Federal State Autonomous Educational Institution of Higher Education "Moscow Institute of Physics and Technology (National Research University)"

APPROVED
Проректор по учебной работе и экономическому развитию
D.A. Zubtsov

Work program of the course (training module)

course:	Introduction to Plasma Physics. Electron Kinetics/Введение в физику плазмы. Электронная кинетика
major:	Applied Mathematics and Physics
specialization:	Beam-Plasma Systems and Technologies/Пучково-плазменные системы и технологии
	Phystech School of Aerospace Technology
	Chair of Logistics Systems and Technologies
term:	1
qualification:	Master

Semester, form of interim assessment: 1 (fall) - Exam

Academic hours: 60 AH in total, including:
lectures: 30 AH.
seminars: 30 AH.
laboratory practical: 0 AH.

Independent work: 45 AH.

Exam preparation: 30 AH.

In total: 135 AH, credits in total: 3

Author of the program: N.L. Aleksandrov, doctor of physics and mathematical sciences, full professor

The program was discussed at the Chair of Logistics Systems and Technologies 09.02.2022

Annotation

The course contains the basic concepts and properties of low-temperature plasma, its difference from neutral and weakly ionized gases, its manifestations in nature and applications in modern technologies.

The course contains a discussion of the generation and existence of plasma in the Earth's atmosphere, in space and in the laboratory. Considerable attention is paid to the basic properties of plasma, including its quasi-neutrality. Elementary processes in plasma and their description based on scattering cross sections during particle collisions are considered. Much attention is paid to the plasma transfer processes and the coefficients describing these processes. Plasma sources are being studied, including those based on a gas discharge, charged particle beams and laser beams. Demonstrations of plasma applications include radiation sources, plasma chemistry, treatment and purification of gases and liquids, ozonators, plasma methods in microelectronics, thin-layer deposition, surface treatment, plasma in medicine, plasma in agriculture, plasma-stimulated gorenje and plasma aerodynamics.

1. Study objective

Purpose of the course

To provide students with basic principles of plasma physics, parameter characterizing plasmas, its manifestations in nature and applications in modern technologies.

Tasks of the course

1. Students will gain preliminary understanding of the physical processes in plasma, the mechanisms of its production, physical phenomena in plasma interacting with solid bodies and aerosols. Student will also understand peculiarities of the electron-beam plasma in comparison with other plasmas.
2. Students will be able to offer the approaches to arrange experiments and computer simulations in the fields of plasma properties and plasma technologies.
3. Students will practice producing high quality graduate level academic essays on research topics suggested/agreed with Lecturer, making class presentations and carrying out research as well as enhance their reading skills in English.

2. List of the planned results of the course (training module), correlated with the planned results of the mastering the educational program

Mastering the discipline is aimed at the formation of the following competencies:

Code and the name of the competence	Competency indicators
Gen.Pro.C-2 Acquire an understanding of current scientific and technological challenges in professional settings, and scientifically formulate professional objectives	Gen.Pro.C-2.3 Understand professional terminology used in modern scientific and technical literature and present scientific results in oral and written form within professional communication
Gen.Pro.C-3 Select and/or develop approaches to professional problem-solving with consideration to the limitations and specifics of different solution methods	Gen.Pro.C-3.1 Analyze problems, plan research strategy to achieve solution(s), propose, and combine solution approaches
	Gen.Pro.C-3.2 Employ research methods to solve new problems and apply knowledge from various fields of science (technology)
	Gen.Pro.C-3.3 Gain knowledge of analytical and computational methods of problem-solving, understand the limitations of the implementation of the obtained solutions in practice

3. List of the planned results of the course (training module)

As a result of studying the course the student should:

know:

The physical processes in plasma, the mechanisms of its production, physical phenomena in plasma interacting with solid bodies and aerosols. Student will also understand peculiarities of the electron-beam plasma in comparison with other plasmas.

be able to:

- To offer the approaches to arrange experiments and computer simulations in the fields of plasma properties and plasma technologies.
- To produce high quality graduate level academic essays on research topics suggested/agreed with Lecturer, making class presentations and carrying out research

master:

- skills of mastering a large amount of interdisciplinary and specialized information;
- the culture of setting problems in the field of plasma physics; the skills of estimating the parameters and properties of plasma systems.

4. Content of the course (training module), structured by topics (sections), indicating the number of allocated academic hours and types of training sessions

4.1. The sections of the course (training module) and the complexity of the types of training sessions

№	Topic (section) of the course	Types of training sessions, including independent work			
		Lectures	Seminars	Laboratory practical	Independent work
1	Plasma in nature and laboratory. Low-temperature plasma.	2	2		
2	Basic plasma parameters. Ideal and non-ideal plasma.	2	5		
3	Dusty plasma.	2	2		5
4	Equilibrium and non-equilibrium plasma.	2	2		
5	Gas-discharge plasmas.	2	2		5
6	Thermal plasma. Plasma of electric arc.	2	2		5
7	Electron-beam plasma. Peculiarities of the electron-beam plasma.	1	2		5
8	Electron beam propagation in vacuum. Electron optics.	2	2		5
9	General description of the electrons scattering. Electron beam propagation in dense gas.	2	2		
10	Electron beams interaction with solids.	2	1		
11	Electrostatic charging of bodies in the electron-beam plasma.	5	2		5
12	Plasma near a surface.	2	2		5
13	General approaches to the electron-beam plasma simulation.	2	2		5
14	Radiation emission in the electron-beam plasma. X-ray radiation of the electron-beam plasma.	2	2		5
AH in total		30	30		45
Exam preparation		30 AH.			
Total complexity		135 AH., credits in total 3			

4.2. Content of the course (training module), structured by topics (sections)

Semester: 1 (Fall)

1. Plasma in nature and laboratory. Low-temperature plasma.

The definition of plasma. Examples of plasma in nature and laboratory plasmas. Space and ionosphere plasma. Ionization and electron-ion recombination. Ionization potential of atoms and molecules. Ways of gas ionization, plasma generated by external ionizers.

2. Basic plasma parameters. Ideal and non-ideal plasma.

Electrostatic energy in plasma. Debye shielding. Debye radius. Coupling parameter.

3. Dusty plasma.

Plasma containing solid dispersed particles. Plasma of aerosols. Dusty plasma as an example of non-ideal plasma. Ordered dust structures in plasma, plasma crystal.

4. Equilibrium and non-equilibrium plasma.

Conditions under which plasma is equilibrium. Equilibrium and non-equilibrium electron energy distributions.

5. Gas-discharge plasmas.

Glow DC-discharge. Plasma of RF- and MW-discharges. V-A characteristics of DC-discharge. Electrons mobility. Plasma conductivity.

6. Thermal plasma. Plasma of electric arc.

Ionization by gas heating. Electric arc. Plasma torch and plasmatrons. V-A characteristics of electric arc. Low- and high-temperature plasmas.

7. Electron-beam plasma. Peculiarities of the electron-beam plasma.

Plasma excited by electron beams. General characteristics of the electron-beam plasma. Beam parameters and medium characteristics responsible for the electron-beam plasma properties.

8. Electron beam propagation in vacuum. Electron optics.

Electron beams formation. Electrons acceleration by means of electrostatic and electromagnetic fields. Electron beam propagation in high vacuum. Space charge of electron beam. Purveyance. Electron optics. Electron beam deflection by means of electric and magnetic fields.

9. General description of the electrons scattering. Electron beam propagation in dense gas.

Particle collisions in plasma. Elastic and inelastic collisions in plasma. Electrons scattering in the electron-beam plasma. Single and multiple scattering. Cross sections for particle scattering (preliminary information).

10. Electron beams interaction with solids.

Motion of fast electrons in solids. Electrons scattering in solids. Electrons deceleration in solids, model of continuous deceleration. Bethe formula.

11. Electrostatic charging of bodies in the electron-beam plasma.

Electrons absorption by solids, electrostatic charge accumulation. Electrostatic charging of aerosols. Super-high charging of aerosol particles by electron beams. Differential charging of solids in the electron-beam plasma.

12. Plasma near a surface.

Interaction of plasma particles with surface of solids. Particles absorption and rebound. Solids heating in the electron-beam plasma. Plasma chemical processes near the surface. Peculiarities of plasma chemical processes in the electron-beam plasma.

13. General approaches to the electron-beam plasma simulation.

Simulation of elastic scattering. Simulation of electrons energy loss in collisions with atoms and molecules. Monte-Carlo technique to model electron beam propagation in dense media.

14. Radiation emission in the electron-beam plasma. X-ray radiation of the electron-beam plasma.

Mechanisms of optical radiation in plasmas. Spectra of plasma optical radiation. Bremsstrahlung in the electron-beam plasma.

5. Description of the material and technical facilities that are necessary for the implementation of the educational process of the course (training module)

Standard classroom.

6. List of the main and additional literature, that is necessary for the course (training module) mastering

Main literature

1. Alexander Fridman, Lawrence A. Kennedy, Plasma Physics and Engineering, CRC Press (2011).
2. Francis F. Chen, Jane P. Chang, Principles of Plasma Processing, Plenum Publishers (2002).
3. Alexander Piel, Plasma Physics, Springer (2010).
4. Alexander Fridman, Plasma Chemistry, Cambridge University Press (2008).

Additional literature

1. Boris M. Smirnov, Fundamentals of Ionized Gases, Wiley (2012).
2. Nonthermal Plasma Chemistry and Physics, Ed. Jurgen Meichsner, Martin Schmidt, Ralf Schneider, Hans-Erich Wagner, CRC Press (2013).
3. Yuri P. Raizer, Gas Discharge Physics, Springer (1991).

7. List of web resources that are necessary for the course (training module) mastering

Not used

8. List of information technologies used for implementation of the educational process, including a list of software and information reference systems (if necessary)

Microsoft Office. Internet access.

9. Guidelines for students to master the course

Successful completion of the course requires a lot of independent work of the student. The course program provides the minimum required time for a student to work on a topic.

Independent work includes:
– reading and taking notes of recommended literature;
– study of educational material (on lecture notes and seminars, educational and scientific literature);
– preparation for control, independent work and tests.

The management and control of the student's independent work is carried out as a result of the analysis of the results of control, independent work and tests, as well as individual consultations.

An indicator of material proficiency is the ability to solve problems. To form the ability to apply theoretical knowledge in practice, the student needs to solve as many problems as possible.

SUPPLEMENT

Assessment funds for course (training module)

major:	Applied Mathematics and Physics
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term:	1
qualification:	Master

Semester, form of interim assessment: 1 (fall) - Exam

Author:	N.L. Aleksandrov, doctor of physics and mathematical sciences, full professor

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
Gen.Pro.C-2 Acquire an understanding of current scientific and technological challenges in professional settings, and scientifically formulate professional objectives	Gen.Pro.C-2.3 Understand professional terminology used in modern scientific and technical literature and present scientific results in oral and written form within professional communication
Gen.Pro.C-3 Select and/or develop approaches to professional problem-solving with consideration to the limitations and specifics of different solution methods	Gen.Pro.C-3.1 Analyze problems, plan research strategy to achieve solution(s), propose, and combine solution approaches
	Gen.Pro.C-3.2 Employ research methods to solve new problems and apply knowledge from various fields of science (technology)
	Gen.Pro.C-3.3 Gain knowledge of analytical and computational methods of problem-solving, understand the limitations of the implementation of the obtained solutions in practice

2. Competency assessment indicators

As a result of studying the course the student should:

know:

The physical processes in plasma, the mechanisms of its production, physical phenomena in plasma interacting with solid bodies and aerosols. Student will also understand peculiarities of the electron-beam plasma in comparison with other plasmas.

be able to:

- To offer the approaches to arrange experiments and computer simulations in the fields of plasma properties and plasma technologies.
- To produce high quality graduate level academic essays on research topics suggested/agreed with Lecturer, making class presentations and carrying out research

master:

• skills of mastering a large amount of interdisciplinary and specialized information;
• the culture of setting problems in the field of plasma physics; the skills of estimating the parameters and properties of plasma systems.

3. List of typical control tasks used to evaluate knowledge and skills

Current control is carried out in the form of independent work or written tests on each topic.
The management and control of the student's independent work is carried out as a result of the analysis of the results of control, independent work, as well as individual consultations.

4. Evaluation criteria

The final certification is carried out in the form of an exam (in oral form).

List of questions for exam preparation:

1. Examples of plasma in nature and in the laboratory. Cosmic and ionospheric plasma. Its main parameters. The main differences between cosmic plasma and laboratory plasma.
2. The concept of plasma and its difference from ionized gas. Weakly ionized, partially ionized and fully ionized plasma. Plasma-like media: weakly ionized gas, electrolytes, plasma of semiconductors and metals.
3. Plasma quasineutrality and screening length. The temporal and spatial scales of the violation of electroneutrality in it. Debye-Hückel theory. The concept of non-ideality of plasma. Parameters of imperfection

4. Scattering cross-section, collision frequency and average path length for electrons, ions and neutral particles in plasma. Short-range and long-range interactions.
5. Mechanisms of ionization in plasma in the collision of electrons, ions, atoms and molecules. Excitation of rotational, vibrational and electronic states of neutral particles.
6. Transfer of charge, particles, momentum and energy in plasma. Electrical conductivity, diffusion, mobility, viscosity and thermal conductivity of plasma and the contribution of individual components to these characteristics.
7. Electrical discharges. Independent and non-independent categories. Discharges in constant electric fields, HF and microwave discharges, laser spark.
8. Plasma generated by electron and ion beams, as well as light. The difference between beam plasma and gas discharge plasma.
9. Plasma applications in modern technologies. Light sources, surface treatment, coating, plasma methods in microelectronics, synthesis of nanomaterials, purification of gases and liquids, ozonators, plasma aerodynamics, plasma-stimulated gorenje, plasma medicine, plasma in agriculture.

Examples of exam tickets:

Examination ticket No. 1
1. Examples of plasma in nature and in the laboratory. Cosmic and ionospheric plasma. Its main parameters. The main differences between cosmic plasma and laboratory plasma.
2. The concept of plasma and its difference from ionized gas. Weakly ionized, partially ionized and fully ionized plasma. Plasma-like media: weakly ionized gas, electrolytes, plasma of semiconductors and metals.

Examination ticket No. 2
1. Mechanisms of ionization in plasma in the collision of electrons, ions, atoms and molecules. Excitation of rotational, vibrational and electronic states of neutral particles.
2. Transfer of charge, particles, momentum and energy in plasma. Electrical conductivity, diffusion, mobility, viscosity and thermal conductivity of plasma and the contribution of individual components to these characteristics.

Examination ticket No. 3
1. Plasma generated by electron and ion beams, as well as light. The difference between beam plasma and gas discharge plasma.
2. Plasma applications in modern technologies. Light sources, surface treatment, coating, plasma methods in microelectronics, synthesis of nanomaterials, purification of gases and liquids, ozonators, plasma aerodynamics, plasma-stimulated gorenje, plasma medicine, plasma in agriculture.

The mark is excellent 10 points - given to a student who has shown comprehensive, systematized, deep knowledge of the curriculum of the discipline, who is interested in this subject area, who has demonstrated the ability to confidently and creatively apply them in practice in solving specific problems, free and correct justification of the decisions made.

An excellent mark of 9 points is given to a student who has shown comprehensive, systematized, in-depth knowledge of the curriculum of the discipline and the ability to confidently apply them in practice in solving specific problems, free and correct justification of decisions made.

An excellent grade of 8 points is given to a student who has shown comprehensive, systematized, in-depth knowledge of the curriculum of the discipline and the ability to confidently apply them in practice in solving specific problems, the correct justification of the decisions made, with some drawbacks.

A good score of 7 points is given to a student if he firmly knows the material, expresses it competently and to the point, knows how to apply the knowledge gained in practice, but does not adequately substantiate the results obtained.

A good score of 6 points is given to a student if he firmly knows the material, expounds it competently and to the point, knows how to apply the knowledge gained in practice, but makes some inaccuracies in the answer or in solving problems.

A good score of 5 points is given to a student if he basically knows the material, expresses it competently and to the point, knows how to apply the knowledge gained in practice, but makes a large number of inaccuracies in the answer or in solving problems.

The mark is satisfactory 4 points - given to a student who has shown a fragmentary, scattered nature of knowledge, insufficiently correct formulations of basic concepts, a violation of the logical sequence in the presentation of the program material, but at the same time he has mastered the main sections of the curriculum necessary for further education and can apply the acquired knowledge in sample in a standard situation.

The mark is satisfactory 3 points - given to a student who has shown a fragmented, scattered nature of knowledge, makes mistakes in the formulation of basic concepts, disruptions in the logical sequence in the presentation of program material, poorly knows the main sections of the curriculum necessary for further education and hardly applies the acquired knowledge even in standard situations.

The score is unsatisfactory 2 points - given to a student who does not know most of the main content of the curriculum of the discipline, makes gross errors in the formulation of basic principles and does not know how to use the knowledge gained when solving typical problems.

The mark is unsatisfactory 1 point - given to a student who does not know the main content of the curriculum of the discipline, makes gross errors in the formulation of the basic concepts of the discipline and generally does not have the skills to solve typical practical problems.

5. Methodological materials defining the procedures for the assessment of knowledge, skills, abilities and/or experience

When conducting an oral exam, the student is given up to 40 minutes to prepare. The student's ticket survey at the oral exam should not exceed one astronomical hour.

The teacher is given the right, in addition to theoretical questions, to students additional questions clarifying the understanding of the course content.

During the exam, when preparing answers to tickets, students can use the discipline program, lecture notes and any other literature.

During the exam, when the student answers questions on the ticket or on the discipline program, he cannot use lecture notes and any other literature.