PH1130  Practice Exam 3

Note: for this practice exam, you'll need to look up atomic masses in your book or other resource. On the exam, you will be provided with a table of atomic and nuclear masses.

1. (a) Determine the binding energy per nucleon in tritium ($^3\text{H}$) in units of MeV.

   (b) Determine the binding energy per nucleon in helium-3 ($^3\text{He}$) in units of MeV.

   (c) In a few succinct sentences, state the physical meaning and significance of the binding energy of a nucleus. Applying this to the results obtained in parts a and b, what can you conclude when comparing tritium and helium-3?

2. Tritium, $^3\text{H}$, can be produced by bombarding $^4\text{He}$ with energetic neutrons.

   (a) Write the nuclear reaction that occurs in the form
      (original particles) $\rightarrow$ (final particles)
      identifying the original and final particles in the usual notation.

   (b) What energy is released in this reaction (i.e., what is the Q-value)?

   (c) Would this reaction occur for arbitrarily low neutron kinetic energy? Explain.

3. A sample has an activity of 2.6 $\mu$Ci at time $t = 0$, and it is found that this activity decreases to 30% of its initial value at $t = 3.5$ hours.

   (a) What is the decay constant and half-life for this radioactive material?

   (b) How many nuclei were present in the sample at time $t = 0$?

   (c) What will be the activity of the sample at $t = 7$ hours?

Solutions are on the following pages. It is strongly suggested that you give the problems a good try on your own first, before looking at the solutions.
c) The binding energy is the energy released when the individual nucleons are brought together from very far away to form a given nucleus. Greater binding energy means that the nucleus is more stable. That is, more energy would be required to break the nucleus up into its separate components. Applying this concept to the preceding results, we see that the tritium nucleus is more stable than the helium-3 nucleus.

2. a)  
\[ O E = \left( m_n + 2m_p - M_{He} \right) c^2 \]
\[ O E = \left( 1,007825 + 2 \left[ 1,008665 \right] - 3,016049 \right) u \]
\[ = 0.0091 \ u \]
\[ O E = (0.0091 \ u) \left( 931.5 \ \text{MeV} \ \frac{u}{\text{MeV}} \right) = 8.48 \ \text{MeV} \]
\[ \frac{O E}{A} = \frac{8.48}{3} = 2.83 \ \text{MeV/nucleon} \]

b)  
\[ O E = \left( 3m_n + m_p - M_{He} \right) c^2 \]
\[ O E = \left( 3 \left[ 1,007825 \right] + 1,008665 - 3,016049 \right) u \]
\[ = 0.000429 \ u \]
\[ O E = (0.000429 \ u) \left( 931.5 \ \text{MeV} \ \frac{u}{\text{MeV}} \right) = 7.72 \ \text{MeV} \]
\[ \frac{O E}{A} = \frac{7.72}{3} = 2.57 \ \text{MeV/nucleon} \]

c) No, Neutron needs at least 17.6 MeV of kinetic energy for reaction to occur.
3.

\[ a) \quad R = R_0 e^{-\lambda t} \]

\[ 0.3 R_0 = R_0 e^{-\lambda t} \]

\[ x_1 = \frac{0.3}{\lambda} \]

\[ \lambda = \frac{0.3}{x_1} = 1.20 \text{ yr} \]

\[ \frac{1.20}{1.26 \times 10^4} = 9.53 \times 10^{-5} \text{ s}^{-1} \]

\[ T_{1/2} = \frac{\ln 2}{\lambda} = 7.25 \times 10^9 \text{ s} = 8.01 \text{ hr} \]

\[ b) \quad R_0 = (2.6 \times 10^{-6})(2.7 \times 10^{10}) = 9.62 \times 10^{-4} \text{ cm}^3 \]

\[ R_0 = N_0 \lambda \]

\[ N_0 = \frac{9.62 \times 10^{-4}}{9.53 \times 10^{-5}} = 1.01 \times 10^9 \]

\[ c) \quad \text{This is twice the time when the activity was 0.3 times the initial value.} \]

\[ R(7 \text{ hr}) = (0.3)^2 R(0) = 8.66 \times 10^{-5} \text{ s}^{-1} \]