Binding Energy

1. What force holds the nucleus together?

   The Strong Force.

2. Where is the energy for this binding force derived?

   From the nucleons (neutrons and protons). Remember that based on the quantum mechanical model, when you are down to the subatomic level, the difference between matter and energy is very grey. So when a nucleus combines some of the proton and neutron characteristics are used as energy to bind the nucleus together and the remaining portion is translated as mass. This leads to a different mass for a nucleus, once the particles have combined, than anticipated based on the mass of the individual protons and neutrons.

3. What do we look at to determine the binding energy?

   We look at the "mass defect" – the difference between the expected mass based on the total number of proton and neutrons in the nucleus and the actual measured mass.

4. What equation can be used to relate mass energy?

   $E = mc^2$

5. The sun radiates 3.9 x 10^{23}J of energy into space every second. What is the rate at which mass is lost from the sun?

$$E = 3.9 \times 10^{23}\ \text{J/s}$$

$$E = mc^2 \rightarrow m = \frac{E}{c^2}$$

$$m = \frac{(3.9 \times 10^{23}\ \text{J/s})}{(3.0 \times 10^{8}\ \text{m/s})^2} = \boxed{4.3 \times 10^{6}\ \text{kg/s}}$$

6. The most stable nucleus in terms of binding energy per nucleon is ^{56}Fe. If the atomic mass of ^{56}Fe is 55.9349 amu. Calculate the binding energy per nucleon for ^{56}Fe. (1 amu = 1.66054×10^{-27} kg)

m_n = 1.00866 amu m_p = 1.00728 amu m_e = 5.48580×10^{-4} amu

The binding energy depends on the mass defect. So the first thing we have to do is determine Δm.

Δm = "expected nuclear mass" – "actual nuclear mass"

"expected nuclear mass"

nuclear mass of ^{56}Fe = 26 (mass of a proton) + 30 (mass of a neutron)
mass = 26 (1.00728 amu) + 30 (1.00866 amu) = 56.4491 amu

"actual nuclear mass"

An important aspect of this question is that we are given the actual *atomic mass*. Though we frequently treat electrons as though they are mass deficient, they actually do contribute a small portion to he overall mass of an atom. However, electrons do not contribute to the binding energy that holds the nucleus together. This means when we deal with these kinds of problems we are only concerned with the mass of the nucleus. Thus means that when we are given the atomic mass of a substance we need to subtract the contribution that the electrons make.

actual nuclear mass of ^{56}Fe = 26 (mass of an electron)
mass = 55.9349 amu – 26 (5.48580×10^{-4} amu) = 55.9209 amu

$$\Delta m = 56.4491 \text{ amu} - 55.9209 \text{ amu} = 0.5285 \text{ amu} \; \frac{1.66054 \times 10^{-27} \text{ kg}}{1 \text{ amu}} = 8.775 \times 10^{-28} \text{ kg}$$

$$E = mc^2 = (8.775 \times 10^{-28} \text{ kg})\,(3.0 \times 10^{8} \text{ m/s})^2 = 7.898 \times 10^{-11} \text{ J}$$

The question asked for units of energy per nucleon. The nucleon value is equal to the total number of protons and neutrons in a nucleus. In the case of ^{56}Fe there are 56 nucleons.

$$\frac{7.898 \times 10^{-11}\ \text{J}}{56\ \text{nucleons}} = \boxed{4.41 \times 10^{-12}\ \text{J/nucleon}}$$