Nuclear Physics Summary

- Recognize the notation used
- Radioactive decay processes
- Nuclear binding energy
- Radioactive half-life
- Other topics:
  - Examples of radioactive decays
  - Fusion, as in stars

Notation

- Atomic nucleus consists of protons and neutrons
- A nucleus of X has Z protons and A total nucleons (n + p)

$$X_Z^A \begin{array}{l} \leftarrow \textit{Total \# nucleons} \\ \leftarrow \textit{Total \# protons} \end{array}$$

- For small nuclei, same number of neutrons as protons, A = 2 Z
- For large nuclei (and isotopes) the number of neutrons may vary
- Example:
  - Ordinary Carbon: 6 protons, 6 neutrons, 12 nucleons C_6^{12}
  - Carbon-14: 6 protons, 8 neutrons, 14 nucleons C_6^{14}

Radioactive Decay Modes

- Alpha decay: the nucleus emits a Helium nucleus

$$X_Z^A \longrightarrow X'^{A-4}_{Z-2} + He_2^4$$

- Beta decay: the nucleus emits an electron and antineutrino

$$X_Z^A \longrightarrow X'^{A}_{Z+1} + \beta^0_{-1} + \overline{\nu}_e$$

- Gamma decay: the nucleus emits a photon (loses some energy, but does not change otherwise)

$$X_Z^A \longrightarrow X_Z^A + \gamma$$

- Deuteron decay (very rare):

  the nucleus emits a deuteron

$$X_Z^A \longrightarrow X'^{A-2}_{Z-1} + H_1^2$$

- An example problem ->

17. Suppose that ${}^{A}_{Z}X$ decays by natural radioactivity in two stages to ${}^{A-4}_{Z-1}Y$. The two stages would most likely be which of the following?

	First Stage	Second Stage
(A)	β^- emission with an antineutrino	α emission
(B)	β^- emission	α emission with a neutrino
(C)	β^- emission	γ emission
(D)	Emission of a deuteron	Emission of two neutrons
(E)	α emission	γ emission

Radioactive Decay Modes Example

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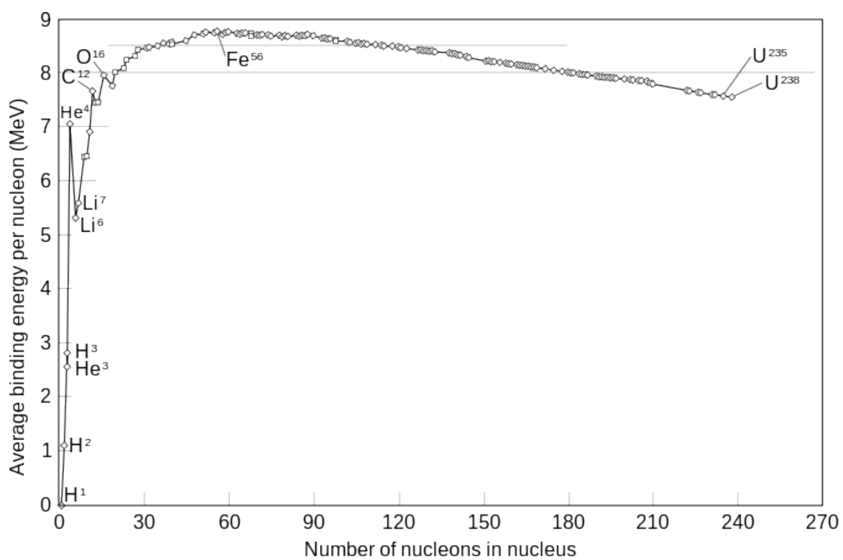
- Alpha decay takes away 4 nucleons and 2 protons (A->A-4, Z->Z-2)
- Beta decay adds one proton (Z -> Z+ 1)
- Beta decay followed by alpha decay: A-> A-4, Z-> Z-1
- If you don't remember the details of beta decay, how do you know whether (A) or (B) is correct?

Nuclear Binding Energy

- Nucleons repel electromagnetically, but are bound in place by the Strong force
- Can define a binding energy per nucleon, varies with size
- Iron (Z = 26) has max energy per nucleon
  - Much larger nuclei are so big that the strong force has smaller effect



http://en.wikipedia.org/wiki/File:Binding_energy_curve_-_common_isotopes.svg

64. The binding energy of a heavy nucleus is about 7 million electron volts per nucleon, whereas the binding energy of a medium-weight nucleus is about 8 million electron volts per nucleon. Therefore, the total kinetic energy liberated when a heavy nucleus undergoes symmetric fission is most nearly

(A) 1876 MeV
(B) 938 MeV
(C) 200 MeV
(D) 8 MeV
(E) 7 MeV

Radioactivity

- Radioactive substances break down over time
- The process occurs at random, but we can model what fraction N radioactive atoms will break down
- The change in the number of radioactive atoms (ie, the atoms that undergo decay) in time dt is proportional to the number of atoms N: $dN = -\lambda N dt$
- Solving, we find exponential decay:

$$N(t) = N(0)e^{-\lambda t}$$

- Radioactive half-life is the time required for half of the N atoms to decay (an invariant, since the decay process is exponential)

$$\tau_{1/2} = \frac{\log 2}{\lambda} \cong \frac{.69}{\lambda}$$

Radioactivity

- How do half-lives add?
- Think: there are **two** processes that are contributing to the disappearance of the material
- Total half-life must be smaller than either of the half-lives of the individual decay processes
- 1/t is the rate at which half of the material disappears
- The rates **add**:

$$\frac{1}{\tau_{total}} = \frac{1}{\tau_1} + \frac{1}{\tau_2}$$

66. A sample of radioactive nuclei of a certain element can decay only by γ-emission and β-emission. If the half-life for γ-emission is 24 minutes and that for β-emission is 36 minutes, the half-life for the sample is

(A) 30 minutes
(B) 24 minutes
(C) 20.8 minutes
(D) 14.4 minutes
(E) 6 minutes