Nuclear Physics

1. The volume of an iron nucleus is $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi(56^{1/3} \times 1.2\times10^{-15}\text{m})^3 = 4.0\times10^{-43}\text{m}^3$. But the volume allowed for each atom/nucleus is $\frac{55.847\text{u}\times1.66\times10^{-27}\text{kg/u}}{7.87\times10^3\text{kg/m}^3}$ $= 1.2\times10^{-29}\text{m}^3$. Thus, $\frac{4.0\times10^{-43}\text{m}^3}{1.2\times10^{-29}\text{m}^3} \cong \mathbf{3\times10^{-14}}$.

2. They must approach to a distance of $r_{\text{gold nucleus}} = 197^{1/3} \times 1.2\times10^{-15}\text{m} = 7.0\times10^{-15}\text{m}$.
$KE_{\text{initial}} = PE_{\text{final}} \rightarrow \frac{1}{2} m_\alpha v^2 = \frac{1}{4\pi\epsilon_0}\frac{(2e)(79e)}{r}$
$\rightarrow \frac{1}{2}(4\times1.66\times10^{-27}\text{kg})v^2 = \frac{1}{4\pi(8.85\times10^{-12}\text{C}^2/\text{N}\cdot\text{m}^2)}\frac{158\times(1.6\times10^{-19}\text{C})^2}{7.0\times10^{-15}\text{m}} \Rightarrow v = 4.0\times10^7\text{m/s}$.
Hmm... Relativistic? $(\gamma_u - 1)\,m c^2 = PE \rightarrow \left(\frac{1}{\sqrt{1-u^2/c^2}} - 1\right)(4\times1.66\times10^{-27}\text{kg})(3\times10^8\text{m/s})^2$
$= \frac{1}{4\pi(8.85\times10^{-12}\text{C}^2/\text{N}\cdot\text{m}^2)}\frac{158\times(1.6\times10^{-19}\text{C})^2}{7.0\times10^{-15}\text{m}} \Rightarrow = u = 0.131c = \mathbf{3.9\times10^7 m/s}$.

3. 0.199 of 10.012937u–mass atoms plus 0.801 of 11.009305u–mass atoms = **10.811u**. Agrees.

4. $r = A^{1/3} \times R_o \Rightarrow \frac{r_{238}}{r_9} = \frac{(A_{238})^{1/3}}{(A_9)^{1/3}} = \frac{(238)^{1/3}}{(9)^{1/3}} = \mathbf{2.98}$. Not much difference!

5. $BE = \left\{Zm_H + Nm_n - M_{^A_ZX}\right\}c^2 = \{(6\times1.007825\text{u} + 6\times1.008665\text{u}) - 12\text{u}\}\,c^2$
$= (0.09894\text{u}) \times 931.5\text{MeV/u} = 92.2\text{MeV}.\quad \frac{92.2\text{MeV}}{12\,\text{nucleons}} = \mathbf{7.68 MeV/nuc}$

6. $BE = \left\{Zm_H + Nm_n - M_{^A_ZX}\right\}c^2 = \{(43\times1.007825\text{u} + 55\times1.008665\text{u}) - 97.907215\text{u}\}\,c^2$
$= (0.90584\text{u}) \times 931.5\text{MeV/u} = 844\text{MeV}.\quad \frac{844\text{MeV}}{98\,\text{nucleons}} = \mathbf{8.61 MeV/nuc}$

7. $BE = 15.8\,A - 17.8\,A^{2/3} - 0.71\frac{Z(Z-1)}{A^{1/3}} - 23.7\frac{(N-Z)^2}{A}$.
$15.8 \times 98 - 17.8\,(98)^{2/3} - 0.71\frac{43(42)}{(98)^{1/3}} - 23.7\frac{12^2}{98} = 857\text{MeV}.\quad \frac{857\text{MeV}}{98\,\text{nucleons}} = \mathbf{8.75 MeV/nuc}$

8. **Only in the coulomb term**. (b) Since nitrogen has an agreeable neutron where oxygen has a repulsive proton, **nitrogen** should be more–tightly bound. (c) **Yes**, oxygen–15 is unstable, while nitrogen–15 is stable. (d) For the oxygen, $BE = \left\{Zm_H + Nm_n - M_{^A_ZX}\right\}c^2$
$= \{(8\times1.007825\text{u} + 7\times1.008665\text{u}) - 15.003065\text{u}\}\,c^2 = (0.1202\text{u}) \times 931.5\text{MeV/u} = \mathbf{112.0 MeV}$
And for the nitrogen, $BE = \{(7\times1.007825\text{u} + 8\times1.008665\text{u}) - 15.000108\text{u}\}\,c^2$
$= (0.1202\text{u}) \times 931.5\text{MeV/u} = \mathbf{115.5 MeV}$. Nitrogen more tightly bound, by **3.5MeV**

12. ${}^{13}_{7}N \rightarrow {}^{13}_{6}C + {}^{0}_{1}\beta^{+}$. **Carbon–13**. $Q = (m_i - m_f)\,c^2$
$= [13.005738u - (13.003355u + 2\times 0.0005486u)]\,c^2 = (0.00129) \times 931.5MeV/u =$ **1.2MeV**

13. ${}^{19}_{8}O \rightarrow {}^{19}_{9}F + {}^{0}_{-1}\beta^{-}$. **Fluorine–19**. $Q = (m_i - m_f)\,c^2 = [19.003577u - 18.998403u]\,c^2$
$= (0.00517) \times 931.5MeV/u =$ **4.82MeV, a <u>maximum</u> KE, since shared with the antineutrino.**

$Q = m\,c\,\Delta T \rightarrow 518J = (0.5kg)(4{,}186J/kg\cdot C^\circ)\,\Delta T \Rightarrow \Delta T = \mathbf{0.25^\circ C}$

31. $Q = (m_i - m_f)\,c^2 = ((7.016003u + 1.007825u) - (7.016928u + 1.008665u))\,c^2$
$= (-0.001765u) \times 931.5MeV/u = \mathbf{-1.64MeV}$. There is a net loss in KE.

32. $Q = (m_i - m_f)\,c^2 = ((2.014102u + 3.016049u) - (4.002603u + 1.008665u))\,c^2$
$= (0.0189u) \times 931.5MeV/u = \mathbf{17.6MeV}$

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Fundamental Particles and Interactions

1. range $\cong \frac{\hbar}{c}\frac{1}{m} \rightarrow 10^{-15}\text{m} = \frac{1.055\times10^{-34}\text{J}\cdot\text{s}}{3\times10^{8}\text{m/s}}\frac{1}{m} \Rightarrow m = 3.51\times10^{-28}\text{kg}$

   $= 0.212\text{u} = \mathbf{197}\frac{\mathbf{MeV}}{\mathbf{c^2}}$. Within about 30% of the correct value!

2. $m \cong 85\times10^{9} \times 1.6\times10^{-19}\text{J} / 9\times10^{16}\text{m}^2/\text{s}^2 = 1.5\times10^{-25}\text{kg}$

   range $\cong \frac{\hbar}{c}\frac{1}{m}\ \frac{1.055\times10^{-34}\text{J}\cdot\text{s}}{3\times10^{8}\text{m/s}}\ \frac{1}{1.5\times10^{-25}\text{kg}} = 2\times10^{-18}\text{m} \cong 10^{-3}\text{fm}$

10. Since the W bosons "couple to" charge/weak–charge, the important property for the electroweak interaction, and possess that very property, they should indeed self–interact. Similarly, the gravitational interaction merely requires that something have mass or any other form of energy. Moving gravitons would certainly have kinetic energy, so they should also self–interact.