Nuclear forces

In the Bohr model of the atom, the nucleus consists of positively-charged protons and electrically neutral neutrons. Since both protons and neutrons exists in the nucleus, they are both referred to as nucleons. One problem that the bohr model of the atom presented was accounting for an attractive force to overcome the repulsive force between protons.

Two forces present in the nucleus are:

1. Electrostatic forces between charged particles.
2. Gravitational forces between any two objects that have mass
   It is possible to calculate the magnitude of the gravitational force and electrostatic force based upon principles from classical physics

Newton stated that the gravitational force between two bodies is directly proportional to the masses of the two bodies and inversely proportional to the square of the distance between the bodies. This relationship is shown in the equation below:

$$F_g = \frac{G\ m_1\ m_2}{r^2}$$

Where:

F_g= gravitational force (newtons)

m_1= mass of the first body (kilograms)

m_2= mass of the second body (kilograms)

G= gravitational constant ($6.67*10^{-11}$ $N.m^2/kg^2$)

R= distance between particles (meters)

E-mail: ahed.hameed.jaaz@uomus.edu.iq

This equation illustrates the larger the masses of the objects or the smaller the distance between the objects the greater the gravitational force. So even Though the masses of nucleons are very small, the fact that the distance between nucleons is extremely short may make the gravitational force significant. It is necessary to calculate the value of gravitational force and compare it to the value for other forces to determine the significance of the gravitational force and compare it to the value of other forces to determine the significance of the gravitational force in the nucleus The gravitational force between two protons that are separated by a distance of 10^{-20} meters is about 10^{-24} Newton.

Coulombs Law can be used to calculate the force between two protons. The electrostatic force is directly proportional to the electrical charges of the two particles and inversely proportional to the square of the distance between the particles. Coulombs Law is stated as the following equation.

$$F_e = \frac{K\ Q_1\ Q_2}{r^2}$$

Where

F_e = electrostatic force (Newton)

K = electrostatic constant ($9.0*10^9$ $N.m^2/C^2$)

Q_1 = charge of first particle (coulombs)

Q_2 = charge of second particle (coulombs)

r = distance between particles (meters)

Using this equation, the electrostatic force between two protons that are separated by a distance of **10^{-20}** meters is about **10^{12}** Newton. Comparing this result with the

E-mail: ahed.hameed.jaaz@uomus.edu.iq

calculation of the gravitational force (**10^{-24}** Newton) shows that the gravitational force is so small that it can be neglected.

If only the electrostatic and gravitational forces existed in the nucleua, then it would be impossible to have stable nuclei composed of protons and neutrons. The gravitational forces are much too small to hold the nucleons together compared to the electrostatic forces repelling the protons. Since stable atoms of neutrons and protons do exist, there must be attractive force acting within the nucleus. This force called the **nuclear force.** The nuclear force is a strong attractive that is independent of charge. It acts equally only between pairs of neutrons, pairs of protons, or a neutron and a proton. The nuclear force has a very short range; it acts only over distances approximately equal to the diameter of the nucleus (10^{-13}) cm. The attractive nuclear force between all nucleons drops off with distance much faster than the repulsive electrostatic force between protons. Table below shows the interaction and range of each force.

TABLE 3
Forces Acting in the Nucleus

Force	Interaction	Range
Gravitational	Very weak attractive force between all nucleons	Relatively long
Electrostatic	Strong repulsive force between like charged particles (protons)	Relatively long
Nuclear Force	Strong attractive force between all nucleons	Extremely short

In stable atoms, the attractive and repulsive forces in the nucleus balance. If the forces do not balance, the atom cannot be stable, and the nucleus will emit radiation in an attempt to achieve a more stable configuration.

E-mail: ahed.hameed.jaaz@uomus.edu.iq

Mass defect

Careful measurements have shown that the mass of a particular atom is always slightly less than the sum of the masses of the individual neutrons, protons, and electrons of which the atom consists. The difference between the mass of the atom and the sum of the masses of its part is called the mass defect (Δm). The mass defect can be calculated using equation (1_1). In calculating the mass defect it is important to use the full accuracy of mass measurements because the difference in mass is small compared to the mass of the atom. Rounding off the masses of atoms and particles to three or four significant digits prior to the calculation will result in a calculated mass defect of zero.

$$\Delta m = [\, Z (m_p+m_e) + (A-Z)\, m_n] - m_{atom} \qquad (1\text{-}1)$$

Where:
Δm = mass defect (amu)
m_p = mass of a proton (1.007277)
m_n = mass of neutron (1.008665)
m_e = mass of electron (0.00054859)
m_{atom} = mass of nuclide ${}^{A}_{Z}X$ (amu)
Z = atomic number (number of proton)
A= mass number (number of nucleons)

Example:

Calculate the mass defect for lithium-7. The mass of lithium-7 is 7.016003 amu.

Solution:

$$\Delta m = [\, Z (m_p+m_e) + (A-Z)\, m_n] - m_{atom}$$

$$\Delta m = [\, 3(1.007826 \text{ amu}) + (7-3)\, 1.008665 \text{ amu}] - 7.016003 \text{ amu}$$

$$\Delta m = 0.0421335$$

E-mail: ahed.hameed.jaaz@uomus.edu.iq

Binding energy

The loss, or mass defect. Is due to the conversion of mass to binding energy When the nucleus is formed. Binding energy is defined as the amount of energy that must be supplied to a nucleus to completely separate its nuclear particle (nucleons). It can also be understood as the amount of energy that would be released if the nucleus was formed from the separate particle. Binding energy is the energy equivalent of the mass defect. Since the mass defect was converted to binding energy (BE) when the nucleus was formed, it is possible to calculate the binding energy using a conversion factor derived by the mass-energy relationship from Einstein Theory of relativity. Einstein's famous equation relating mass and energy $E=mc^2$ where c is the velocity of light ($c=2.998*10^8 m/sec$). The energy equivalent of *1 amu* can be determined by inserting this quantity of mass into Einstein's equation and applying conversion factors.

$$E = mc^2$$

$$= 1 \text{ amu} \left(\frac{1.6606 \times 10^{-27} \text{ kg}}{1 \text{ amu}}\right)\left(2.998 \times 10^8 \frac{\text{m}}{\text{sec}}\right)^2$$

$$= 1.4924 \times 10^{-10} \text{ J} \left(\frac{1 \text{ MeV}}{1.6022 \times 10^{-13} \text{ J}}\right)$$

$$= 931.5 \text{ MeV}$$

Conversion Factors:

1 amu	=	1.6606×10^{-27} kg
1 newton	=	1 kg-m/sec^2
1 joule	=	1 newton-meter
1 MeV	=	1.6022×10^{-13} joules

E-mail: ahed.hameed.jaaz@uomus.edu.iq

Since 1 amu is equivalent to 931.5 MeV of energy, the binding energy can be calculated using Equation (1-2).

$$\text{B.E.} = \Delta m \left(\frac{931.5 \text{ MeV}}{1 \text{ amu}}\right) \quad (1\text{-}2)$$

Example:

Calculate the mass defect and binding energy for uranium-235. One uranium-235 atom has a mass of 235.043924 amu.

Solution:

Step 1: Calculate the mass defect using Equation (1-1).

$$\Delta m = \left[Z (m_p + m_e) + (A - Z) m_n\right] - m_{atom}$$

$$\Delta m = \left[92 (1.007826 \text{ amu}) + (235 - 92) 1.008665 \text{ amu}\right] - 235.043924 \text{ amu}$$

$$\Delta m = 1.91517 \text{ amu}$$

Step 2: Use the mass defect and Equation (1-2) to calculate the binding energy.

$$\text{B.E.} = \Delta m \left(\frac{931.5 \text{ MeV}}{1 \text{ amu}}\right)$$

$$= 1.91517 \text{ amu} \left(\frac{931.5 \text{ MeV}}{1 \text{ amu}}\right)$$

$$= 1784 \text{ MeV}$$

E-mail: ahed.hameed.jaaz@uomus.edu.iq

Energy Levels of Atoms:

The electrons that circle the nucleus move in fairly well defined orbits. Some of these electrons are more tightly bound in the atom than others. For example, only 7.38 eV is required to remove the outermost electron from a lead atom, while 88.000 eV is required to remove the innermost electron. The process of removing an electron from an atom is called **ionization**, and the energy required to remove the electron is called the **ionization energy**.

In a neutral atom (number of electron =z) it is possible for the electrons to be in a variety of different orbits, each with a different energy levels. The state of lowest energy is the one in which the atom is normally found and is called the ground state. When the atom possesses more energy than its ground state energy. It is said to be an excited state.

An atom cannot stay in the excited state for an indefinite period of time. An excited atom will eventually transition to either a lower energy excited state, or directly to its ground states, by emitting a discrete bundle of electromagnetic energy called an x-ray. The energy of the x-ray will be equal to the different between the energy levels of the atom and will typically range from several eV to 100,000 eV in magnitude.

Energy Levels of the Nucleus

The nucleons in the nucleus of an atom, like the electrons that circle the nucleus, exist in shells that correspond to energy state. There is a state of lowest energy shells of the nucleus are less defined and less understood than those of the electron. There is a state of lowest energy (the ground state) and discrete possible excited states for a nucleus. Where the discrete energy states for the electrons of an atom are measured in eV or keV, the energy levels of the nucleus are considerably greater and typically measured in MeV. A nucleus that is in the excited state will not remain at that energy level for an indefinite period. Like the electrons in the excited atom, the nucleons in an excited nucleus will transition towards their lowest energy configuration and in doing so emit a discrete bundle of electromagnetic radiation called a gamma ray (γray) are their energy levels and whether they are emitted from the electron shell or from the nucleus. The ground state and the excited states of a nucleus can be depicted in a nuclear energy-level diagram. The nuclear energy-level diagram consists of a stack of horizontal bar, one bar for each of the excited states of the nucleus. The vertical distance between the bar representing excited state and the bar representing the ground state is proportional to the energy level of the excited state with respect to the ground state. This difference in the energy between the ground state and the excited state is called the excitation energy of the excited state. The ground state of a nuclide has **zero** excitation energy. The bars for the excited states are labeled with their respective energy levels. Figure 7 is the energy levels diagram for nickel-60

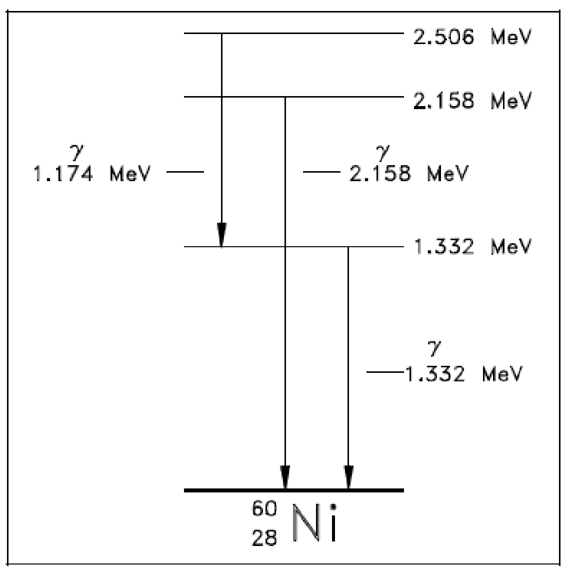

Figure 7 Energy Level Diagram - Nickel-60

E-mail: ahed.hameed.jaaz@uomus.edu.iq