I. I. Mechnikov Odesa National University
Faculty of Mathematics, Physics and Information Technologies
Department of Physics and Astronomy

Course Syllabus

Elementary particles physics and nuclear astrophysics

Volume	5credits, 150 hours.
Semester, year of study	1 semester, 1st year of study
Days, time, place	Tuesday at 13.50, room 18, Pastera st, 42
Teacher(s)	Prof. Panko O.O., prof. Susko M.Ya.
Контактний телефон	0974334518
E-mail	panko.elena@onu.edu.ua
Workplace	room 18, Pastera 42 st
Consultations	Face-to-face consultations: Monday at 15.00, room 18, Pastera 42

Фізика елементарних частинок та ядерна астрофізика

Обсяг	5 кредитів, 150 год.
Семестр, рік навчання	1 семестр, 1-й рік навчання
Дні, час, місце	Вівторок, 12.50, ауд.18, Пастера 42
Викладач (-і)	проф. Панько О.О.
Контактний телефон	
E-mail	panko.elena@onu.edu.ua
Робоче місце	НДІ Астрономічна обсерваторія ОНУ імені І.І.Мечникова, парк Шевченка, головна будова, приміщення кафедри.
Консультації	Очні консультації: понеділок, 14.30-17.00, АО, парк Шевченка

Communication with students:

E-mail: panko.elena@onu.edu.ua; Viber; face-to-face meetings (Phone number ONLY for contact in Viber).

COURSE SUMMARY

The subject of study of the academic discipline is physical processes that occur in space objects involving elementary particles.

The study of the discipline "Physics of Elementary Particles and Nuclear Astrophysics" is preceded by the sections of the course "Nuclear and Elementary Particle Physics", "General Astronomy", "Computational Methods", "General Astrophysics", "Celestial Mechanics, "Instruments and Methods of Astrophysics", "Theoretical Astrophysics and MHD", "Stellar Astronomy", "Astropraktikum", "Thermodynamics and Statistical Physics", "Physical Variables and Binary Stars". Knowledge of the course "Physics of elementary particles and nuclear astrophysics" is the basis for further professional activity, and may also be needed when writing master's theses

The goal of the course of teaching the academic discipline "Physics of elementary particles and nuclear astrophysics" is to train specialists who are able to freely operate with concepts related to the classification of elementary particles, the interactions in which they participate, with possible paths of nuclear transformations involving elementary particles. Within the framework of the course, the chemical evolution of the Universe is considered precisely as a sequential chain of thermonuclear reactions, which leads to the experimentally detected quantitative composition of baryonic matter. As a result of mastering the course material, students should become familiar with thermonuclear reactions occurring in stars of different types; thermal neutron capture reactions, reactions occurring in the interstellar medium, as well as with the chemical evolution of our Galaxy and the Universe as a whole in particular.

In space objects, physical conditions differ significantly from those that can be obtained in terrestrial laboratories. Therefore, future physicists and astronomers must be fluent in information and mathematical apparatus that describes the state of space objects and environments, their rapid and evolutionary changes, and be able to analyze physical processes occurring in conditions that are unattainable in terrestrial laboratories. This knowledge is necessary for future professional activities for both physicists and astrophysicists.

The task of the discipline is to form in students stable knowledge about the classes of elementary particles, the interactions associated with them, the types of nuclear reactions, the processes occurring in stars and the interstellar medium, as well as the evolution of chemical elements in the Universe.

Learning outcomes provide the ability to:

know: basic experimental facts in particle physics; basic methods for describing particle interactions; the standard model and its main extensions; conservation laws and types of thermonuclear reactions; proton-proton cycle reactions; CNO cycle

reactions; hot cycle reactions (Ne-Na, Mg-Al); thermonuclear fusion in supernovae; slow neutron capture processes; features of the chemical composition of stars of different types; basic principles of spectroscopic analysis, the purpose of which is to determine the chemical composition of a star; processes of primary nucleosynthesis; transformations of atomic nuclei in the interstellar medium.

be able to: apply knowledge of the laws of symmetry conservation in quantum field theory to describe the results of specific thermonuclear reactions; explain the patterns of chemical evolution of stars; explain the formation of chemical anomalies in stars of different types; explain the features of the chemical evolution of our Galaxy and the Universe as a whole.

COURSE DESCRIPTION

Forms and methods of study

The course will be taught in the form of lectures (28 hours), practical classes (20 hours), and organization of independent work of students (102 hours).

The following forms of work are used during teaching the discipline - lecture, practical classes, independent work. During lectures and practical classes, the following teaching methods are used: explanatory-illustrative method; information-receptive; reproductive method (reproduction-reproduction); problem-based presentation method; partial-search method.

During practical classes, the following teaching methods are used: partial-search, or heuristic method; research, when defending practical works and individual tasks, the discussion method is used. During independent work, the research method is used (the student masters the literature on the specified topic).

Content of the educational discipline

Content module 1. Elementary particles

Topic 1. Formation of modern ideas about the physics of elementary particles and atomic nuclei. Historical overview. Scales of quantities characteristic of the physics of the atomic nucleus and elementary particles. Levels of the structure of baryonic matter.

Topic 2. Fundamental particles. Principles of classification of elementary particles. Hadrons (baryons, mesons), leptons, gauge bosons. Quarks. Bosons and fermions. Interaction between fundamental fermions. Particle masses. Lifetime. Charges and numbers. Conservation laws in elementary particle physics. Particles and antiparticles.

Topic 3. Parameters of thermonuclear reactions. Reaction cross section. Mean free path. Reaction energy. Reaction threshold. Stable proton-neutron combinations. □ decay and parity. Violation of the law of conservation of parity in the weak interaction. □ decay and cluster decay. Isobars, □– and □+ decays. Binding energy of the nucleus. Weizsäcker formula. Models of the nucleus – liquid drop, shell model. Magic numbers. Atomic nuclei and reactions at ultrahigh densities (in the zones of energy release of stars).

Content module 2. Transformation of elements in the Universe

Topic 1. Chemical composition of the observed Universe. Methods for determining the chemical composition of stars. Chemical composition of the Sun. Distribution of elements by atomic number. Paired peaks. Iron peak. Chemical composition of stars in different subsystems of the Galaxy. Types of stellar population and the difference in the content of chemical elements in stars of different types Chemical composition of other galaxies.

Topic 2. Primary nucleosynthesis. The problem of antimatter. The first reactions of thermonuclear fusion. Formation of ultralight nuclei: 2H, He, Li, Be, B. The problem of Li, Be, B. Thermonuclear reactions in type III stars.

Topic 3. Reactions in main sequence stars. Proton-proton cycle. Neutrinos as an indicator of reactions. CNO cycle (Bethe – Weizsäcker).

Topic 4. Subsequent reactions. Triple 3 reaction. Restructuring of the star. Features of the following reactions: burning C, O, S, Si. Hot cycles (Ne – Na and Mg – Al). Formation of Fe.

Topic 5. Formation of nuclei of chemical elements heavier than iron and nickel. Thermal neutron capture processes. s-process; r-process. Formation of nuclei of ultraheavy chemical elements: rp-process.

Topic 6. Supernovae. Thermonuclear fusion in the depths of supernovae. Neutronization of matter. Multiparticle nuclear reactions of fusion of several

alpha - particles and nucleons. Processes of enrichment of the interstellar medium with synthesized chemical elements. Chemical evolution of the Galaxy and other galaxies. Anomalies of the chemical composition of stars.

Topic 7. Cosmic particles, transformations of elements in the interstellar medium. Fission reactions. Neutron stars. Piconuclear reactions. Formation of elements during the merger of neutron stars.

Topic 8. Future chemical evolution of the Universe.

Recommended literature

Basic

1. Ніцук Ю.А. Ядерна фізика: Навч. посібник. – Одеса.: Одеський національний університет імені І.І. Мечникова, 2008. – 168 с.
2. Захожай В. А. Вступ до астрофізики та космології. – Харків, 2017.
3. Андрієвський С.М., Кузьменков С.Г. Ядерна астрофізика. Навчальний посібник. Одеса: Одеський національний університет імені І.І. Мечникова, 2022. 120 с. http://dspace.onu.edu.ua:8080/handle/123456789/33025
4. Климишин І.А., Дубицький І.М. Основи космології. Івано-Франківський Теологічно-катехитичний духовний інститут, 1999. – 147 с.

Additional

1. Кудря Ю.М., Вавилова І.Б. Позагалактична астрономія. Книга 1. Галактики: основні фізичні властивості. Навчальний посібник. К.: Наукова думка, 2016. 344 с. ISBN 978-966-00-1517-3 Режим доступу http://mao.kiev.ua/biblio/mono/pzastr.pdfhttp://mao.kiev.ua/biblio/mono/pzastr.pdf

2. Мишенина Т.В. Галактика, ее строение и обогащение химическими элементами. Одесса: Астропринт, 2017. 168 с.
3. Климишин І. А., Гарбузов Г. О., Мурніков Б. О., Кабанова Т. І. Астрономія / Навчальний посібник. – Одеса: «Астропринт», 2012. – 352 с.
4. Вакарчук І.О. Теорія зоряних спектрів. Підручник. Львів: Львівський національний університет імені Івана Франка, 2002. – 359 с.
5. Каретніков В. Г., Мурніков Б. О., Кабанова Т. І. Спектральна класифікація зір // Методичні вказівки для студентів фізичного факультету спеціальності «астрономія». – Одеса: Астропринт, 2015. – 28 с.
6. Кузьменков С.Г. Фундаментальні фізичні та математичні константи. Задачі з розв'язками. Херсон, 2021. – 96 с.
7. Александров Ю. В. Астрофізика / Навчальний посібник. – Харків, 2014. – 216 с.

Resources

1. http://dspace.onu.edu.ua/
2. phys.onu.edu.ua

ASSESSMENT

The academic discipline "Physics of Elementary Particles and Nuclear Astrophysics" is assessed on a 100-point scale.

Methods of current control: current control is carried out based on the results of practical tasks and independent work. The results of preparing theoretical material for practical classes are assessed by oral examination.

The student's activity in the process of classes is also assessed: oral examination, writing reports when performing practical tasks, evaluating reports, essays, solving situational problems. Final semester control (exam).

Criteria for assessing the performance of practical tasks.

The student must complete all practical classes. Up to 4 points are awarded for each class for performing calculations and recording results. Up to 3 points are deducted for errors in calculations or in deriving formulas. Up to 7 points are awarded for more voluminous tasks of the 6th semester and up to 3 points are deducted, respectively. When setting the final grade for the semester, the sum of all grades is taken.

Forms and methods of final control:

Distribution of points received by students

Current control, independent work, individual tasks	Final control (exam)	Total points

<table>
<tr><td colspan="4">Content module 1
Current control during lectures</td><td>Test work</td><td>Individual tasks</td><td>Performance and defense of laboratory work</td><td>Practical task</td><td>Total
Разом</td><td></td><td></td></tr>
<tr><td>T1</td><td>T2</td><td>T3</td><td></td><td></td><td></td><td></td><td>12</td><td>70</td><td>30</td><td>100</td></tr>
<tr><td>2</td><td>3</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Content module 2
Current control during lectures</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>T1</td><td>T2</td><td>T3</td><td>T4</td><td></td><td></td><td></td><td>28</td><td></td><td></td><td></td></tr>
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When assessing the level of material mastery in points, the general criteria for assessing the academic achievements of higher education applicants are used:

The final semester control (exam) is conducted orally. The exam paper contains two theoretical questions, each of which is evaluated separately on a 15-point scale

Criteria for evaluating a theoretical question:

– a complete, detailed answer – 15 points;

– a complete, but not detailed answer – 14 points;

– a complete, but not detailed answer that contains a minor error or contradiction –

13 points, 1 point is deducted for each subsequent minor error or contradiction;

– an incomplete answer that does not contain critical errors or contradictions – 10 points,

1 point is deducted for each subsequent minor error or contradiction;

– an answer that contains a critical error or inaccuracy, or the absence of an answer is evaluated at 0 points.

The number of points that the candidate received on the exam is the sum of the points that were received for each task on the exam paper.

The final grade is given based on the sum of the points of the current and final control.

Independent work of students.

Forms of independent work of students are: preparation of theoretical material (lectures). The goal of independent work of the student is to ensure solid knowledge of theoretical material.

Results of independent work tasks are evaluated by answers to control questions and correctly performed calculations.

Results of individual tasks are presented in the form of a report (7-10 min.), which is accompanied by a presentation (6-8 slides).

Evaluation criteria are: completeness of the presented material, quality of the report and presentation, answers to questions of the teacher and fellow students.

COURSE POLICY

Determined by regulatory documents/Regulations that are in force at ONU named after I.I.Mechnikov (https://onu.edu.ua/uk/geninfo/official-documents).

The deadline for completing course tasks is determined by the teacher. In case of good reasons, the teacher allows the postponement of the deadline for completing tasks. Recalculation of debts - with the permission of the dean's office.

Each student must remember about academic integrity, which is ensured by independent performance of educational tasks, tasks of current and final control, proper reference to sources of information in case of performing creative works, compliance with the norms of the legislation on copyright and related rights, provision of reliable information about the results of their own scientific activities.

For violation of academic integrity, students may be held academically liable in accordance with the Regulations on Academic Integrity at I.I. Mechnikov ONU. (https://onu.edu.ua/pub/bank/userfiles/files/documents/acad-dobrochesnost.pdf).

Attendance at classes for a 1st-year student is mandatory, as is timely arrival at classes. Mobile devices must be blocked during study.