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

APPROVED
Vice Rector for Academic Affairs

A.A. Voronov

Work program of the course (training module)

course:	General Physics: Thermodynamics and Molecular Physics/Общая физика: термодинамика и молекулярная физика
major:	Biotechnology
specialization:	Biomedical Engineering/Биомедицинская инженерия
	Phystech School of Biological and Medical Physics
	Chair of General Physics
term:	2
qualification:	Bachelor

Semester, form of interim assessment: 3 (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

Authors of the program:

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The program was discussed at the Chair of General Physics 04.06.2020

Annotation

Mastering basic knowledge by students for further study of other branches of physics.

1. Study objective

Purpose of the course

Development of students ' basic knowledge in the field of mechanics for further study of other branches of physics and in-depth study of the fundamentals of statistical physics and physical kinetics.

Tasks of the course

- Formation of students ' basic knowledge in the field of thermodynamics and molecular physics;
- formation of skills and abilities to apply the studied theoretical laws and mathematical tools to solve various physical problems;
- formation of physical culture: the ability to distinguish the essential physical phenomena and to disregard the irrelevant; ability to conduct evaluations of physical quantities; the ability to build the simplest theoretical model describing physical processes.

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
UC-1 Search and identify, critically assess, and synthesize information, apply a systematic approach to problem-solving	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
Gen.Pro.C-2 Use modern IT and software tools to perform professional tasks in compliance with information security requirements	Gen.Pro.C-2.1 Apply modern computing tools and Internet services in professional settings
	Gen.Pro.C-2.2 Apply numerical mathematical methods and use software applications for scientific problem-solving in professional settings
	Gen.Pro.C-2.3 Fulfill basic information security requirements
Pro.C-2 Analyze research data and make scientific conclusions	Pro.C-2.1 Adopt methods of statistical process and scientific data analysis

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

As a result of studying the course the student should:

know:

- fundamental laws and concepts of thermodynamics and molecular physics, as well as the limits of their applicability;
- basic laws of thermodynamics (1, 2, 3 "beginnings»");
- the concept of equilibrium and nonequilibrium processes, thermodynamic definition of entropy, the law of increasing entropy, the entropy of an ideal gas;
- basis of molecular-kinetic theory (the basic equation of molecular-kinetic theory, the mean free path, Boltzmann distribution, Maxwell);
- fundamentals of statistical physics (statistical meaning of entropy, the concept of Gibbs distribution);
- basis of quantum theory of heat capacity (degrees of freedom and exhilaration, ha racteristics temperature, the law Dulong-PTI);
- fundamentals of the theory of phase transitions (phase diagrams, heat of transitions, equation Clapeyron Clausius);
- the basic laws of surface tension (the surface tension, the Laplace's equation, the internal energy per unit of surface);
- fundamentals of the theory of transport processes: diffusion, thermal conductivity, viscosity. Transport co-efficients in gaseous media. Brownian motion, Einstein-on-Smoluchowski law. Relationship between mobility and diffusion coefficient.

be able to:

- apply the studied General physical laws to solve specific problems of mechanics;
- to apply the conservation laws to calculate the processes of compression/expansion of gases, including for the gas to expand into the void; the flow of gases from small openings; the flow in terms of the effect of Joule-Thomson;
- calculate the efficiency of the equilibrium cycles of heat and refrigeration machines, including those specified in the coordinates TS;
- calculate the change in entropy in nonequilibrium processes, as well as the maximum and minimum operation of systems;
- calculate thermal processes taking into account the presence of phase transitions and surface tension effects;
- calculate thermal processes for non-ideal gases (for the van der Waals equation);
- use probability distributions, be able to calculate mean values and standard deviations of parameters for the cases of Boltzmann and Maxwell distributions;
- calculate statistical weight and entropy based on statistical theory for the simplest systems with discrete energy levels;
- calculate the velocity of mass transfer (or heat) for the diffusion (or heat of provodnosti) in the stationary and quasistationary cases;
- analyze physical problems, highlighting the essential and non-essential aspects of the phenomenon, and on the basis of the analysis to build a simplified theoretical model of physical phenomena;
- apply various mathematical tools for solving problems based on the formulated physical laws, and carry out the necessary analytical and numerical calculations.

master:

- the main methods of solving problems of thermodynamics and molecular physics;
- basic mathematical tools characteristic of the task thermodynami-CI and molecular physics.

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	The first law of thermodynamics. Heat capacity. Adiabatic and polytropic processes.	2	2		3
2	Heat engines. The second law of thermodynamics. Entropy.	2	2		3

3	Entropy changes in irreversible processes. Surface phenomena.	2	2		3
4	Thermodynamic potentials. Transformations of thermody-namic functions.	2	2		3
5	Phase transitions. The Clausius–Clapeyron relation.	2	2		3
6	Elements of the hydrodynamics. Bernoulli equation. Viscous flow.	2	2		3
7	Real gases. The Joule–Thomson effect.	2	2		3
8	Test № 1	2	2		3
9	Feedback Session.	2	2		3
10	Basics of the kinetic theory of gases. The Maxwell distribu-tion.	2	2		3
11	The Boltzmann distribution.Theory of heat capacity.	2	2		3
12	Statistical meaning of entropy. Fluctuations.	2	2		3
13	Collisions, mean free path. Molecular transport phenomena	2	2		3
14	Brownian motion. Phenomena in rarefied gases.	2	2		3
15	Test № 2	2	2		3
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: 3 (Fall)

1. The first law of thermodynamics. Heat capacity. Adiabatic and polytropic processes.

Solving problems via the use of the thermal equation of state of an ideal gas, the first law of thermodynamics in integral and differential forms. Solving differential equations via the variable separation, derivation of adiabatic and polytrope equations.

2. Heat engines. The second law of thermodynamics. Entropy.

Determination of the efficiency of heat engines and the coefficient of performance of refrigerators. Application of the second law of thermodynamics to reversible processes. Calculation of the change in entropy in processes with constant heat capacity.

3. Entropy changes in irreversible processes. Surface phenomena.

Evaluating the change in entropy in irreversible processes. Solving problems on the mechanical and thermodynamic properties of liquid surfaces.

4. Thermodynamic potentials. Transformations of thermody-namic functions.

Application of the method of thermodynamic potentials for calculation of thermodynamic derivatives. Obtaining of thermal and caloric equations of state from the canonic equation of state.

5. Phase transitions. The Clausius–Clapeyron relation.

Solving problems on the phase equilibrium of single-component systems. Calculation of the saturated vapor pressure using the Clausius-Clapeyron relation.

6. Elements of the hydrodynamics. Bernoulli equation. Viscous flow.

Discussion of problems on the flow of ideal (Bernoulli principle) and viscous (Poiseuille equation) liquids and gases.

7. Real gases. The Joule–Thomson effect.

Determination of phase transition parameters of real gas described by the van der Waals equation. Evaluation of critical parameters and the temperature change in Joule-Thomson process.

8. Test № 1

Written test on the material of seminars 1-7.

9. Feedback Session.

Feedback session. Discussion on mistakes made in written test.

10. Basics of the kinetic theory of gases. The Maxwell distribu-tion.

Solving problems on the basics of kinetic theory of gases. Calculation of average speeds and related values in systems composed of molecules having Maxwell distribution for velocities.

11. The Boltzmann distribution.Theory of heat capacity.

Solving problems on the behavior of gases in the conservative force field. Calculation of heat capacity using the basics of quantum theory.

12. Statistical meaning of entropy. Fluctuations.

Determination of statistical weight of thermodynamic systems. Calculation of fluctuations of volume, particle number etc.

13. Collisions, mean free path. Molecular transport phenomena

Study of molecular transport phenomena in gases, such as diffusion, viscosity and heat conduction.

14. Brownian motion. Phenomena in rarefied gases.

Problems on application of Brownian motion laws. Phenomena in rarefied gases, i.e. the gases whose molecules have mean free path comparable with the size of the vessel in which they are contained.

15. Test № 2

Preparation to the written exam. Submission of second assignment.

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

Facilities and Resources:
- A lecture audience equipped with a multimedia projector and a screen.
- Equipment for lecture demonstrations.
- Classrooms equipped with a board.
- Libraries of educational and technical literature, including electronic libraries, necessary for individual work of students.

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

Main literature

1. Physics: A General Course v. 1: Mechanics, Molecular Physics (by I.V. Savelyev), Central Books Ltd (1981), Mir Publishers (1989)
2. General Physics: Mechanics and Molecular Physics (by L. Landau, A. Akhiezer, E. Lifshitz), Pergamon Press (1967)
3. Problems in General Physics (by I.E. Irodov), Mir Publishers (Revised edition 1988)

Additional literature

1. Fundamental Laws of Mechanics (by I.E. Irodov), Mir Publishers (Moscow), CBS Publishers & Distributors (India), 6th edition (2016)
2. Berkeley Physics Course: Vol. 1 - Mechanics (by C. Kittel, W.D. Knight, and M.A. Ruderman), McGraw-Hill, New York, second edition (1973)
3. The Feynman Lectures on Physics, The Definitive Edition Volume 1: (2nd Edition) by Richard P. Feynman and Robert B. Leighton, Addison Wesley; 2nd edition (2005)

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

1. http://mipt.ru/education/chair/physics/S_IV/Metod_4/— методический раздел сайта кафедры Общей физики
2. http://lib.mipt.ru/catalogue/1412/?t=750 – электронная библиотека МФТИ, раздел «Общая физика»

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

The lectures use multimedia technologies, including demon-stration of presentations.
The literature recommended for the course is available in electronic form (see[1,2] of the list of resources of the information and telecommunication network "Internet", necessary for the development of the discipline (module)), so that students can read textbooks directly from their tablets.

9. Guidelines for students to master the course

Guidelines for Students on Mastering the Discipline:
A student studying the general physics course must learn the general physics laws and concepts, and how to apply them in practice.
Successful mastering of the course requires intensive individual work of each student. The course program informs of the minimum time required for the student to work on the course topics. The individual work includes:
- reading and making summary of recommended literature,
- studying educational materials (lecture notes, educational and scientific literature), preparing answers to questions intended for self-study;
- solving the problems offered to students in lectures and seminars,

- passing assignments and preparing for seminars, tests, and exams.

Guidance and control of individual work is offered to students in the form of individual consultations.

The ability to solve problems is an indicator of the student's mastery of physics. To develop such ability, a student needs to solve as many problems as possible. When solving a problem, a student must be able to explain each action on the basis of the studied theoretical topics and carry out all the necessary calculations to bring the solution to a final answer. A problem is considered solved if it contains substantiated actions including references to the applicable physical laws and correct calculations, as well as the correct numerical answer (if the problem contains numerical data).

When preparing for a seminar, students must learn the basic concepts and laws to which the seminar will be devoted, and solve the problems envisaged for preparation to the seminar topic.

Physics makes use of many concepts and methods of calculus. If a student encounters a mathematical concept that has not yet been studied in the framework of mathematical courses then he/she must learn the relevant section of math individually. The necessary minimum of mathematical information is presented both at lectures and in the recommended literature.

The mid-semester control of knowledge is conducted in the form of a written test, in which the student is offered to solve five problems on the studied topics. The written test is given in the format similar to a written exam. In order to test the student's level of knowledge and understanding of the material, the teacher may ask the student, during the presentation of the assignment, additional theoretical questions on the syllabus or give additional problems to solve. Each student is required to complete, in a special notebook, the homework assignments and submit them for inspection.

At the written exam, the student is asked to solve five problems. The subjects of the problems are fully consistent with the physics course syllabus. However, all the problems in the written exam are completely non-typical. At the exam, students are allowed to use a sheet of paper with formulas written on it in advance. Such form of exam eliminates mindless memorization of formulas and is aimed at checking the depth of understanding of the material and the ability to apply physical laws in an unusual situation.

Students are recommended to study individually various topics related to general physics, possibly beyond the scope of the program, thus expanding their physical horizon. At the exam, the student is offered to present any theoretical or experimental topic prepared in advance and related to the course of physics. This can be either an in-depth presentation of one of the syllabus topics or a topic not covered in the syllabus, which can, however, be considered as part of the physics course studied, thus demonstrating the ability to understand various issues and problems of physics based on the use of general physical laws.

SUPPLEMENT

Assessment funds for course (training module)

major:	Biotechnology
specialization:	Biomedical Engineering/Биомедицинская инженерия Phystech School of Biological and Medical Physics Chair of General Physics
term:	2
qualification:	Bachelor

Semester, form of interim assessment: 3 (fall) - Exam

Authors:

P.V. Popov, candidate of physics and mathematical sciences
A.V. Ilin, candidate of physics and mathematical sciences, associate professor

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
UC-1 Search and identify, critically assess, and synthesize information, apply a systematic approach to problem-solving	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
Gen.Pro.C-2 Use modern IT and software tools to perform professional tasks in compliance with information security requirements	Gen.Pro.C-2.1 Apply modern computing tools and Internet services in professional settings
	Gen.Pro.C-2.2 Apply numerical mathematical methods and use software applications for scientific problem-solving in professional settings
	Gen.Pro.C-2.3 Fulfill basic information security requirements
Pro.C-2 Analyze research data and make scientific conclusions	Pro.C-2.1 Adopt methods of statistical process and scientific data analysis

2. Competency assessment indicators

As a result of studying the course the student should:

know:

- fundamental laws and concepts of thermodynamics and molecular physics, as well as the limits of their applicability;
- basic laws of thermodynamics (1, 2, 3 "beginnings»);
- the concept of equilibrium and nonequilibrium processes, thermodynamic definition of entropy, the law of increasing entropy, the entropy of an ideal gas;
- basis of molecular-kinetic theory (the basic equation of molecular-kinetic theory, the mean free path, Boltzmann distribution, Maxwell);
- fundamentals of statistical physics (statistical meaning of entropy, the concept of Gibbs distribution);
- basis of quantum theory of heat capacity (degrees of freedom and exhilaration, ha racteristics temperature, the law Dulong-PTI);
- fundamentals of the theory of phase transitions (phase diagrams, heat of transitions, equation Clapeyron Clausius);
- the basic laws of surface tension (the surface tension, the Laplace's equation, the internal energy per unit of surface);
- fundamentals of the theory of transport processes: diffusion, thermal conductivity, viscosity. Transport co-efficients in gaseous media. Brownian motion, Einstein-on-Smoluchowski law. Relationship between mobility and diffusion coefficient.

be able to:

- apply the studied General physical laws to solve specific problems of mechanics;
- to apply the conservation laws to calculate the processes of compression/expansion of gases, including for the gas to expand into the void; the flow of gases from small openings; the flow in terms of the effect of Joule-Thomson;
- calculate the efficiency of the equilibrium cycles of heat and refrigeration machines, including those specified in the coordinates TS;
- calculate the change in entropy in nonequilibrium processes, as well as the maximum and minimum operation of systems;
- calculate thermal processes taking into account the presence of phase transitions and surface tension effects;
- calculate thermal processes for non-ideal gases (for the van der Waals equation);
- use probability distributions, be able to calculate mean values and standard deviations of parameters for the cases of Boltzmann and Maxwell distributions;
- calculate statistical weight and entropy based on statistical theory for the simplest systems with discrete energy levels;
- calculate the velocity of mass transfer (or heat) for the diffusion (or heat of provodnosti) in the stationary and quasistationary cases;
- analyze physical problems, highlighting the essential and non-essential aspects of the phenomenon, and on the basis of the analysis to build a simplified theoretical model of physical phenomena;
- apply various mathematical tools for solving problems based on the formulated physical laws, and carry out the necessary analytical and numerical calculations.

master:

- the main methods of solving problems of thermodynamics and molecular physics;
- basic mathematical tools characteristic of the task thermodynami-CI and molecular physics.

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

Examples of simple problems which student should be able to solve to acquire a satisfactory mark:

- Find the energy of an ideal gas with the constant heat capacity CV, at a pressure of P and volume of V.
- Express the pressure of an ideal gas via the number density and the average kinetic energy of translational motion of its molecules.
- Write down the first law of thermodynamics in the differential form.
- Calculate the work done by ideal gas in isothermal/adiabatic process.
- Derive the adiabatic equation of an ideal gas
- Obtain the difference CP-CV for an ideal gas.
- Adiabatic flow of gases. Speed of sound.
- Find the speed of outflow of an ideal monatomic gas at temperature T through the hole to vacuum.
- Calculate the speed of sound in air at room temperature.
- Draw a Carnot cycle in TS coordinates. Indicate on the graph the heat of the heater and the refrigerator, as well as the work done in the cycle.
- Obtain the expression for the efficiency of an ideal Carnot heat engine.
- A system absorbs the amount of heat Q at a temperature of T. Find possible values of the entropy change dS.
- Give a statistical definition of entropy. How an equilibrium state is defined?
- Find the entropy change of a mole of an ideal gas that undergoes a transition between two states defined by the given T and V (or T and P).
- Two solids with known heat capacities having different temperatures are brought into thermal contact. Find the entropy change of the system when the equilibrium is established.
- Find the entropy change of an ideal gas during nonequilibrium free expansion in a ther-mally insulated shell.
- Write the differential of internal energy/enthalpy/Helmholtz energy/Gibbs energy.
- Obtain the expression for the enthalpy of an ideal gas with the constant heat capacity CP.
- In the process, at a constant pressure, heat Q was absorbed by the system. Find the change in the enthalpy of the system.
- In the isothermal process, work A was done on the system. Find the change in the free en-ergy of the system.

- Find the pressure of a saturated vapor of water at a temperature 100 °C.
- Obtain the temperature dependence of the pressure of water vapor.
- Draw the phase diagram of water.
- Write van der Waals equation and explain the physical meaning of its constants.
- Schematically draw a family of van der Waals gas isotherms and corresponding isotherms of a real gas.
- Find the temperature change of a van der Waals gas during free expansion in a thermally insulated shell.
- Find the temperature change of an ideal gas in Joule-Thompson process.
- Find the pressure inside a soap bubble.
- Find the height to which water will rise in the capillary with a known wetting angle.
- Express the free energy of the liquid surface through the coefficient of surface tension.
- Write (up to a normalization constant) and schematically plot the Maxwell distribution of the velocity projections on the x axis.
- Write (up to a normalization constant) and schematically plot the Maxwell distribution of speeds.
- Write expressions for the rms and most probable speeds of the molecules.
- Find the number of particles hitting the area S per second in a gas with temperature T and pressure P.
- Derive the barometric formula for an isothermal atmosphere.
- The energy of an atom in an excited state is greater by E than in the ground state. Find the fraction of excited atoms in the system at temperature T. Other energy levels should not be taken into account.
- Formulate the equipartition. How much energy corresponds to one fully excited vibra-tional degree of freedom of a molecule?
- Plot schematically the temperature dependence of molar heat capacity CV of diatomic gas (nitrogen).
- The average number of particles of an ideal gas in a selected volume is N. Estimate the root-mean-square fluctuation of the number of particles in it.
- Find the standard deviation of the load on a spring with a stiffness k from the equilibrium position at temperature T.
- Obtain an approximate formula for the mean free path of molecules in a gas of solid balls.
- Provide a definition of the particle flux density (heat, momentum) and the diffusion coef-ficient (thermal conductivity, viscosity).
- Write an estimate of the diffusion/thermal conductivity/viscosity coefficient of an ideal gas with known parameters.
- How does the thermal conductivity of a gas in a vessel depend on pressure (including high vacuum)?
- Write the equilibrium condition between two vessels with ideal gases connected by a thin pipe if the radius of the pipe is much less than the mean free path (Knudsen effect).
- The diffusion coefficient of particles is D. Estimate the mean square displacement of the particle in space from the initial position over time t.
- Give a definition of the mobility of a particle and write a relation between the mobility of a Brownian particle and the diffusion coefficient.

4. Evaluation criteria

1. Ideal and non-ideal gases. Ideal gas pressure as a function of the kinetic energy of mole-cules. The relation between the temperature of an ideal gas and the kinetic energy of its molecules.
2. Thermodynamic system. Microscopic and macroscopic parameters. Equation of state. Sta-tionary, equilibrium, and non-equilibrium states and processes.
3. Work, heat, internal energy. State functions. The first law of thermodynamics.
4. Work done by an ideal gas in isothermal and isobaric processes. The internal energy of an ideal gas.
5. Heat capacity. Heat capacities CV and CP. CV and CP of ideal gases. Mayer's relation.
6. Adiabatic and polytropic processes. Adiabatic and polytropic equations for an ideal gas.
7. Heat engines. The efficiency of a heat engine. Carnot cycle. Carnot's theorems.
8. The second law of thermodynamics. The Clausius theorem (the inequality and equality of Clausius). Entropy. The law of increasing entropy.

9. The entropy of an ideal gas.
10. Thermodynamic potentials. Maxwell relations (reciprocal relations). The Gibbs-Helmholtz equations.
11. The relation between the derivative $\partial U/\partial V$ and the equation of state.
12. Difference CP-CV in general case.
13. First-order phase transitions. The Clausius–Clapeyron relation. The vapor-liquid equilibri-um curve. Critical point.
14. Temperature dependence of latent heat of phase transition.
15. Phase diagram "ice-water-steam." Triple point.
16. Van der Waals gas as a model of real gas. Van der Waals gas isotherms. Critical parame-ters. Reduced equation of state. The theorem of corresponding states.
17. Metastable states. Superheated water and supercooled steam. Stability of states. Max-well's rule.
18. Internal energy and entropy of a van der Waals gas. Temperature change upon nonequilib-rium expansion into a vacuum.
19. Integral Joule-Thomson effect. Temperature of inversion.
20. Surface phenomena. Contact angles, wetting, and non-wetting. Laplace formula.
21. Dependence of the vapor pressure on the curvature of the liquid surface.
22. Boiling. The role of nucleation in the phase transition.
23. Maxwell distribution for velocities and momenta of particles. The most probable, average, and rms speed.
24. Maxwell distribution for energy of particles. The most probable and average energy.
25. The average number of particles colliding with an area per unit of time.
26. The average kinetic energy of effusing particles.
27. The barometric formula. The Boltzmann distribution.
28. Macroscopic and microscopic states. The Gibbs distribution.
29. Partition function and its application for finding the average energy of a subsystem.
30. Statistical definition of entropy. Additivity of entropy. The law of increasing entropy.
31. Entropy change in mixing two gases, Gibbs paradox.
32. Fluctuations of the number of particles in a given volume.
33. Fluctuations of temperature in a given volume.
34. Fluctuations of volume in an isothermic and adiabatic process.
35. The influence of fluctuations on the accuracy of measuring devices (on the example of a spring scale).
36. The classical theory of heat capacity. The law of equipartition.
37. Elements of the quantum theory of specific heat. Characteristic temperatures. Heat capac-ity of solids (Dulong-Petit law).
38. The third law of thermodynamics.
39. Collisions. Effective collisional cross-section. Mean free path. Molecular free path distri-bution.
40. Diffusion. Fick's law. The diffusion coefficient.
41. Thermal conductivity. Fourier's law. Coefficient of thermal conductivity. Heat equation.
42. Viscosity. Newton's law. Viscosity coefficient.
43. Brownian motion. Mobility. Einstein-Smoluchowski law.
44. The relation between the particle mobility and the diffusion coefficient.
45. Transport phenomena in rarefied gases. Knudsen effect. Effusion. Gas mixture separation via effusion.
46. The flow of rarefied gas.

The mark given for the written exam depends on the problem solutions presented by a student. Each problem's solution is evaluated according to a three-point grading scale, i.e., each solution is assigned from 0 to 3 points according to the following criteria:

3 points: The problem is solved completely and correctly, i.e., the correct well-founded solution is given and all questions of the problem are answered. Minor flaws may be present (a slip of the pen, or insignificant arithmetic errors).

2 points: The problem is solved, the logic of solution as a whole is correct, but there are signifi-cant shortcomings (errors in calculations, an absurd answer, etc.).

1 point: The problem is not solved, but all the basic physical laws necessary for the solution are formulated correctly.

0 points: The problem is not solved or solved incorrectly (the basic laws are written with errors, or not completely, the approach to solving the problem is fundamentally wrong, or the solution to the problem does not match the statement).

The points for the five problems of the written exam are summed up, the mark, and the final score for the written exam are set according to the following scheme:

The sum of all points	Score	Mark
15	10	Excellent
13-14	9	
12	8	
11	7	Good
9-10	6	
8	5	
6-7	4	Satisfactory
5	3	
2-4	2	Unsatisfactory
0-1	1	

The written exam score determines the maximum final score that a student may get at the oral exam. In exceptional cases, when the student demonstrates, during the oral exam, excellent theo-retical knowledge and superb level of understanding of the subject, the final score for the oral exam may be increased but no more than by two points (on a 10-point scale).

At the oral exam, the teacher will assess the student’s answer as a whole and assign a mark ac-cording to the criteria set forth below and the above comments regarding the written exam score:

The mark “excellent” (10 points) is given to a student who has shown comprehensive and sys-tematic knowledge of the syllabus and beyond, as well as the ability to confidently apply the knowledge in solving complicated non-standard problems.

The mark “excellent” (9 points) is given to a student who has shown comprehensive and system-atic knowledge of the syllabus and the ability to confidently apply the knowledge in solving non-standard problems.

The mark “excellent” (8 points) is given to a student who has shown comprehensive and system-atic knowledge of the syllabus and the ability to confidently apply the knowledge in solving non-standard problems but who has allowed for some inaccuracies.

The mark “good” (7 points) is given to a student who has demonstrated firm knowledge and confident understanding of the syllabus and the ability to apply physical laws in solving typical problems.

The mark “good” (6 points) is given to a student who has demonstrated a solid knowledge of the syllabus and the ability to apply physical laws in solving typical problems.

The mark “good” (5 points) is given to a student who has demonstrated firm knowledge and un-derstanding of the syllabus and the ability to apply physical laws in solving typical problems, however, made a number of gross inaccuracies when answering.

The mark “satisfactorily” (4 points) is given to a student who has shown a fragmentary knowledge and made mistakes in the formulation of basic laws and concepts, but at the same time demonstrated the ability to solve simple problems and understanding of the main sections of syllabus necessary for further education.

The mark “satisfactorily” (3 points) is given to a student who has shown a highly fragmented knowledge, made gross mistakes in the formulation of basic laws and concepts, but at the same time demonstrated the ability to solve simple problems and understand the main sections of the syllabus required for further education.

The mark “unsatisfactory” (2 points) or “unsatisfactory” (1 point) is given to a student who knows little of the main content of the syllabus, systematically makes gross mistakes in formulat-ing basic physical laws, or is unable to apply correctly physical laws even to solve simple prob-lems.

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

The oral exam is held in the traditional form of teacher's conversation with a student on the topic contained in the examination card.

The student is given from 30 to 45 minutes to prepare the answer on the given topic. During the exam, the student is not allowed to use any literature, computers, preprepared own rec-ords, or other materials related to the subject, except for the examination program of the course.

In discussing the exam card topic, the examiner may ask clarifying questions. Also, the examiner has the right to ask the student any additional questions on the syllabus.

In the aggregate, the duration of the oral exam for one student should not exceed two as-tronomical hours.

3. The list of typical assignments used to assess the level of knowledge and skills of the students.

Intermediate certification of students in *General Physics* is carried out in the form of examination. The exam consists of two parts: a written test and an oral exam.

At the written test, a student is offered to solve five problems. Each problem is an original work of authorship, specially prepared for the exam.

At the oral exam, each student has to choose an exam card from a pile of exam cards. Each card contains a theoretical question from the below list of exam questions. In addition, the student is asked to present a "question of choice" prepared in advance, which may be either one of the items in the below list of questions, or any question that is addressed in the course being studied or directly related to it. Also, the results of a laboratory work done by the student may be presented as a question of choice.

The List of Oral Exam Questions:

1. Ideal and non-ideal gases. Ideal gas pressure as a function of the kinetic energy of molecules. The relation between the temperature of an ideal gas and the kinetic energy of its molecules.
2. Thermodynamic system. Microscopic and macroscopic parameters. Equation of state. Stationary, equilibrium, and non-equilibrium states and processes.
3. Work, heat, internal energy. State functions. The first law of thermodynamics.
4. Work done by an ideal gas in isothermal and isobaric processes. The internal energy of an ideal gas.
5. Heat capacity. Heat capacities C_V and C_P. C_V and C_P of ideal gases. Mayer's relation.
6. Adiabatic and polytropic processes. Adiabatic and polytropic equations for an ideal gas.
7. Heat engines. The efficiency of a heat engine. Carnot cycle. Carnot's theorems.
8. The second law of thermodynamics. The Clausius theorem (the inequality and equality of Clausius). Entropy. The law of increasing entropy.
9. The entropy of an ideal gas.
10. Thermodynamic potentials. Maxwell relations (reciprocal relations). The Gibbs-Helmholtz equations.
11. The relation between the derivative $\partial U/\partial V$ and the equation of state.
12. Difference C_P-C_V in general case.
13. First-order phase transitions. The Clausius–Clapeyron relation. The vapor-liquid equilibrium curve. Critical point.
14. Temperature dependence of latent heat of phase transition.
15. Phase diagram "ice-water-steam." Triple point.
16. Van der Waals gas as a model of real gas. Van der Waals gas isotherms. Critical parameters. Reduced equation of state. The theorem of corresponding states.
17. Metastable states. Superheated water and supercooled steam. Stability of states. Maxwell's rule.
18. Internal energy and entropy of a van der Waals gas. Temperature change upon nonequilibrium expansion into a vacuum.
19. Integral Joule-Thomson effect. Temperature of inversion.
20. Surface phenomena. Contact angles, wetting, and non-wetting. Laplace formula.
21. Dependence of the vapor pressure on the curvature of the liquid surface.
22. Boiling. The role of nucleation in the phase transition.
23. Maxwell distribution for velocities and momenta of particles. The most probable, average,

and rms speed.

24. Maxwell distribution for energy of particles. The most probable and average energy.
25. The average number of particles colliding with an area per unit of time.
26. The average kinetic energy of effusing particles.
27. The barometric formula. The Boltzmann distribution.
28. Macroscopic and microscopic states. The Gibbs distribution.
29. Partition function and its application for finding the average energy of a subsystem.
30. Statistical definition of entropy. Additivity of entropy. The law of increasing entropy.
31. Entropy change in mixing two gases, Gibbs paradox.
32. Fluctuations of the number of particles in a given volume.
33. Fluctuations of temperature in a given volume.
34. Fluctuations of volume in an isothermic and adiabatic process.
35. The influence of fluctuations on the accuracy of measuring devices (on the example of a spring scale).
36. The classical theory of heat capacity. The law of equipartition.
37. Elements of the quantum theory of specific heat. Characteristic temperatures. Heat capacity of solids (Dulong-Petit law).
38. The third law of thermodynamics.
39. Collisions. Effective collisional cross-section. Mean free path. Molecular free path distribution.
40. Diffusion. Fick's law. The diffusion coefficient.
41. Thermal conductivity. Fourier's law. Coefficient of thermal conductivity. Heat equation.
42. Viscosity. Newton's law. Viscosity coefficient.
43. Brownian motion. Mobility. Einstein-Smoluchowski law.
44. The relation between the particle mobility and the diffusion coefficient.
45. Transport phenomena in rarefied gases. Knudsen effect. Effusion. Gas mixture separation via effusion.
46. The flow of rarefied gas.

Examples of simple problems which student should be able to solve to acquire a satisfactory mark:

- Find the energy of an ideal gas with the constant heat capacity C_V, at a pressure of P and volume of V.
- Express the pressure of an ideal gas via the number density and the average kinetic energy of translational motion of its molecules.
- Write down the first law of thermodynamics in the differential form.
- Calculate the work done by ideal gas in isothermal/adiabatic process.
- Derive the adiabatic equation of an ideal gas
- Obtain the difference C_P-C_V for an ideal gas.
- Adiabatic flow of gases. Speed of sound.
- Find the speed of outflow of an ideal monatomic gas at temperature T through the hole to vacuum.
- Calculate the speed of sound in air at room temperature.
- Draw a Carnot cycle in TS coordinates. Indicate on the graph the heat of the heater and the refrigerator, as well as the work done in the cycle.
- Obtain the expression for the efficiency of an ideal Carnot heat engine.
- A system absorbs the amount of heat Q at a temperature of T. Find possible values of the entropy change dS.
- Give a statistical definition of entropy. How an equilibrium state is defined?
- Find the entropy change of a mole of an ideal gas that undergoes a transition between two states defined by the given T and V (or T and P).

- Two solids with known heat capacities having different temperatures are brought into thermal contact. Find the entropy change of the system when the equilibrium is established.
- Find the entropy change of an ideal gas during nonequilibrium free expansion in a thermally insulated shell.
- Write the differential of internal energy/enthalpy/Helmholtz energy/Gibbs energy.
- Obtain the expression for the enthalpy of an ideal gas with the constant heat capacity C_P.
- In the process, at a constant pressure, heat Q was absorbed by the system. Find the change in the enthalpy of the system.
- In the isothermal process, work *A* was done on the system. Find the change in the free energy of the system.
- Find the pressure of a saturated vapor of water at a temperature 100 °C.
- Obtain the temperature dependence of the pressure of water vapor.
- Draw the phase diagram of water.
- Write van der Waals equation and explain the physical meaning of its constants.
- Schematically draw a family of van der Waals gas isotherms and corresponding isotherms of a real gas.
- Find the temperature change of a van der Waals gas during free expansion in a thermally insulated shell.
- Find the temperature change of an ideal gas in Joule-Thompson process.
- Find the pressure inside a soap bubble.
- Find the height to which water will rise in the capillary with a known wetting angle.
- Express the free energy of the liquid surface through the coefficient of surface tension.
- Write (up to a normalization constant) and schematically plot the Maxwell distribution of the velocity projections on the x axis.
- Write (up to a normalization constant) and schematically plot the Maxwell distribution of speeds.
- Write expressions for the rms and most probable speeds of the molecules.
- Find the number of particles hitting the area S per second in a gas with temperature *T* and pressure *P*.
- Derive the barometric formula for an isothermal atmosphere.
- The energy of an atom in an excited state is greater by *E* than in the ground state. Find the fraction of excited atoms in the system at temperature *T*. Other energy levels should not be taken into account.
- Formulate the equipartition. How much energy corresponds to one fully excited vibrational degree of freedom of a molecule?
- Plot schematically the temperature dependence of molar heat capacity C_V of diatomic gas (nitrogen).
- The average number of particles of an ideal gas in a selected volume is *N*. Estimate the root-mean-square fluctuation of the number of particles in it.
- Find the standard deviation of the load on a spring with a stiffness k from the equilibrium position at temperature *T*.
- Obtain an approximate formula for the mean free path of molecules in a gas of solid balls.
- Provide a definition of the particle flux density (heat, momentum) and the diffusion coefficient (thermal conductivity, viscosity).
- Write an estimate of the diffusion/thermal conductivity/viscosity coefficient of an ideal gas with known parameters.
- How does the thermal conductivity of a gas in a vessel depend on pressure (including high vacuum)?
- Write the equilibrium condition between two vessels with ideal gases connected by a thin pipe if the radius of the pipe is much less than the mean free path (Knudsen effect).

- The diffusion coefficient of particles is D. Estimate the mean square displacement of the particle in space from the initial position over time t.
- Give a definition of the mobility of a particle and write a relation between the mobility of a Brownian particle and the diffusion coefficient.

4. Evaluation Criteria

The mark given for the written exam depends on the problem solutions presented by a student. Each problem's solution is evaluated according to a three-point grading scale, i.e., each solution is assigned from 0 to 3 points according to the following criteria:

3 points: The problem is solved completely and correctly, i.e., the correct well-founded solution is given and all questions of the problem are answered. Minor flaws may be present (a slip of the pen, or insignificant arithmetic errors).

2 points: The problem is solved, the logic of solution as a whole is correct, but there are significant shortcomings (errors in calculations, an absurd answer, etc.).

1 point: The problem is not solved, but all the basic physical laws necessary for the solution are formulated correctly.

0 points: The problem is not solved or solved incorrectly (the basic laws are written with errors, or not completely, the approach to solving the problem is fundamentally wrong, or the solution to the problem does not match the statement).

The points for the five problems of the written exam are summed up, the mark, and the final score for the written exam are set according to the following scheme:

<table>
<tr><th>The sum of all points</th><th>Score</th><th>Mark</th></tr>
<tr><td>15</td><td>10</td><td rowspan="3">Excellent</td></tr>
<tr><td>13-14</td><td>9</td></tr>
<tr><td>12</td><td>8</td></tr>
<tr><td>11</td><td>7</td><td rowspan="3">Good</td></tr>
<tr><td>9-10</td><td>6</td></tr>
<tr><td>8</td><td>5</td></tr>
<tr><td>6-7</td><td>4</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>5</td><td>3</td></tr>
<tr><td>2-4</td><td>2</td><td rowspan="2">Unsatisfactory</td></tr>
<tr><td>0-1</td><td>1</td></tr>
</table>

The written exam score determines the maximum final score that a student may get at the oral exam. In exceptional cases, when the student demonstrates, during the oral exam, excellent theoretical knowledge and superb level of understanding of the subject, the final score for the oral exam may be increased but no more than by two points (on a 10-point scale).

At the oral exam, the teacher will assess the student's answer as a whole and assign a mark according to the criteria set forth below and the above comments regarding the written exam score:

The mark **“excellent”** (10 points) is given to a student who has shown comprehensive and systematic knowledge of the syllabus and beyond, as well as the ability to confidently apply the knowledge in solving complicated non-standard problems.

The mark **“excellent”** (9 points) is given to a student who has shown comprehensive and systematic knowledge of the syllabus and the ability to confidently apply the knowledge in solving non-standard problems.

The mark **“excellent”** (8 points) is given to a student who has shown comprehensive and systematic knowledge of the syllabus and the ability to confidently apply the knowledge in solving non-standard problems but who has allowed for some inaccuracies.

The mark **“good”** (7 points) is given to a student who has demonstrated firm knowledge and confident understanding of the syllabus and the ability to apply physical laws in solving typical problems.

The mark **“good”** (6 points) is given to a student who has demonstrated a solid knowledge of the syllabus and the ability to apply physical laws in solving typical problems.

The mark **“good”** (5 points) is given to a student who has demonstrated firm knowledge and understanding of the syllabus and the ability to apply physical laws in solving typical problems, however, made a number of gross inaccuracies when answering.

The mark **“satisfactorily”** (4 points) is given to a student who has shown a fragmentary knowledge and made mistakes in the formulation of basic laws and concepts, but at the same time demonstrated the ability to solve simple problems and understanding of the main sections of syllabus necessary for further education.

The mark **“satisfactorily”** (3 points) is given to a student who has shown a highly fragmented knowledge, made gross mistakes in the formulation of basic laws and concepts, but at the same time demonstrated the ability to solve simple problems and understand the main sections of the syllabus required for further education.

The mark **“unsatisfactory”** (2 points) or **“unsatisfactory”** (1 point) is given to a student who knows little of the main content of the syllabus, systematically makes gross mistakes in formulating basic physical laws, or is unable to apply correctly physical laws even to solve simple problems.

5. Teaching Aids Defining the Procedures for Assessing Knowledge, Skills, Abilities and/or Experience

The Procedure for Written Exam

The duration of the written exam is four astronomical hours. The exam offers to solve five original problems, which correspond to the topics studied at seminars during the semester. A problem is considered solved if it contains a justified solution that includes references to the applied physical laws and correct calculations, as well as the correct numerical answer (if the problem contains numerical data). A student can use at the exam a sheet of paper with formulas prepared in advance. It is strictly forbidden to use any notebooks, or compendiums of lectures, or textbooks, or devices that can serve as means of communication, like laptops, tablets, phones, etc. Violators are removed from the exam with the "unsatisfactory" mark. It is allowed to use calculators with no communication facilities. It is forbidden to use calculators in mobile phones, laptops, etc.

The Procedure for Oral Exam

The oral exam is held in the traditional form of teacher's conversation with a student on the topic contained in the examination card.

The student is given from 30 to 45 minutes to prepare the answer on the given topic. During the exam, the student is not allowed to use any literature, computers, pre-prepared own records, or other materials related to the subject, except for the examination program of the course.

In discussing the exam card topic, the examiner may ask clarifying questions. Also, the examiner has the right to ask the student any additional questions on the syllabus.

In the aggregate, the duration of the oral exam for one student should not exceed two astronomical hours.

6. Selected oral exam cards.

Card #12.

1) Difference C_P-C_V in general case.
2) A question of student's choice.

Card #14.

1) Temperature dependence of latent heat of phase transition.
2) A question of student's choice.

Card #32.

1) Fluctuations of the number of particles in a given volume.
2) A question of student's choice.

Card #36.

1) The classical theory of heat capacity. The law of equipartition.
2) A question of student's choice.