/sec} \]

\[ t_{1/2} = \frac{\ln 2}{\lambda} = \frac{5 \text{ sec}}{} \]

(b) After 20 sec, 2 half lives have elapsed from t = 10 sec

\[ \text{counts/sec} \cdot \frac{1}{2} \cdot \frac{1}{2} = 250 \text{ counts/sec} \]

11.35 \[ F_C = \frac{k e^2}{d^2} \]

Nuclear Diameter of Carbon

\[ 2R = 2 \cdot (1.2 \text{ fm}) = 2 \cdot (1.2 \cdot 10^{-13} \text{ m}) = 2.4 \cdot 10^{-13} \text{ m} \]

\[ F_g = -\frac{G m_p^2}{d^2} \]

\[ m_p = 1.67 \cdot 10^{-27} \text{ kg} \]

\[ F_g = -5.9 \cdot 10^{-32} \text{ N} \]

Potential \[ U = F \cdot d \]

\[ U_C = 7.3 \text{ N} \cdot 5.64 \text{ fm} \cdot (1.602 \cdot 10^{-19} \text{ J/eV})^{-1} = 0.25 \text{ MeV} \]

\[ U_g = -5.9 \cdot 10^{-32} \text{ N} \cdot 5.64 \text{ fm} \cdot (1.602 \cdot 10^{-19} \text{ J/eV})^{-1} = 2.10^{-37} \text{ MeV} \]

\[ U_{\text{nuclear}} = 50 \text{ MeV (given)} \]

Thus, \[ |U_{\text{nuclear}}| > |U_C| > |U_g| \]

11.47 (a) \[ R_{[\text{cm}]} = (1.31)(5^{3/2}) \text{ cm} = 3.46 \text{ cm} \]

(b) \[ R_{[\text{cm}]} \cdot \rho [\text{g/cm}^3] = 3.46 \text{ cm} \cdot 1.29 \cdot 10^{-3} \text{ g/cm}^3 = 4.47 \cdot 10^{-3} \text{ g/cm}^3 \]

(c) \[ R_{[\text{cm}^2]} = \frac{R_{[\text{cm}]} \cdot [\text{cm}^2]}{\rho} = \frac{4.47 \cdot 10^{-3} \text{ cm}^2}{2.709 \text{ cm}^2} = 1.65 \text{ cm} \]
(a) Find net reaction for

1. \(2^1H \rightarrow 3^1H + \beta^+ + \nu\)
2. \(1^1H + 2^3H \rightarrow 3^3He + \gamma\)
3. \(2^3He \rightarrow 4^2He + 2^1H\)

We want to obtain \(4^1H \rightarrow 3^3He + 2\nu + 2\beta^+\) (error in text)

So we need to multiply the 1st two reactions by 2 and then sum:

particles in = \(2 \times (1) + 2 \times (2) + (3)\)
particles out = \(2^3H + 2\beta^+ + 2\nu + 2^3He + 2\beta^+ + 4^2He + 2^1H\)

canceling terms that appear in both:
\(4^1H \rightarrow 3^3He + 2\nu + 2\beta^+\) as required.

Now consider reaction (4) \(1^1H + 3^3He \rightarrow 4^3He + \beta^+ + \nu\) instead of (3). This time we get the required answer by adding (1)+(2)+(4):

Particles in = \(1^1H + 3^3He + 2^3H + 4^2He + 2^1H\)

Particles out = \(2^3H + \beta^+ + \nu + 3^3He + \gamma + 4^2He + \beta^+ + \nu\)

Net reaction = \(4^1H \rightarrow 3^3He + 2\beta^+ + 2\nu + \gamma\) as required.

(b) Energy of \(\gamma\) = \(4E_{\gamma} - \frac{1}{2}E_{4^1He} + 2E_{\beta^+}\)

\(E_{\gamma} = (1.60 \times 10^{-13} \text{ MeV}) c^2 = 4.93 \times 10^{-7} \text{ MeV}\)

\(E_{4^1He} = (4.0026 \times 10^{-33} \text{ MeV}) c^2 = 3.728 \times 10^{-7} \text{ MeV}\)

\(E_{\beta^+} = (1.51 \times 10^{-10} \text{ MeV}) \) (same as electron)

\(E_{\gamma} = 4.93 \times 10^{-7} \text{ MeV} - 3.728 \times 10^{-7} \text{ MeV} - 2 \times 1.51 \times 10^{-10} \text{ MeV} = 1.25 \times 10^{-7} \text{ MeV} \)

Counting the additional energy released gives 26.72 MeV.

(c) \(P = 4 \times 10^{20} \text{ m/s} \times \frac{1 \text{ eV}}{1.602 \times 10^{-19} \text{ J}} = 2.49 \times 10^{15} \text{ eV/m}\)

Rate of \(P\) consumption = \(2.49 \times 10^{15} \text{ eV/s} \times 4 \times P = \frac{3 \times 4 \times 10^{35} \text{ eV/s}}{26.7 \times 10^{16} \text{ eV}}\)

\# of \(P\) = \(1.67 \times 10^{-27} \text{ km} \times \frac{4 \times 10^{35} \text{ eV/s}}{26.7 \times 10^{16} \text{ eV}}\)

\# of seconds to consume all \(P\) = \(\frac{4 \times 10^{35} \text{ eV/s}}{2 \times 10^{18} \text{ seconds}}\) (more than 10 billion years)
[13-47] (a) Initially have no kinetic energy, so \( E_i = m_0 c^2 = 1166 \text{ MeV} \)

Final rest energy = \( m_1 c^2 + m_2 c^2 \)

\( = 938.3 \text{ MeV} + 139.6 \text{ MeV} = 1077.9 \text{ MeV} \)

\[ E_i = E_f \text{ requires } 1116 \text{ MeV} = KE_f + 1077.9 \text{ MeV} \]

\[ \Rightarrow KE_f = 38.1 \text{ MeV} \]

(b) Conservation of momentum gives

\[ \frac{KE_\pi}{KE_p} = \left( \frac{m_\pi}{m_p} \right) \frac{u_\pi^2}{u_p^2} = \frac{u_\pi}{u_p} = \frac{938.3}{139.6} = (6.72) \]

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

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

\[ KE_p = 4.91 \text{ MeV}, KE_\pi = 33.2 \text{ MeV} \]

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

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

\( u_1, u_2 \approx c^2 \) so \( u_1 u_2 \approx c^2 \Rightarrow \Delta t \approx \frac{x \Delta u}{a^2} \quad \text{ QED.} \)

(b) \( E = \frac{m_0 c^2}{\sqrt{1 - u^2 c^2}} \)

\( \text{REARRANGING, } 1 - \frac{u^2}{c^2} = \left( \frac{m_0 c^2}{E} \right)^2 \)

\[ \text{OR } \frac{u}{c} = \sqrt{1 - \left( \frac{m_0 c^2}{E} \right)^2} \quad \text{since } E \gg m_0 c^2, \text{ can Taylor expand } \frac{(m_0 c^2)^2}{E} \text{ around zero.} \]

Let \( x = \left( \frac{m_0 c^2}{E} \right)^2 \), then \( \frac{u}{c} = \sqrt{1 - x} \approx 1 + \frac{1}{2} x + \ldots \)

\[ \text{so } \frac{u}{c} \approx 1 + \frac{1}{2} \left( \frac{m_0 c^2}{E} \right)^2 \quad \text{QED.} \]
#11

(DINE SPECIAL)

\[ Rw \leq \frac{h c}{m c^2} = \frac{(197.3 \text{ nm ev})}{91 \cdot 10^9 \text{ ev}} = 2.1 \cdot 10^{-9} \text{ nm} = 2.1 \cdot 10^{-18} \text{ m} \]

Compare to range of nuclear force: \( R_N = 1.4 \cdot 10^{-18} \text{ m} \):
\[ Rw \ll R_N \]

#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 (i.e., \( B_{\text{tot}} = 0 \)), then conservation of baryon number would have to be violated in order to produce the universe we see today.

#13-2

(a) \( E_{y_{\text{min}}} = \text{rest energy of } \Delta^+ \pi^- \]
\[ = m_{\Delta} c^2 + m_{\pi} c^2 = 2285 \text{ MeV} + 139.6 \text{ MeV} = 2424 \text{ MeV} \]

(b) \( \gamma \rightarrow p + \bar{p} \]
\[ E_{y_{\text{min}}} = 2 (498.3 \text{ MeV}) = 1007 \text{ MeV} \]

(c) \( \gamma \rightarrow \mu^- + \mu^+ \]
\[ E_{y_{\text{min}}} = 2 (105.7 \text{ MeV}) = 211.4 \text{ MeV} \]

#13-8

(a) \( \eta \rightarrow p + \bar{p} + \bar{\nu}_e \]
Leptons produced but no photons: \text{ weak}

(b) \( \pi^\circ \rightarrow \gamma + \gamma \]
Photons produced: \text{ EM}

(c) \( \Delta^+ \rightarrow \pi^0 + p \]
Hypercharge conserved: \text{ strong}

(d) \( \pi^- \rightarrow \mu^- + \nu \]
Leptons but no photons: \text{ 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
WARNING: ANSWERS MAY DIFFER ACCORDING TO LEVEL OF PRECISION USED IN CALCULATIONS.

\[ u_1 - u_2 = c \left[ -\frac{1}{2} \left( \frac{m_e c^2}{E_1} \right)^2 + \frac{1}{2} \left( \frac{m_e c^2}{E_2} \right)^2 \right] = \frac{(2.4 \text{ eV})^2}{2} \left[ \frac{-1}{(20 \text{ MeV})^2} + \frac{1}{(547 \text{ MeV})^2} \right] \]

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

\[ \Delta t = \frac{\sqrt{\Delta u}}{c^2} = \frac{(170,000 \text{ c-y}) (1.08 \cdot 10^{-13} c)}{c^2} = 1.8 \cdot 10^{-8} \text{ y} \approx 16 \text{ sec} \]

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

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

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