BASIC CONCEPT OF NUCLEAR PHYSICS IN SCHOOL COURSE

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ABSTRACT

In this article, the author reveals the basic concepts of nuclear physics in a school course.

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INTRODUCTION, LITERATURE REVIEW AND DISCUSSION

When selecting the content of educational material, it is necessary to take into account its relevance to general education of students, as well as the need to avoid overloading students.

The correct explanation of the above phenomena will help the introduction and formation of concepts about the binding energy of nucleons in the nucleus.

Using the law of proportionality of mass and energy of Einstein, we carry out the following reasoning.

If we have a system of interacting bodies, then the mass of this system is not equal to the sum of the masses of the bodies entering the system, since there is still an interaction energy in the system.

For example, a certain volume of crystalline substance consisting of molecules has energy, which is composed of the energy of these molecules and the interaction energy of the molecules.

By melting or evaporating a crystal, separating it into individual molecules, we do positive work against the forces of attraction of the molecules, therefore, the energy of the separated molecules is greater than the energy of the molecules combined into a crystal system.

This means that the sum of the masses of the molecules is larger than the mass of the crystal, but this difference in mass is not detected by measurements, since the interaction energy of the molecules is much less than their rest energy.
In general, the energy of the system is expressed by the formula

$$\mathrm{E} = \sum_i \mathrm{E}i + W,$$

where Ei are the energies of the components of the system, and W is the energy of their interaction.

If the interaction energy is a positive quantity, then
$\mathrm{E} > \sum_i \mathrm{E}i$, if W- negative value, then $\mathrm{E} < \sum_i \mathrm{E}i$.

So, for example, the energy of a system of two electric charges q1 and q2 is the sum of the energy of the first charge E1, the energy of the second E2 and the energy from the interaction

$$W = k\frac{q_1 \cdot q_2}{r}$$

$$\text{т.е. } E = E_1 + E_2 + k\frac{q_1 \cdot q_2}{r}$$

if the charges q1 and q2 are of the same sign, then the energy of their interaction will be negative and, therefore, $E < E_1 + E_2$.

In a system of particles between which tensile forces act, external forces work to crush the system into these particles, and therefore the energy reserve of the system increases.

The work done by external forces and spent on the separation of such a system into its component parts (destruction of the crystal lattice, separation of electrons from an atom, separation of a nucleus into protons and neutrons) is called the binding energy of the system. Since in the process of work the energy reserve of the system$\sum_i Ei + EE_{св}$.,
those. the sum of the masses of the separated particles is greater than the mass of the system by the amount of binding energy divided by c2. This excess of the sum of the masses of particles over the mass of the system is sometimes called a mass defect. Denote the mass defect Δm, then

$$\Delta m = \sum_i m_i - m = \frac{E_{св}}{c^2}$$

So, for example, the sum of the masses of two protons and two neutrons entering the nucleus of a helium atom is greater than the mass of the helium nucleus. The mass difference in this case is equal to:

$$\Delta m = 2m_p + 2m_n - m_я$$

where m_p is the mass of the proton, m_n is the mass of the neutron, m_i is the mass of the nucleus of the helium atom.

Indeed, the masses of the proton, neutron, and helium nuclei were determined experimentally with great accuracy and independently of each other (by the mass spectral method), and the mass difference, as well as the binding energy of this system of particles — the helium nucleus — were calculated.
The mass defect Δm for any nucleus can be calculated by the formula:

$$\Delta m = Zm_p + (A - Z)m_n - m_я$$

and binding energy - by the formula:

$$E_{св} = \Delta mc^2 = [Zm_p + (A - Z)m_n - m_я]c^2.$$

The concept of binding energy is one of the most important concepts of nuclear physics. In addition to calculating nuclear reactions with its help, and estimating the energy released during reactions, it also serves to estimate the magnitude of nuclear forces acting between nucleons in nuclei.

We give a calculation that allows us to compare the values of nuclear forces and chemical bonding forces of atoms in a molecule.

Binding energy of nucleons in a helium nucleus: $E_{св} = (2 \cdot 1{,}00759 + 2 \cdot 1{,}00898 - 4{,}00387) \cdot 1{,}66035 \cdot 10^{-27}кг \cdot 9 \cdot 10^{16}\frac{м^2}{c^2} \approx 4{,}5 \cdot 10^{-12}kj \approx 28МэВ.$
We calculate the binding energy of chemical compounds from the following conditions: when one kilomol of water is formed, a chemical reaction proceeds

$$2H_2 + O_2 \rightarrow 2H_2O + 5{,}75 \cdot 10^5 kj.$$

The conditions of the problem allow us to calculate the binding energy of a water molecule. Using the Avogadro number, which shows how many molecules of a substance are contained in its gram molecule, we calculate:

$$E_{\text{св}} = \frac{5{,}75 \cdot 10^{2}}{6{,}02 \cdot 10^{23}} = 0{,}96 \cdot 10^{21}(kj) = 6\ \text{эВ}$$

So, the binding energy of the helium nucleus due to nuclear forces is 28 MeV, and the binding energy of atoms in the water molecule is 6 MeV., I.e. about 5 million times less. This suggests that a nucleus is incomparably stronger formation than a molecule, and it is the binding energy that allows us to estimate the colossal strength of atomic nuclei.

As can be seen from the analysis of the content of the question on the binding energy, for the presentation of the question, references to systems of interacting particles and the attraction of polymers of various interaction forces (crystals, systems of charged bodies) are necessary. Therefore, we consider it methodologically more expedient to begin the study of the concept of binding energy in the topic "Electric charges and electric field" by introducing the concept of the interaction energy of charged bodies and the formula:

$$W = k\frac{q_1 \cdot q_2}{r}$$

Here one can also draw examples from the already studied molecular physics for the concept of binding energy. Then, when studying the structure of the nucleus, repeat the law of proportionality of mass and energy, the previously introduced concepts of the binding energy of a system of interacting bodies and consider the concept of the binding energy of the nucleon in the nucleus and the specific binding energy.

The concept of the binding energy of nucleons in the nucleus should precede familiarization with the peculiarities of nuclear forces. Indeed, we judge the magnitude of the latter by the binding energy of nuclei in comparison with the energy of molecular and chemical bonds, and not by direct measurements.

Studying the concept of specific binding energy, calculating it in tasks, examining a graph of its dependence on the number of particles in the nucleus is necessary for consciously understanding the issue of nuclear reactions, justifying the exothermic nature (with energy output) of heavy fission reactions and fusion of light nuclei. On the other hand, the concept of the binding energy of nucleons in the nucleus contributes to the understanding of the law of proportionality of mass and energy, and also to the development of the concept of energy.

When introducing nuclear forces into the school curriculum, one should learn that the nature-nuclear forces are currently unknown. However, there is a number of information about their properties. First of all, it should be pointed out that these are forces of non-electric origin, since, despite the absence of an electric charge from the neutron, there is a stable system consisting of a proton and a neutron, namely, a deuteron. Nuclear forces cannot be gravitational either, have a magnetic origin, since the binding energy of nucleons in the nucleus would also be less than that calculated on the basis of experimental data.

Nuclear force-forces short-range; their radius of action is of the order of 10-15 m. This was established from experiments on the scattering of neutrons and α-particles by different nuclei.

Of great importance for nuclear theory is the establishment of the so-called charge independence of nuclear forces, which consists in the fact that the nuclear forces acting between a proton and a neutron are the same as the forces acting between a proton-proton and a neutron-neutron pair.

The charge independence of nuclear forces can be easily explained on the basis of a comparison of the binding energy of tritium nuclei 1H3 and helium isotope 2He3. Their binding energies are equal to 8.448 and 7.724 MeV, respectively. Knowing that there is only one proton in the tritium nucleus, which means that there are no nucleon repulsive forces, we can assume that the binding energy in it is entirely due to nuclear forces. There is 2He3 in the nucleus for a proton, the potential energy of their Coulomb interaction can be calculated by the formula:

$$W = k\frac{e^2}{r}$$

where r = 1.5 • 10-15 m (natural value of the core diameter). It is equal to 0.9 MeV. Therefore, the Coulomb forces reduce the binding energy of the helium nucleus by 0.9 MeV compared to the tritium nucleus, where these forces are absent. If there were this decrease, then the binding energy of the helium nucleus would be equal to 7.724 MeV + 0.9 MeV = 8.624 MeV, i.e. would be the same as the tritium core.
It follows that the energy of nuclear interaction depends on the nucleon charge. The property of nuclear forces-saturation can be explained by referring to the graphs of the dependence of the specific binding energy of the nucleus on the mass number, from which it can be seen that there is no quadratic dependence between these values (Fig. 1).

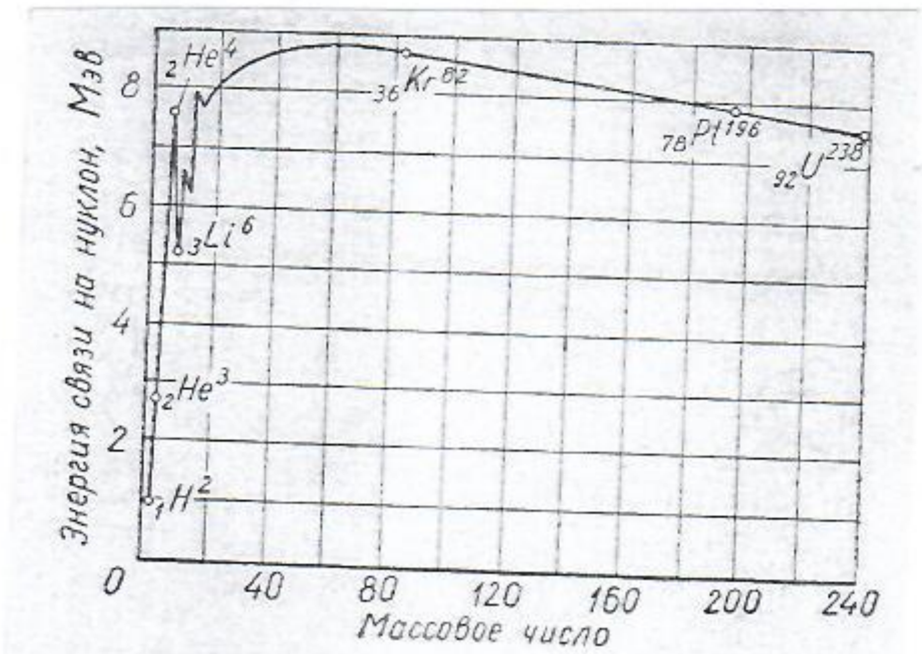

Fig. 1. The binding energy per nuclear particle as a function of the number of particles in the nucleus.

An examination of some properties of nuclear forces suggests that nuclear material resembles a liquid in its properties, and a core is a drop of liquid.

Of the listed properties of nuclear forces, two properties: their large value in comparison with gravitational, electric and magnetic forces, as well as their small radius of action, should be considered in the school course.

Based on this knowledge, it is possible to implement a deductive approach to the study of nuclear reactions. For the school course, the reactions that are of the greatest importance in nuclear energy are selected: the reactions of fission of heavy nuclei and synthesis of the lungs.

So, consideration of the concept of binding energy in a school course will explain many of the main issues studied in the course of nuclear physics.

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