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- 13.00.00 Pedagogika fanlari
- 13.00.01 Pedagogika nazariyasi. Pedagogik ta'limotlar tarixi
- 13.00.02 Ta'lim va tarbiya nazariyasi va metodikasi (sohalar bo'yicha)
- 13.00.03 Maxsus pedagogika
- 13.00.04 Jismoniy tarbiya va sport mashg'ulotlari nazariyasi va metodikasi
- 13.00.05 Kasb-hunar ta'limi nazariyasi va metodikasi
- 13.00.06 Elektron ta'lim nazariyasi va metodikasi (ta'lim sohaları va bosqichlari bo'yicha)
- 13.00.07 Ta'limda menejment
- 13.00.08 Maktabgacha ta'lim va tarbiya nazariyasi va metodikasi
- 13.00.09 Ijtimoiy pedagogika
- 07.00.00 Tarix fanlari
- 19.00.00 Psixologiya fanlari
- 01.00.00 Fizika-matematika fanlari
- 02.00.00 Kimyo fanlari
- 03.00.00 Biologiya fanlari
- 09.00.00 Falsafa fanlari
- 10.00.00 Filologiya fanlari
- 11.00.00 Geografiya fanlari

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STUDYING THE ROLE OF MAGIC NUMBERS AND NUCLEON SHELLS IN NUCLEAR STRUCTURE

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Annotatsiya: This article examines the role of magic numbers and nucleon shells in the formation of nuclear structure. Based on the nuclear shell model, the stability of nuclei with closed nucleon shells corresponding to the magic numbers of protons and neutrons is analyzed. It is demonstrated that the presence of completely filled shells leads to enhanced nuclear stability, which is manifested in binding-energy anomalies, even-spin characteristics, and a reduced probability of nuclear decay.

Kalit so'zlar: magic numbers, nucleon, proton, neutron, nuclear shell model, nuclear stability, binding energy, spherical symmetry.

Abstract: Ushbu maqolada yadro tuzilishini shakllantirishda magik sonlar va nuklon qobiqlarining roli tahlil qilinadi. Yadroning qobiq modeli asosida proton va neytronlarning magik sonlariga mos keluvchi yopiq nuklon qobiqlariga ega yadrolarning barqarorligi o'rganiladi. To'liq to'ldirilgan qobiqlarning mavjudligi yadro barqarorligining ortishiga olib kelishi, bu holat bog'lanish energiyasi anomaliyalarida, juft-spin xususiyatlarda hamda yadro parchalanish ehtimolining kamayishida namoyon bo'lishi ilmiy asosda ko'rsatib berilgan.

Key words: magik sonlar, nuklon, proton, neytron, yadro qobiq modeli, yadro barqarorligi, bog'lanish energiyasi, sferik simmetriya.

Аннотация: В данной статье рассматривается роль магических чисел и нуклонных оболочек в формировании структуры атомного ядра. На основе оболочечной модели ядра проводится анализ устойчивости ядер с замкнутыми нуклонными оболочками, соответствующими магическим числам протонов и нейтронов. Показано, что наличие полностью заполненных оболочек приводит к повышению ядерной стабильности, что проявляется в аномалиях энергии связи, чётно-спиновых характеристиках и снижении вероятности ядерных распадов.

Ключевые слова: магические числа, нуклон, протон, нейтрон, оболочечная модель ядра, ядерная устойчивость, энергия связи, сферическая симметрия.

INTRODUCTION

In nuclear physics, the study of the internal structure of the atomic nucleus and the interaction of nucleons – protons and neutrons – is one of the important directions of modern theoretical and applied research. The theory of magic numbers makes it possible to achieve a deeper understanding of the microscopic properties of nuclear structure, to identify stable isotopes, and to predict the outcomes of nuclear reactions. This theory is also essential for improving nuclear models, studying the synthesis of new elements, and analyzing nuclear stability in astrophysical processes. Therefore, in this work, the role of magic numbers and nucleon shells in nuclear structure, their influence on stability, and their significance in nuclear models are subjected to scientific analysis.

LITERATURE REVIEW

The conceptual significance of magic numbers lies in their ability to relate many bulk nuclear properties – stability, shapes, and spectroscopy – to a limited set of organizing principles: mean-field level ordering, residual interactions, and correlations. This mechanism was established in the classical works of Maria Goeppert Mayer and of Haxel–Jensen–Suess (1949–yil). Mayer's papers explicitly connect stability systematics to closed shells and demonstrate how a strong spin–orbit term resolves the discrepancy observed in simple central potentials.

The “Mayer–Jensen” shell model originated as an independent-particle model (IPM), in which nucleons occupy orbitals within a mean field, with shell gaps occurring at the magic numbers. However, real nuclei do not behave as perfectly independent-particle systems. Residual interactions give rise to correlations such as pairing, multipole collectivity, and configuration mixing. Consequently, the modern nuclear shell model is generally formulated as a configuration-interaction problem within a truncated valence space (core + valence nucleons + effective interaction). A major synthesis of this perspective is presented in the comprehensive review by Caurier, Martínez-Pinedo, Nowacki, Poves, and Zuker (2005–yil), which frames the shell model as a unified theoretical approach capable of reproducing both single-particle and collective phenomena when effective interactions and valence spaces are appropriately defined.

RESEARCH METHODOLOGY

The atomic nucleus is the central part of matter, consisting of protons and neutrons, i.e., nucleons. The nucleons forming the nucleus, under the influence of strong interactions (nuclear forces), occupy specific energy states. These states are organized in the form of nucleon shells, analogous to electron shells in atoms. The nucleon shell model is one of the principal theoretical models used to explain nuclear structure.

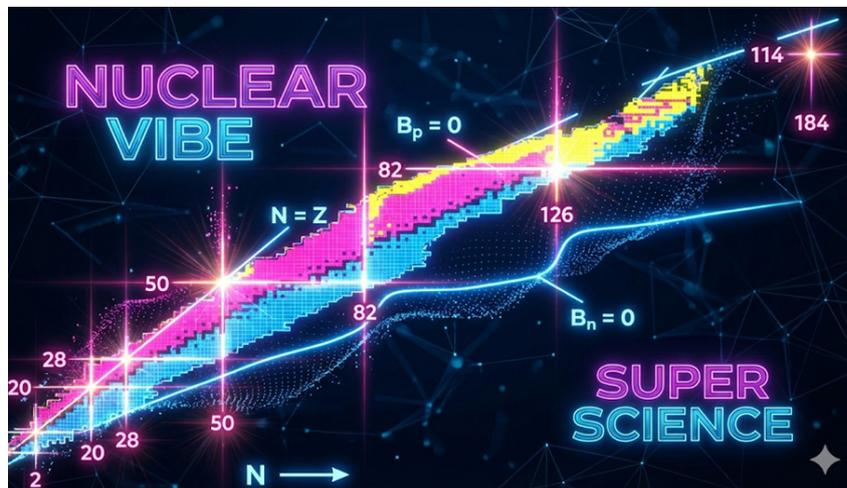
Magic numbers represent the numbers of protons or neutrons that correspond to maximally stable configurations in completely filled shells. According to experimental results, the magic numbers are 2, 8, 20, 28, 50, 82, and 126. When N or Z equals these values, the spectra of such nuclei differ sharply from those of neighboring even–even nuclei. Nuclei with one magic number (N or Z equal to a magic number) or double-magic nuclei (both N and Z equal to magic numbers) exhibit distinctive properties that remained unexplained for many years; hence, they are referred to as magic numbers [1].

The dependence of the reduced quadrupole moments of atomic nuclei, the energy of the first excited states, the specific binding energy, the energy of extracting a nucleon from the nucleus, and the distribution of nuclei in nature on the number of neutrons and protons proves our point. The energy required to extract a neutron from the nucleus is measured by the difference in binding energies between the (Z,N) and (Z,N-1) nuclei, i.e., the analysis of the difference

$$S_n(Z, N) = E_{\text{bon}}(Z, N) - E_{\text{bon}}(Z, N - 1)$$

In this case, from the Weizsäcker formula for bond energies

$$E_{\text{con}} = a_{\text{surf}} \cdot A - a_{\text{land}} A^{2/3} - 1/2 a_{\text{symmet}} (N - Z)^2/A - a_{\text{dyn}} Z^2/A^{1/3}$$



Picture 1: Shows the analysis of the difference in $S_n(Z, N)$ values between isotopes

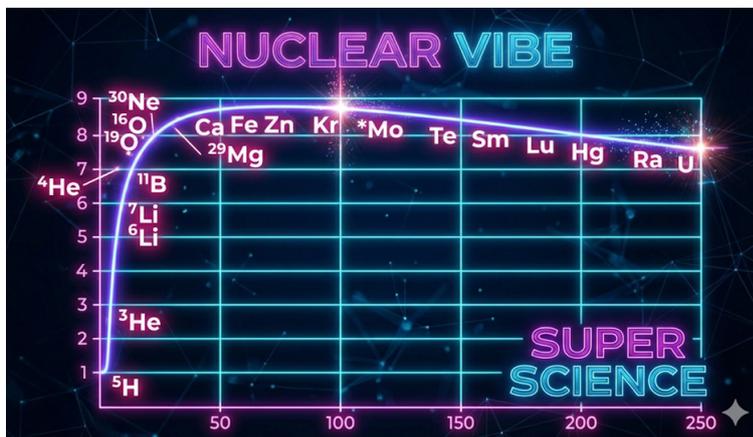
between the obtained results and the experimentally measured corresponding $S_n(Z, N)$ (ΔE) depending on the number of neutrons in the nucleus is shown in Picture 1.

The first term in formula (2) above is called the volume term and reflects that an increase in the number of nucleons in the nucleus leads to an increase in the total binding energy. The second term reflects an increase in the surface area of the nucleus and a decrease in binding energy, and the larger the surface area, the greater the number of nucleons located on it, and their separation requires less energy than the separation of the nucleon located in the middle. The third term is called a symmetrical term, and $N=Z$ reflects that the nuclei are more stable than the others. Finally, the fourth term, called the Coulomb term, reflects the fact that the number of protons leads to an increase in the repulsion between them and a decrease in the binding energy.



Although this formula has been supplemented with new terms in accordance with modern experimental results and even in various forms, the results calculated for the values of the constants included in it (independent of N , Z , A) turned out to be quite consistent with the smoothly changing part of the measured coupling energies in the experiments.

$$\begin{aligned} a_v &= 15,6 \text{ MeV} \\ a_{\text{con}} &= 17,2 \text{ MeV} \\ a_{\text{symm}} &= 22,5 \text{ MeV} \\ a_{\text{coul}} &= 0,70 \text{ MeV} \end{aligned}$$



Picture 2: Specific binding energy

The binding energy per nucleon in the nucleus is called the specific energy and is defined as

$$W(N,Z) = E_{\text{con}} / A$$

The dependence of the specific binding energy on A , determined experimentally, is shown in pic. 2.

As can be seen from the picture, it is energetically more favorable for light nuclei ($A < 4$) to combine to form a heavier nucleus, or for heavy nuclei ($A > 200$) to split into lighter nuclei. Secondly, for some values of A (for some values of N or Z), the specific binding energy differs sharply from that of neighboring nuclei, which corresponds to magic numbers [2].

Such a change in nuclear properties was explained simply by the recognition of the existence of nucleon shells in the nucleus. For example, the dependence of ΔE on N , considered above, corresponds very well to the change in ionization energy in inert gases. A magic number is characterized by the presence of a single neutron in the new shell of the nucleus obtained by adding one more neutron to the nucleus. Because, as mentioned above, nucleons also obey the Pauli principle, and the energy of the last neutron must be higher, located in a new shell, therefore it is easy to pull it out of the nucleus [3].

The direct application of the Schrödinger equation for electrons in the atom did not lead to the expected result, i.e., the filling of shells in magic numbers in the nucleus. Of course, the Schrödinger equation for a nucleon in the nucleus must be solved with corresponding transformations only in the case considered above. Firstly, the forces acting on the neutron and proton in the nucleus differ by at least a Coulomb force. Secondly, the nuclear interaction between nucleons is still unclear today.

Only in 1948 did M. Mayer and G. Jensen show that in the shell model of nuclei, it is possible to achieve shell filling in magic numbers by taking into account strong spin-orbit interactions for nucleons. If we denote the principal quantum number n , the orbital quantum number l , and the spin quantum number $s=1/2$ for a nucleon in a shell, then in spin-orbit interaction, states with total angular momentum $j=l-1/2$ and $j=l+1/2$ split into two and have different energies. The main merit of Mayer and Jensen lies in the connection with magic numbers that this interaction is much larger than the corresponding interaction in an atom. For these services, they were awarded the Nobel Prize in 1963. The state of a nucleon in the nucleus is explained by quantum numbers similar to the quantum numbers of an electron in an atom. Principal quantum number values for nucleons in the nucleus will change as below

$$n = 1, 2, 3, 4, \dots$$

The orbital quantum number l also changes from 0 to $n-1$ at given values of n , and its values correspond to lowercase letters of the Latin alphabet.

$$\begin{aligned} l &= 0, 1, 2, 3, 4, 5, 6, 7, \dots \\ & \text{s, p, d, f, q, h, i, j, } \dots \end{aligned}$$

In addition, the state of a nucleon is also explained by the value of its total angular momentum:

$$\vec{J} = \vec{l} + \vec{s}$$

However, when $s = 1/2$ each (nl) subshell, due to spin-orbit interaction, splits into $j=l+1/2$ and $j=l-1/2$, where the energy of the state $j=l+1/2$ is less. Finally, it was agreed to explain the states of a nucleon not by the principal quantum number, but by a number l indicating the number of times the value of a given quantum number arrives. For example, the state $1p_{1/2}$ corresponds to the first state, which is explained by the quantum numbers $l=1$, $j=1-1/2$, and the second state, which is explained by the same quantum numbers $2p_{1/2}$, etc. Of course, in the case of $1p_{1/2}$, since $n=1$, $2p_{1/2}$ corresponds to $n=2$ [4, 5].

ANALYSIS AND RESULTS

From this, it is clear that the energies of certain neighboring states differ more significantly than others, thereby forming shells that terminate at magic numbers. Each major shell may itself consist of several subshells. According to the Pauli principle, for each nucleon state characterized by the total angular momentum quantum number j , nucleons can occupy that state, differing in the values of their angular momentum projections, where

$$m_j = j, j-1, \dots, 1, \dots, 1/2, -1/2, -3/2, \dots, -j+1, -j.$$

In general, this filling scheme is analogous to the filling of electron shells in atoms. The consideration of strong spin-orbit interaction modifies both the number of shells in the nucleus and the number of nucleons occupying them.

The shell model is one of the most effective and widely applied theoretical frameworks for explaining nuclear properties. It successfully accounts for a wide range of experimental data, including nuclear stability, magic numbers, spin values, and magnetic moments. Furthermore, this model reveals the quantum nature of microscopic motion within the nucleus and serves as a theoretical foundation for modern directions in nuclear physics – including nuclear spectroscopy, nuclear reactions, and nuclear synthesis processes in astrophysics.

CONCLUSION AND RECOMMENDATIONS

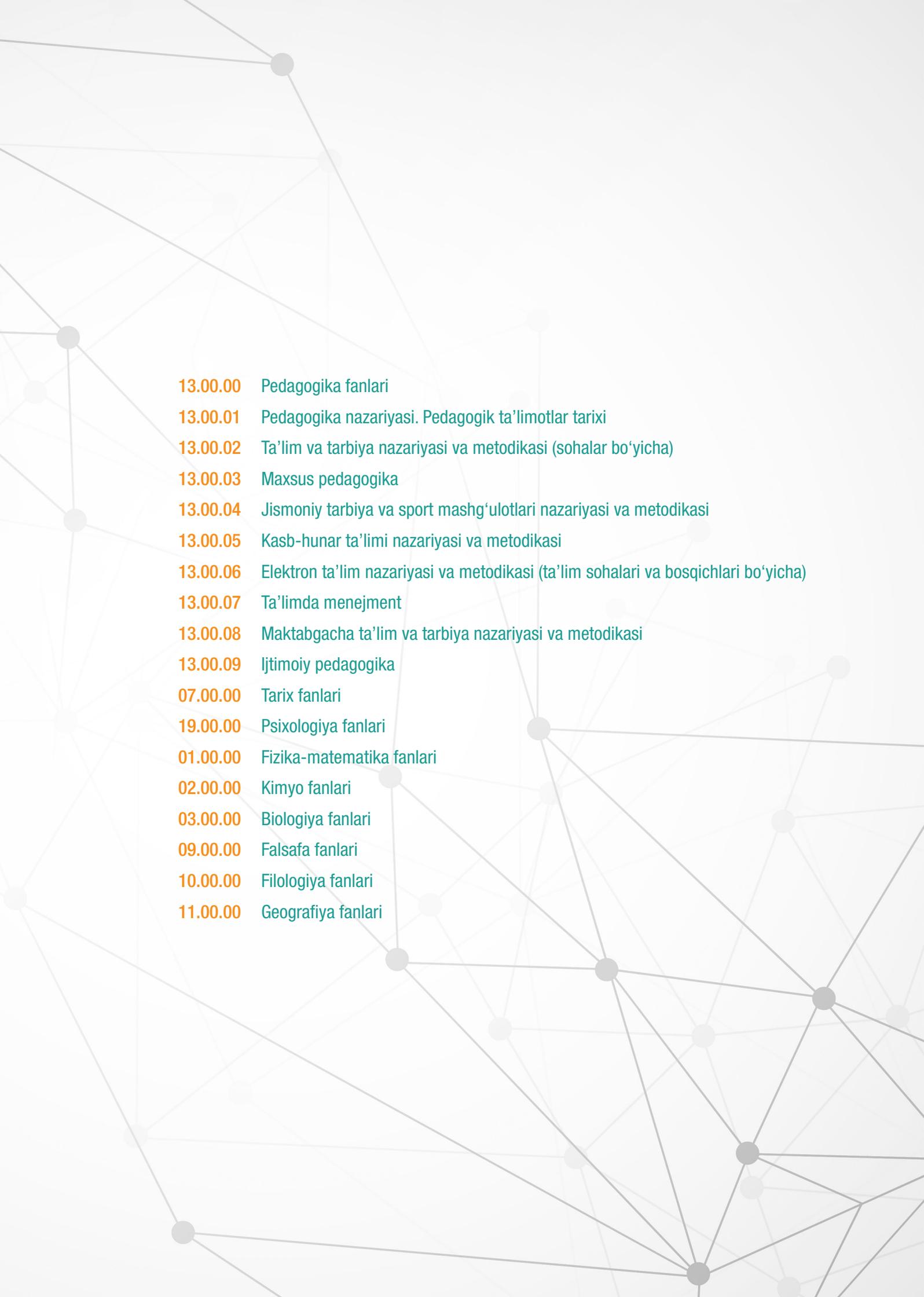
The present study confirms that magic numbers and nucleon shells play a fundamental role in determining the structural and stability properties of atomic nuclei. The shell model provides a consistent quantum-mechanical framework for explaining the existence of enhanced stability in nuclei with closed proton and/or neutron shells. The observed anomalies in binding energy, separation energy, spin characteristics, and excitation spectra are in strong agreement with the predictions of the shell model, particularly when the spin-orbit interaction is taken into account. The concept of magic numbers not only explains known stable configurations but also serves as an essential tool for predicting the properties of exotic and superheavy nuclei.

The results demonstrate that the inclusion of strong spin-orbit coupling is crucial for reproducing experimentally observed shell closures. Furthermore, the semi-empirical mass formula and neutron separation energy analysis confirm the energetic significance of closed-shell configurations. Thus, the shell model remains one of the most reliable theoretical approaches in modern nuclear physics.

Future research should focus on refining effective nucleon-nucleon interactions within extended valence spaces to improve the predictive accuracy of shell-model calculations. It is also recommended to apply advanced computational methods and large-scale configuration-interaction techniques to investigate nuclei far from stability. Experimental studies of exotic isotopes and superheavy elements should continue in order to test the evolution of magic numbers under extreme conditions. Finally, integrating shell-model approaches with modern astrophysical models will enhance our understanding of nucleosynthesis processes and the formation of heavy elements in the universe.

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- 13.00.00 Pedagogika fanlari
 - 13.00.01 Pedagogika nazariyasi. Pedagogik ta'limotlar tarixi
 - 13.00.02 Ta'lim va tarbiya nazariyasi va metodikasi (sohalar bo'yicha)
 - 13.00.03 Maxsus pedagogika
 - 13.00.04 Jismoniy tarbiya va sport mashg'ulotlari nazariyasi va metodikasi
 - 13.00.05 Kasb-hunar ta'limi nazariyasi va metodikasi
 - 13.00.06 Elektron ta'lim nazariyasi va metodikasi (ta'lim sohaları va bosqichlari bo'yicha)
 - 13.00.07 Ta'limda menejment
 - 13.00.08 Maktabgacha ta'lim va tarbiya nazariyasi va metodikasi
 - 13.00.09 Ijtimoiy pedagogika
 - 07.00.00 Tarix fanlari
 - 19.00.00 Psixologiya fanlari
 - 01.00.00 Fizika-matematika fanlari
 - 02.00.00 Kimyo fanlari
 - 03.00.00 Biologiya fanlari
 - 09.00.00 Falsafa fanlari
 - 10.00.00 Filologiya fanlari
 - 11.00.00 Geografiya fanlari



MAKTABGACHA VA MAKTAB TA'LIMI

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