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

APPROVED
Head of the Phystech School of Aerospace Technology
S.S. Negodyaev

Work program of the course (training module)

course:	Plasma Physics/Физика плазмы
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: 2 (spring) - 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 training course is targeted at student's familiarization with scientific principles of plasma physics to provide them with knowledge and understanding of fundamental properties of equilibrium and non-equilibrium plasmas. Students will be able to analyze the basic plasma processes that are important for modern plasma-based technologies. Plasma excited by electron beams and scientific principles of the beam-plasma systems design are considered in detail. Theoretical sections of the training course are supported by laboratory practice on laboratory generators of thermal, gas discharge and electron-beam plasmas.

1. Study objective

Purpose of the course

1. To provide students with knowledge and understanding of plasma physics fundamentals regarding properties of discharge and beam plasmas.
2. To develop critical analytical and debate skills enabling students to engage in independent analysis of plasma physical and related problems based on credible sources of information.
3. To enhance students' research, academic essay writing and presentation skills to graduate- level studies of the international standard.

Tasks of the course

1. Students will gain solid understanding of the physical processes in plasma, the mechanisms of its production, transport and radiation phenomena in plasma media and peculiarities of discharge and electron-beam plasma.
2. Students will analyze case studies that highlight the basic plasma properties that could be used in modern 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-1 Gain fundamental scientific knowledge in the field of physical and mathematical sciences	Gen.Pro.C-1.1 Apply fundamental scientific knowledge in the field of physical and mathematical sciences
	Gen.Pro.C-1.2 Consolidate and critically assess professional experience and research findings
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of the studied phenomena and processes, systematically analyze scientific problems and obtain new scientific results	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within the subject area
	Pro.C-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model

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

As a result of studying the course the student should:

know:

- general parameters of ideal and non-ideal plasmas processes;
- kinetics of elementary processes in equilibrium and non-equilibrium plasmas;
- features of processes in non-equilibrium plasmas;
- main transport plasma properties;
- fundamentals of thermodynamics and hydrodynamics of plasmas;
- principles for calculating the main plasma parameters;
- principles of plasma generation in a laboratory and plasma phenomena in nature;
- scientific basis of modern plasma technologies;
- Electron-Beam Plasma peculiarities and scientific principles of beam-plasma technologies.

be able to:

- apply in practice the basic concepts used in the analysis and description of plasma-physical processes in equilibrium and non-equilibrium plasmas;
- analyze plasma processes under various conditions of the plasma generation;
- numerically estimate the key characteristics of plasma generated by various ionizers, including the Electron-Beam generated plasma characteristics;
- analyze mechanisms of plasma-matter interaction and predict effect of plasma action on substances;
- to master new subject areas and theoretical approaches related to the analysis, design and application of Electron-Beam Plasma.

master:

- skills of mastering a large amount of interdisciplinary and special information;
- culture of setting goals in the field of design and application of plasma setups;
- initial skills in working on beam-plasma laboratory setups and in plasma physical experiments arrangement.

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	3			
2	Thermodynamics of plasma.		4		
3	Non-ideal plasma.	3			
4	Hydrodynamics of plasma.	3			
5	Plasma conductivity.		4		8
6	Transport phenomena in plasma.		4		7
7	Plasma permittivity.	3			
8	Ambipolar diffusion.		4		8
9	Particle collisions in plasma.	3			
10	Cross sections for particle scattering.	3			
11	Classical theory of scattering.		4		8
12	Relaxation of electron momentum and energy.	3			
13	Ionization and electron-ion recombination. Electron attachment and detachment.	3			
14	Plasma decay.		5		7
15	Non-equilibrium plasma.	3			
16	Radiation in plasma.	3			
17	Properties of discharge plasma and electron-beam plasma.		5		7
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: 2 (Spring)

1. Plasma in nature and laboratory

Examples of plasma in nature and laboratory plasmas. Space and ionosphere plasma. Atmospheric electricity. Gas discharge plasma. Plasma generated by external ionization. The definition of plasma. Plasma-like media.

2. Thermodynamics of plasma.

Thermodynamics of plasma. Principle of detailed balance. Thermodynamic approach to determine ionization degree and plasma composition. Saha equation.

3. Non-ideal plasma.

Non-ideal plasma. Debye shielding. Coupling parameter. Electrostatic energy in plasma. Equation of state for non-ideal plasma. System of equation to determine the composition of non-ideal plasma.

4. Hydrodynamics of plasma.

Hydrodynamics of plasma. Hydrodynamic description of fluid and plasma. Balance equations and transport coefficients. Relation between hydrodynamic description and thermodynamic description of plasma.

5. Plasma conductivity.

Plasma conductivity. Conductivity in steady electric field. The effect of magnetic field on plasma conductivity. Conductivity in sinusoidal electric field.

6. Transport phenomena in plasma.

Transport phenomena in plasma. Transport of particles, particle momentum and energy in plasma. Diffusion, mobility, viscosity and thermal conductivity of plasma.

7. Plasma permittivity.

Plasma permittivity. Conductivity current and polarization current. Plasma permittivity with and without collisions. Propagation of electromagnetic waves through plasma.

8. Ambipolar diffusion.

Ambipolar diffusion. Unipolar diffusion of electrons and ions in partially ionized plasma. Ambipolar electric field and ambipolar plasma diffusion. Ambipolar diffusion coefficient. Conditions that ambipolar diffusion occurs.

9. Particle collisions in plasma.

Particle collisions in plasma. Elastic and inelastic collisions in plasma. Two-body and three-body collisions. First-kind and second-kind collisions. Collisions and momentum and energy conservation laws.

10. Cross sections for particle scattering.

Cross sections for particle scattering. Definitions of differential and integral cross sections. Momentum transfer cross sections. Methods to measure and calculate cross sections.

11. Classical theory of scattering.

Classical theory of scattering. Scattering for model of rigid balls. Scattering theory for arbitrary interaction potential. Ion-neutral interaction. Resonant scattering of ions. Electron and ion scattering. Differential cross section for Coulomb interaction. Momentum cross section. Transport phenomena in fully ionized plasma.

12. Relaxation of electron momentum and energy.

Relaxation of electron momentum and energy. Relaxation of electron properties in collisions with ions and neutrals. Electron momentum relaxation frequency and characteristic length. Electron energy relaxation frequency and characteristic length.

13. Ionization and electron-ion recombination. Electron attachment and detachment.

Ionization and electron-ion recombination. Electron attachment and detachment. Electron-impact ionization of atoms and molecules. Step-wise electron-impact ionization. Ionization in collisions between neutrals. Photoionization. Dissociative, three-body and photo- electron-ion recombination. Electron attachment to molecules to form negative ions. Electron detachment from negative ions. Two-body and three-body ion-ion recombination.

14. Plasma decay.

Plasma decay. Plasma decay in diffusion regime. Decay under electron attachment. Recombination decay of plasma. Methods to determine attachment and recombination rates during plasma decay.

15. Non-equilibrium plasma.

Non-equilibrium plasma. Conditions that plasma is non-equilibrium. Non-equilibrium electron and ion energy distributions. Transport and rate coefficients in non-equilibrium plasma. Methods to calculate non-equilibrium electron and ion distributions.

16. Radiation in plasma.

Radiation in plasma. Bremsstrahlung radiation, radiation due to photorecombination and radiation in lines. Mechanisms of broadening of spectral lines: natural broadening, Doppler broadening, collisional broadening and broadening due to microscopic electric fields in plasma.

17. Properties of discharge plasma and electron-beam plasma.

Properties of discharge plasma and beam plasma. Glow discharge, arc, spark discharge, corona, streamer, leader, lightning discharge. Photoplasma, plasma generated by electron and ion beams. Similarities and difference between discharge plasma and 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)

Experimental complex "Beam-plasma systems and technologies" as part of the ELU-1 and ELU-2 installations, the PPT-2 plasma torch, RF gas-discharge plasma generators, hybrid plasma systems, diagnostic equipment, auxiliary and special technological equipment (room 222 of the UPM building) . Necessary equipment for practical exercises: computer and multimedia equipment (projector, marker board, Internet connection).

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).
5. J. Leon Shohet, Encyclopedia of Plasma Technology - Two Volume Set, CRC Press (2016).

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

The discipline presenting and studying are implemented in the following forms of activity:

- lectures aimed at obtaining the necessary information and how to use it in solving practical problems;
- practical classes aimed at enhancing the cognitive activity of students and acquiring skills for solving practical problems;
- independent extracurricular work is aimed at acquiring the skills of discipline problem self solving and is implemented in the form of special practical tasks in all discipline sections;
- consultations on lectures materials and self tuition.

The training course program provides for the acquaintance of students with the equipment and instruments used in the experiments, the features of the operation of the main and auxiliary systems of the experimental complex and a number of independent measurements on operating setups.

Successful mastering of the discipline requires intense student's self tuition. It includes:

- reading the recommended basic and additional literature;
- study of technical descriptions and manuals for the equipment used in experiments;
- preparation of proposals for setting up experiments within the framework of individual and group projects;
- familiarity with publications on the subject of studied topics.

The main indicators of knowledge of the material are the ability to demonstrate knowledge obtained from the materials of lectures and practical classes, as well as recommended literature.

SUPPLEMENT

Assessment funds for course (training module)

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: 2 (spring) - 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-1 Gain fundamental scientific knowledge in the field of physical and mathematical sciences	Gen.Pro.C-1.1 Apply fundamental scientific knowledge in the field of physical and mathematical sciences
	Gen.Pro.C-1.2 Consolidate and critically assess professional experience and research findings
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of the studied phenomena and processes, systematically analyze scientific problems and obtain new scientific results	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within the subject area
	Pro.C-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model

2. Competency assessment indicators

As a result of studying the course the student should:

know:

- general parameters of ideal and non-ideal plasmas processes;
- kinetics of elementary processes in equilibrium and non-equilibrium plasmas;
- features of processes in non-equilibrium plasmas;
- main transport plasma properties;
- fundamentals of thermodynamics and hydrodynamics of plasmas;
- principles for calculating the main plasma parameters;
- principles of plasma generation in a laboratory and plasma phenomena in nature;
- scientific basis of modern plasma technologies;
- Electron-Beam Plasma peculiarities and scientific principles of beam-plasma technologies.

be able to:

- apply in practice the basic concepts used in the analysis and description of plasma-physical processes in equilibrium and non-equilibrium plasmas;
- analyze plasma processes under various conditions of the plasma generation;
- numerically estimate the key characteristics of plasma generated by various ionizers, including the Electron-Beam generated plasma characteristics;
- analyze mechanisms of plasma-matter interaction and predict effect of plasma action on substances;
- to master new subject areas and theoretical approaches related to the analysis, design and application of Electron-Beam Plasma.

master:

- skills of mastering a large amount of interdisciplinary and special information;
- culture of setting goals in the field of design and application of plasma setups;
- initial skills in working on beam-plasma laboratory setups and in plasma physical experiments arrangement.

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

The list of laboratory works during the course:

- Thermal plasma, Electron-Beam Plasma and gas discharge plasma generation;
- Electron-Beam Plasma radiation;
- Electron-Beam Plasma decay.

4. Evaluation criteria

Examples of exam questions:

1. Plasma in nature and laboratory.
2. Thermodynamics of plasma.
3. Non-ideal plasma. Debye screening.
4. Plasma hydrodynamics.

5. Plasma electrical conductivity.
6. Processes of transfer in plasma.
7. Dielectric permittivity of plasma.
8. Ambipolar diffusion.
9. Collisions of particles in plasma.
10. Scattering cross sections. Integral and differential sections..
11. Classical scattering theory.
12. Processes of transfer in plasma.
13. Relaxation of momentum and energy of electrons.
14. Ionization and electron-ion recombination.
15. Formation and destruction of negative ions.
16. Pair and triple ion-ion recombination.
17. Mechanisms of plasma decay.
18. Non-equilibrium plasma in an electric field.
19. Non-equilibrium velocity distributions of electrons and ions.
20. Kinetic coefficients in nonequilibrium plasma.
21. Radiation processes in plasma.
22. Mechanisms of broadening of spectral lines in plasma.
23. Properties of gas-discharge plasma.
24. Beam plasma properties.

The main indicators of mastery of the material are the ability to demonstrate knowledge obtained from lecture materials and recommended literature, the correctness and completeness of answers to the teacher's questions that are asked to them during classes and related discussions. An additional survey of students when passing a differentiated test is not provided, however, the assessment given to a student involves taking into account the quality of the reports prepared by the student for seminars.

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

The main indicators of the materials assimilation for discipline "Plasma Physics" are the assessments of the teacher during the midterm control, and on the final (exam) certification of the ability to demonstrate the knowledge gained from the study of lecture materials и practical exercises, answering basic and additional questions of the examination ticket.

Boundary control is applied in the following forms:

- assessment of answers to questions in the process of a short (up to 5 minutes) selective oral survey before the start of each practical lesson based on the materials of the previous lesson;
- assessment of the ability to solve at the blackboard and / or in writing typical examples and / or tasks considered in practical classes;
- assessment of activity and answers to questions when solving typical problems in accordance with the program of practical classes.

The exam in the discipline is the final stage of studying of the entire course. It is aims to check the knowledge of students in theory and identify the skills of their application in solving practical problems, as well as the skills of self tuition with the recommended basic and additional literature.

The exam is carried out orally on tickets approved by the head of the department. The examiner is given the right, in addition to the theoretical questions of the ticket, to give students tasks and examples, typical options of which were considered in practical classes. Students with the permission of the examiner can use lecture notes, seminars, reference books only during the preparation for the exam. Time is allotted for preparation for the exam and the survey in accordance with the approved standards.