Preview of Period 9: Energy and Mass

9.1 Einstein's Equation, $E = Mc^2$

What happens to the mass of a substance that gains or loses energy?

9.2 Nuclear Processes

How can an atom's nucleus change?

What is the difference between physical, chemical, and nuclear changes?

9.3 Nuclear Forces

What holds nuclei together?

9.4 Nuclear Stability

Which nuclei are stable?

Forms of Energy

Mechanical Energy of Motion: The energy exhibited by objects in motion.

Thermal Energy: The unorganized energy of motion of vibrating atoms and molecules.

Sound Energy: The organized energy of motion of vibrating atoms and molecules.

Electrical Energy: The energy resulting from forces between charged particles.

Magnetic Energy: The energy resulting from the forces between magnets.

Radiant Energy: The energy resulting from vibrations of charges, such as radio waves, microwaves, or visible light.

Gravitational Potential Energy: The energy stored in raised objects, which could fall.

Strain Potential Energy: The energy stored in a stretched or compressed spring.

Chemical Energy: The energy available in the chemical bonds binding atoms together.

Electrical Potential Energy: The energy stored by static electric charges.

Nuclear Energy: Energy available in the nuclei of radioactive atoms.

Einstein's Equation relates mass and energy

The amount of energy contained in matter equals the mass times c^2 (c= the speed of light)

$$E = M c^2$$

E = energy (joules)

M = mass (kilograms)

c = the speed of light = 3×10^8 m/s or 186,000 miles/s

As we will see, this is probably the most important equation of the 20th century.

Act. 9.1 Einstein's Equation applied to stored potential energy

Does the mass of the radio change when energy is added to its spring?

The weight of an object equals the object's mass times the acceleration of gravity (*g*)

$$Weight = F = M g$$

F = force (newtons)

M = mass of object (kilograms)

g = acceleration of gravity = 9.8 m/s^2

Work is done when a force moves an object over some distance in the direction of the force.

$$W = F D$$

W = work (joules)

F = force applied (newtons)

D = distance moved in the direction of the force (meters)

Review of Atomic Structure

The nucleus of an atom contains nucleons – positively charged protons and neutral neutrons. The strong nuclear force holds the nucleons together in the nucleus.

The nucleus is surrounded by a cloud of negative electrons. The electromagnetic force binds the electrons to the nucleus.

The number of protons (Z) determines which element an atom is. Example: an atom with 6 protons is the element carbon.

Isotopes

Isotopes are species of atoms of a given element that have different numbers of neutrons.

Carbon-12 has 6 protons and 6 neutrons. $^{12}_{6}C$

Carbon-14 has 6 protons and 8 neutrons. $^{14}_{6}C$

$$^{A}_{Z}X$$

Z = the number of protons (identifies the element X)

A = the total number of nucleons (protons + neutrons)

A - Z = the number of neutrons (identifies the isotope of the element)

Nuclear Processes

Protons can be added to or removed from atomic nuclei.

> A neutron in the nucleus can be changed into a proton, or a proton can be changed into a neutron.

Since the number of protons (Z) determines which element an atom is, adding or removing protons changes the identity of the element.

Nuclear reactions involve changes to the nuclei of atoms that result in the formation of atoms of new elements.

Chemical changes involve making and breaking chemical bonds to create new molecules.

Physical changes involve no changes to the identity of atoms or molecules.

Energy Calculation: $E = Mc^2$

Energy released when nuclei form =

[(mass of unbound protons + neutrons)

– (mass of nucleus)] c^2

Energy = $[Z M_p + (A - Z) M_n - M_{nuc}] c^2$

M_p = **mass of a free proton = 1.6726×10^{-27} kg**

M_n = **mass of a free neutron = 1.6749×10^{-27} kg**

M_{nuc} = **mass of the assembled nucleus in kg**

Z = **number of protons in the nucleus**

$A\text{-}Z$ = **number of neutrons in the nucleus**

c^2 = **(speed of light)^2 = $(3 \times 10^8 \text{ m/s})^2$**

Binding Energy

Chemical changes involve making and breaking chemical bonds to create new molecules.

The binding energy of a molecule is the energy you must supply to break the molecule up into its constituent atoms.

Nuclear reactions involve changes to the nuclei of atoms that result in the formation of atoms of new elements.

The binding energy of a nucleus is the energy you must supply to break the nucleus up into free protons and neutrons.

Binding energy per nucleon $= \dfrac{\text{binding energy}}{\text{number of nucleons}}$

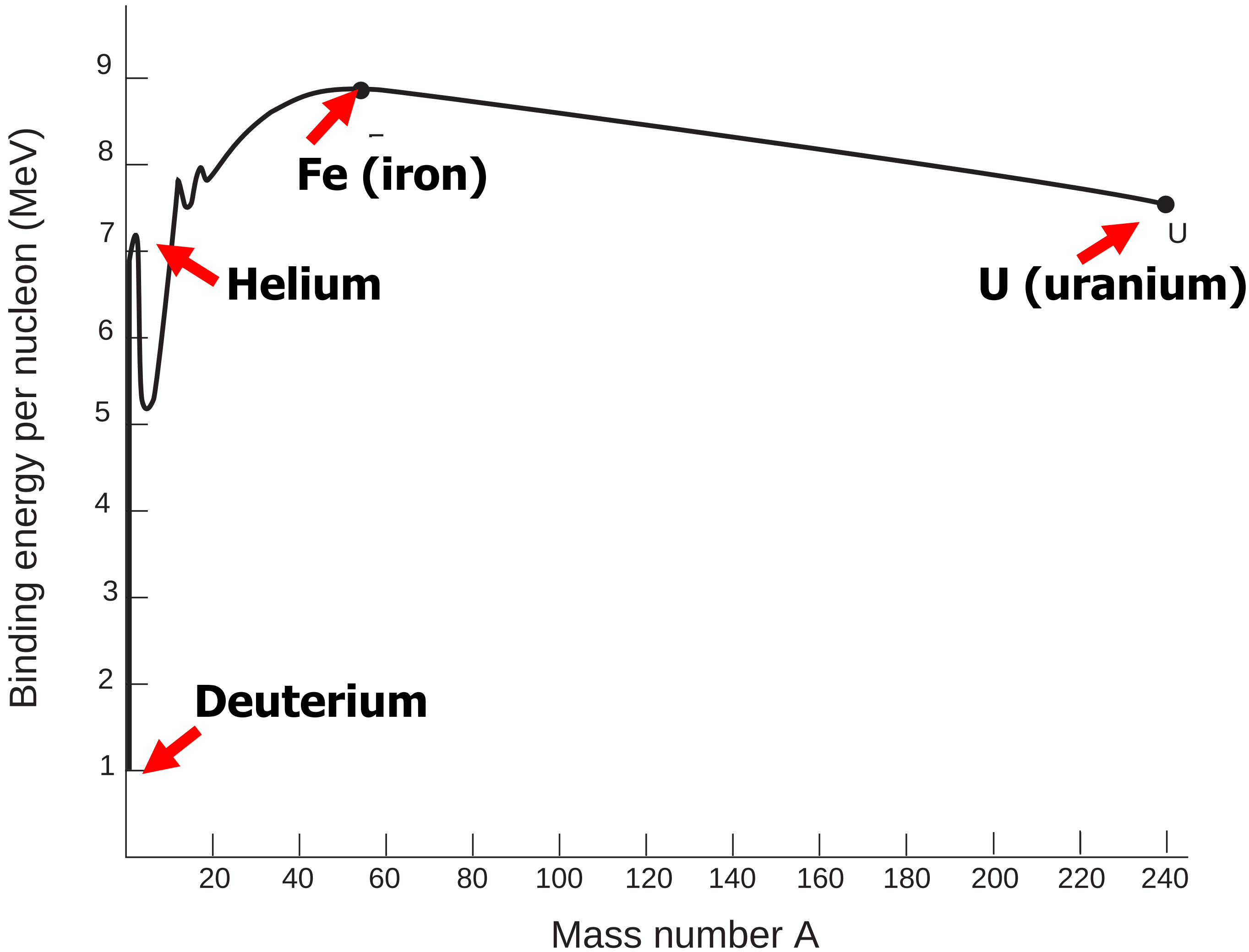
To convert units between mega electron volts (MeV) and joules, use:

$$1 \text{ Mev} = 10^6 \text{ eV} = 1.6 \times 10^{-13} \text{ joules}$$

or

$$1 \text{ joule} = 6.25 \times 10^{12} \text{ MeV}$$

Nuclear Binding Energy Graph



(Total number of nucleons)

Which Nuclei are Stable?

Stable nuclei have

- 83 or fewer protons.
- the same number of protons and neutrons for light elements with 20 or fewer protons.
- more neutrons than protons for elements with more than 20 protons.

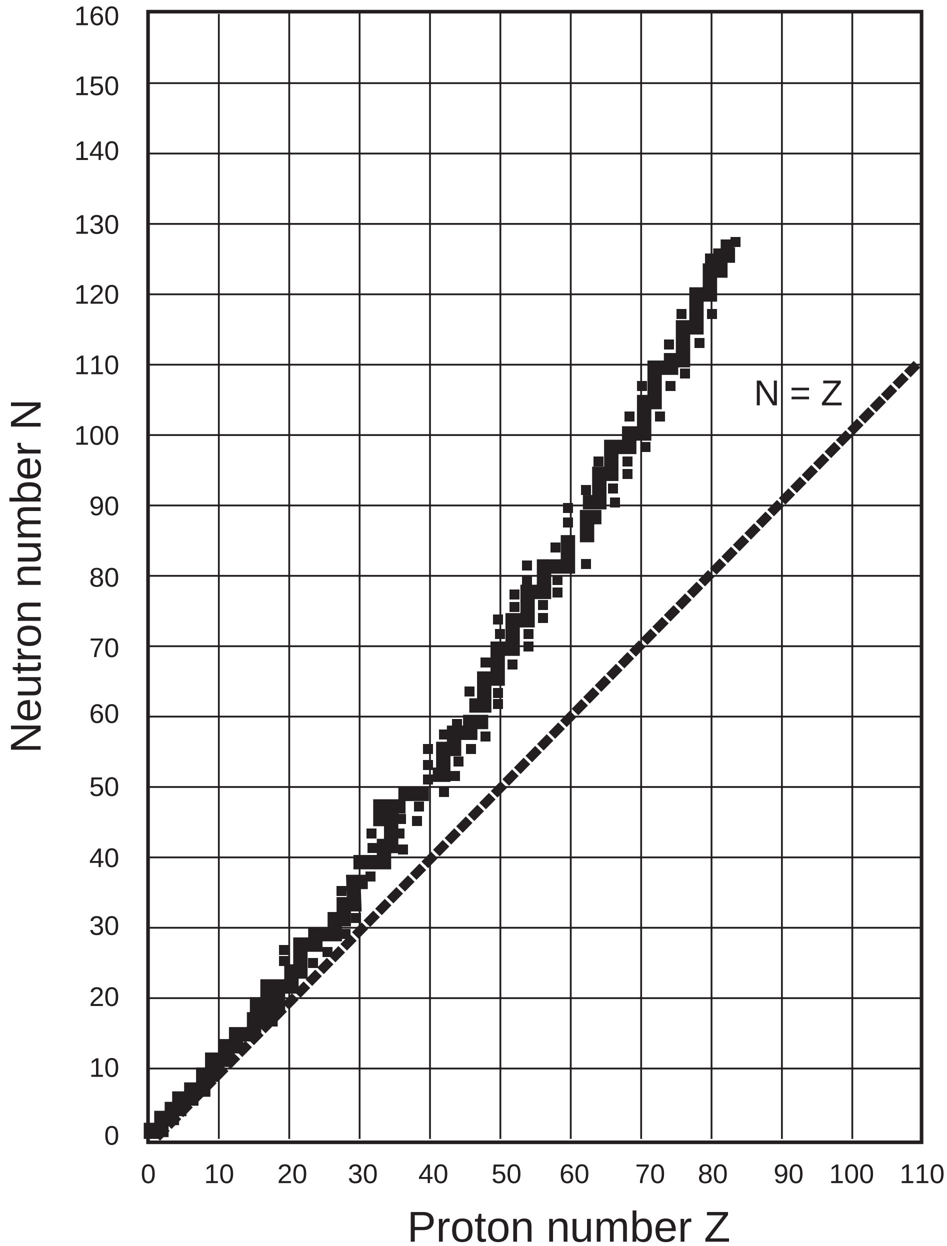
Unstable nuclei become more stable by changing protons into neutrons or neutrons into protons.

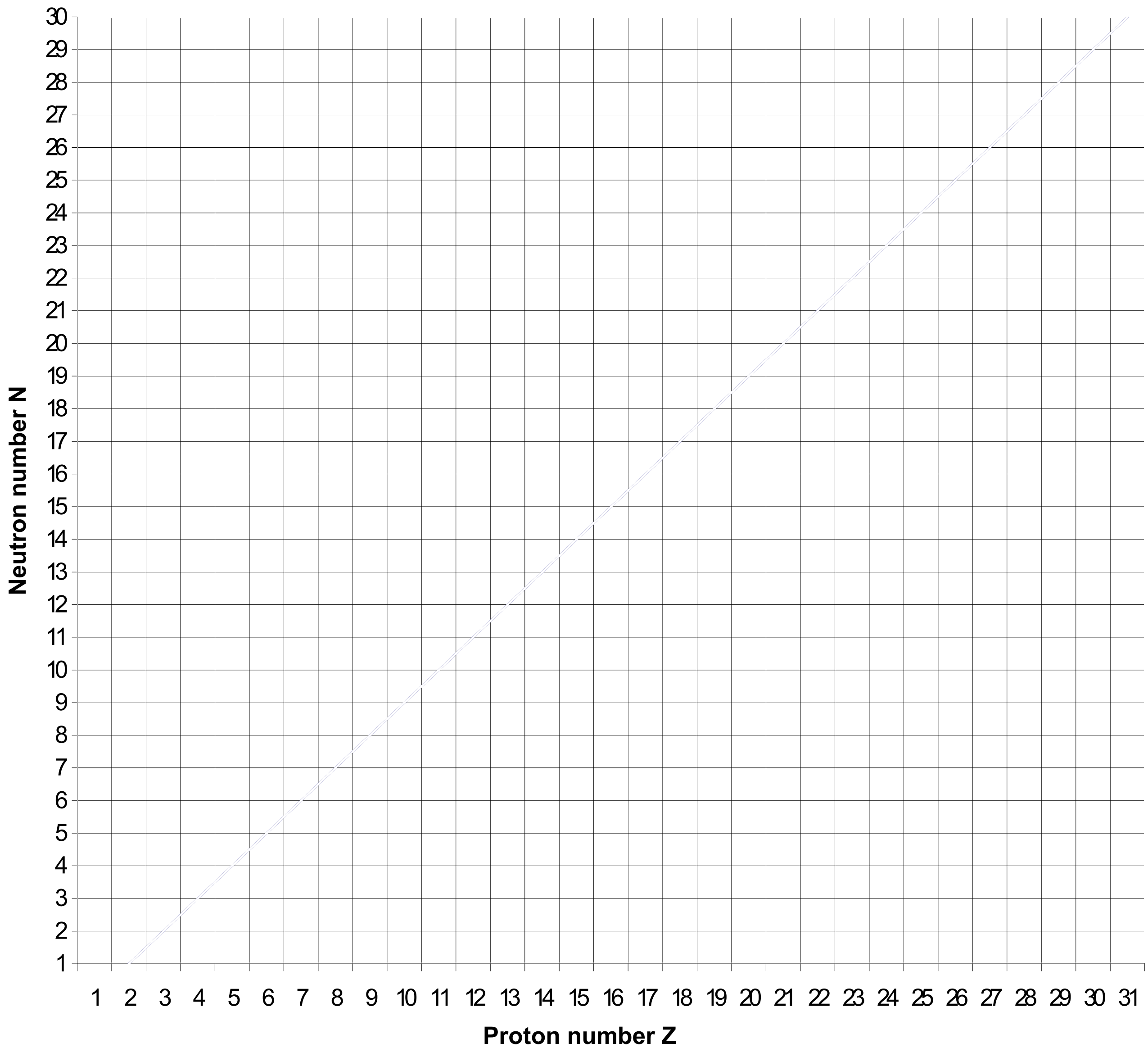
Strong and Weak Nuclear Forces

The strong nuclear force binds nucleons together into the nucleus.

The weak nuclear force can change a proton into a neutron or a neutron into a proton.

Graph of neutron number N vs proton number Z for stable nuclei




Neutron number N
Proton number Z

Period 9 Summary

9.1: **Atoms consist of a nucleus of nucleons – positively charged protons and neutrons with no charge. Surrounding the nucleus is a cloud of electrons.**

The number of protons (Z) determines which element an atom is.

9.2: **Chemical changes involve making and breaking chemical bonds to create new molecules.**

Nuclear reactions involve changes to the nuclei of atoms that result in the formation of atoms of new elements.

9.3: **The strong nuclear force binds nucleons into a nucleus by overcoming the electromagnetic repulsion of the positively charged protons.**

9.4: **Isotopes are nuclei of the same element (same number of protons, Z) that have different numbers of neutrons (N)**

Nuclei with more than 83 protons are unstable.

Stable nuclei of smaller atoms tend to have the same number of neutrons and protons.

Stable nuclei of large atoms that contain many protons have more neutrons than protons.

Period 9 Review Questions

R.1 **Suppose that the size of an atom were represented by the diameter of the OSU oval (about 250 meters). On this scale, how large would the nucleus of the atom be? What sort of object could represent it?**

R.2 **Why does an H_2 molecule have very nearly the same mass as a deuterium atom?**

R.3 **What is the difference between a chemical change and a nuclear process? Why is the energy released when H atoms combine to form H_2 molecules so much less than the energy released when protons and neutrons combine to form deuterium molecules?**

R.4 **If you know the mass of a nucleus and the number of protons and neutrons, how would you find the binding energy?**

R.5 **What is an isotope of an element? Which of the following isotopes of carbon – $^{12}_{6}C$ or $^{14}_{6}C$ – is stable? Why?**

R.6 **Why do stable nuclei of large atoms that contain many protons have more neutrons than protons?**