Brief information about the project

Name of the project	AP09258757 «Investigation of resonance mechanisms of clustering in the nucleon medium»
Relevance	Experiments on the interaction of light nuclei with nuclei, cluster decays, including α-decays of heavy nuclei, indicate the existence of 2, 3 and more nucleon associations in atomic nuclei. As a rule, these associations are called nuclear clusters, associating them with existing light nuclei. In some approaches of cluster description, they are associated with light nuclei compressed in the external field of the remaining nucleons. At the same time, the theoretical description of nuclear matter based on the nuclear clusters specified in the model, as a rule, gives a very mediocre agreement with the experiment. Moreover, the most accurate variational calculations, which describe the spectra of nuclei up to A=10 very well, do not provide any justification for the cluster model of atomic nuclei and currently there are no theoretical models explaining the cause of clusters. On the other hand, the effects of three-particle dynamics are known for interactions that generate a pole of a paired t-matrix close to zero, such as the Efimov effect (thickening of the spectrum of three particles as the scattering lengths of the paired interaction tend to zero) and the Thomas theorem (collapse of three particles as the radius of action of paired forces tends to zero). These effects were discovered theoretically in the study of three-nucleon nuclei and are currently being investigated theoretically and experimentally in the physics of atomic interaction. In nuclear physics, the ratio of scattering lengths to the effective radii of paired forces is not large enough for the appearance of additional components of the spectrum generated by these effects. At the same time, there remains a remarkable self-similarity of the effective interaction, which generates a weak dependence of the wave function on the model of pair interaction. Consideration of the manifestation of the Efimov effects and the Thomas theorem in a multi-nucleon medium is limited to the technically unsolved problem of isolating the spectrum of subsystems in Faddeev-Yakubovsky type equations. Nevertheless, the successes of the generalized model of atomic nuclei, in which each nucleon is in an external field created by the remaining nucleons, allow us to hope for an adequate description of two- and three-nucleon associations of atomic nuclei, placing these associations in an external field. Thus, the main idea of this project was the assumption that two and three nucleon systems in the external field of the remaining nucleons of the nucleus will create stable formations (clusters) with binding energies per nucleon, greater binding energy per nucleon of the original nucleus. At the same time, the expected mechanisms for the formation of such clusters will be three-particle effects such as the Thomas theorem and the Efimov effect in the external field. These effects are determined by the pole of the t-matrix close to zero and in the theory of low-energy scattering are traditionally called resonance effects, which determines the name of the project.
Purpose	The aim of the Project was to study changes in the spectra of nuclear systems due to paired and three-particle nucleon associations in the realistic case when the length of paired scattering significantly exceeds the radius of action of paired forces.
Objectives	The goals of the Project were solved four tasks to achieve it: 1 Investigation of the spectrum of two particles in an external oscillatory field 2 Investigation of nucleon associations in atomic nuclei 3 Investigation of the spectra of three particles in an oscillatory external field

<table>
<tr><td></td><td colspan="2">4 Evaluation of the effect of the spectra of two and three particles in the external field on the structure of atomic nuclei</td></tr>
<tr><td>Expected and achieved results</td><td colspan="2">All the works planned in the Grant Application have been completed according to the schedule.
The most important positive result of the grant research is the possibility of describing the nucleon pairing energy with satisfactory agreement with experimental data based on the simple idea of the interaction of valence nucleons through a realistic pair potential NN-potential without using any fitting parameters This is all the more surprising because the accepted model of nucleon pairing relies on collective models such as BCS or N.N. Bogolyubov with fitting parameters for the residual interaction. At the same time, the selected parameters never describe the spectrum of all known atomic even-even nuclei.
The second most important result is the observation of different pairing energies for even-even and even-odd nuclei. This observation appeared in the analysis of more than 600 known nuclei. In fact, the dependence of the neutron pairing energy on the odd proton and the proton pairing energy on the odd neutron casts doubt on the statement about the independence of the neutron and proton components of nuclear matter adopted in nuclear shell models. The conclusion suggests a significant influence of the three-particle spectrum on the dynamics of the nucleus.
The third significant, albeit negative, result of the study is the statement that it is impossible to manifest the Efimov effect in the spectrum of atomic nuclei.</td></tr>
<tr><td rowspan="3">Research team members with their identifiers (Scopus Author ID, Researcher ID, ORCID, if available) and links to relevant profiles</td><td>Pen’kov Fedor, the head of project
ScopusAuthor ID: 6701854086
https://www.scopus.com/authid/detail.uri?authorId=6701854086
Researcher ID: M-7870-2015
https://publons.com/researcher/2351456/feodor-penkov/
ORCID: 0000-0002-7001-6134 https://orcid.org/0000-0002-7001-6134</td><td>  </td></tr>
<tr><td>Zholdybayev Timur, executor
ScopusAuthor ID: 8433851200
https://www.scopus.com/authid/detail.uri?authorId=8433851200
Researcher ID: M-7435-2015
https://publons.com/researcher/2351832/timur-zholdybayev/
ORCID: 0000-0003-3534-1000 https://orcid.org/0000-0003-3534-1000</td><td>  </td></tr>
<tr><td>Krassovitskiy Pavel, executor
ScopusAuthor ID: 2642307380
https://www.scopus.com/authid/detail.uri?authorId=26423073800
Researcher ID: ABA-7012-2021
https://publons.com/researcher/4710845/krassovitskiy-pavel/
ORCID: 0000-0001-8145-7974 https://orcid.org/0000-0001-8145-7974</td><td>  </td></tr>
</table>

	Kurmangalieva Venera, executor Scopus Author ID: 57200796046 https://www.scopus.com/authid/detail.uri?authorId=57200796046 Researcher ID: O-3346-2014 https://publons.com/researcher/2464070/venera-vko-kurmangalieva/ ORCID: 0000-0001-8046-8508 https://orcid.org/0000-0001-8046-8508	
	Tutebayeva Aisulu, executor ORCID: 0000-0002-0345-0395 https://orcid.org/0000-0002-0345-0395	
List of publications with links to them	According to the results of the study, three articles have been published, indexed in the Scopus and Web of Science databases. At the same time, one of the papers was published in the journal from Q1 to Web of Science. 1. Pen'kov F.M., Kurmangalieva V.O., Zholdybayev T.K., Krassovitskiy P.M. Residual interaction and nucleon pairing energy // Acta Physica Polonica B, Proceedings Supplement. – 2023. –V.16. – 2-A15. https://doi.org/110.5506/APhysPolBSupp.16.2-A15 (Q4). 2. Pen'kov F.M., Zholdybayev T.K., Krassovitskiy P.M., Kurmangalieva V.O. Isotriplet pairing energy of nucleons in nuclei // Results in Physics. – 2023. – V.52. – 106856. https://doi.org/110.1016/j.rinp.2023.106856 (Q1) 3. Mukhametkaliuly A., Pen'kov F.M. Resonant scattering of μ-mesons by atomic nuclei // Recent Contributions to Physics. – 2023. – V.85, is. 2. – P. 4-11. https://doi.org/10.26577/RCPh.2023.v85.i2.01 (CQAFSHE).	
Patents	-	