Introduction to Physical Science

Nuclear Structure

Presented by Robert Wagner

Nuclear Reactions

- What we have studied so far involves the electrons in an atom
  - Nuclear reactions are changes that occur within the nucleus of an atom
- Recall:
  - Atoms have a nucleus consisting of protons and neutrons
  - Z = Atomic number = number of protons
  - A = Atomic mass = number of protons + number of neutrons
- - A = 14, Z = 6 ; Also called Carbon-14
- Nucleons - term to refer to nuclear particles - both protons and neutrons

Example

- What is the density of a neutron star with a mass of 2.4 solar masses (1 solar mass = $1.99 x 10^{30}$ kg) and a diameter of 26 kilometers?

$$m = 2.4x1.99x10^{30}kg = 4.776x10^{30}kg$$
$$r = 13km = 13000m$$

$$\rho = \frac{m}{V}\ ;\ V = \frac{4}{3}\pi r^3$$

$$\rho = \frac{4.776x10^{30}kg}{\frac{4}{3}\pi(13000)^3}$$

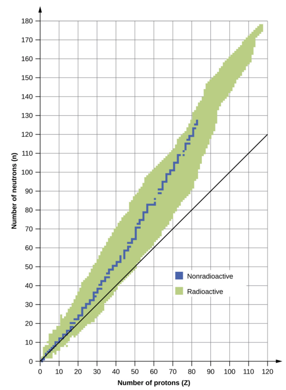
$$\rho = 5.2x10^{17}kg/m^3$$

Nuclear Force

- Strong nuclear force - one of the four fundamental forces of nature
  - Acts between nucleons in the nucleus
  - Much stronger than the electrostatic forces at the very small, nuclear distances
- Nuclear binding energy
  - Energy produced when the nucleons are bound together
  - These are much greater than the chemical bond energies
- Mass defect
  - Difference between calculated and measured mass of a nucleus
  - Can be equated to energy through:

Nuclear Stability

- Only a small percentage of nuclei that exist are stable
  - Fall in "Band of Stability"
- Stable nuclei of higher mass will have more neutrons than protons
  - Needed to keep nucleus bound together
- Radioactive nuclei
  - Around band of stability
  - Will decay in to another isotope



Nuclear Stability (2)

- Nuclei with even numbers of protons and neutrons are more likely to be stable
- Magic numbers
  - Specific numbers of protons or neutrons are stable against decay
  - 2, 8, 20, 28, 50, 82, and 126
- Double magic - Extremely stable isotopes
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Stable Nuclear Isotopes

Number of Stable Isotopes	Proton Number	Neutron Number
157	even	even
53	even	odd
50	odd	even
5	odd	odd

Binding Energy per Nucleon

- Divide the total binding energy of the nucleus by the number of nucleons
- Energy gain by nuclear fusion
  - Move from lower mass nuclei to higher mass nuclei
- Energy gain from nuclear fission
  - Move from higher mass nuclei to lower mass nuclei
- - highest binding energy per nucleon
- Electron volt (eV) used to measure nuclear binding energies
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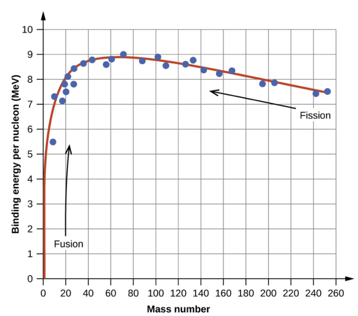

Example

- has the highest binding energy per nucleon - what is this binding energy (in MeV/nucleon)? (Atomic mass = 55.9349 amu)

26 protons, 30 neutrons, 26 electrons

Mass defect:

$$= [(26x1.0073\ amu) + 30x1.0087\ amu$$
$$+ (26x0.00055\ amu)] - 55.9349\ amu$$
$$= 0.5302\ amu$$

$$E = mc^2 = 0.5302\ amu x \frac{1.6605x10^{-27}\ kg}{amu} x (2.998x10^8\ m/s)^2$$
$$E = 7.913x10^{-11}\ J$$

$$7.913x10^{-11}\ J x \frac{1 MeV}{1.602x10^{-13}\ J} = 493.9 MeV$$

$$\frac{493.9 MeV}{56} = 8.820\ MeV/nucleon$$

Summary

- In nuclear reactions, we look at the changes in nuclear structure
- The nuclear binding energy is the energy needed to break the nucleus in to its components
- Stable atomic nuclei tend to have even numbers of protons and neutrons