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: Laboratory Practicum/Общая физика: лабораторный практикум
major:	Biotechnology
specialization:	Biomedical Engineering/Биомедицинская инженерия
	Phystech School of Biological and Medical Physics
	Chair of General Physics
term:	1
qualification:	Bachelor

Semesters, forms of interim assessment:

2 (spring) - Grading test
3 (fall) - Grading test
4 (spring) - Grading test
5 (fall) - Grading test
6 (spring) - Grading test

Academic hours: 300 AH in total, including:
lectures: 0 AH.
seminars: 0 AH.
laboratory practical: 300 AH.

Independent work: 375 AH.

In total: 675 AH, credits in total: 15

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

Formation of basic knowledge of physics and the ability to work in the laboratory for further use in other disciplines of natural science content; formation of the culture of experiment, research skills and the ability to apply knowledge in practice.

Tasks of the course

- Formation of experiment culture: ability to work in the laboratory, to know the basic methods of experiment, to establish logical connections between concepts;
- formation of skills and abilities to apply the knowledge gained for the formulation of the experiment, self-analysis of the results.

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 Apply knowledge of mathematical, physical, chemical, biological laws, patterns, and interrelation to study, analyze, and utilize biological objects and processes	Gen.Pro.C-1.1 Analyze the task in hand, outline the ways to complete it
Pro.C-1 Plan and conduct scientific experiments (in a selected subject area) and/or theoretical (analytical and simulation) research	Pro.C-1.1 Understand the fundamental concepts, laws, and theories of modern physics and biology

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

As a result of studying the course the student should:

know:

- methodology of the experiment;
- methods of processing the results.

be able to:

- work with modern measuring equipment;
- correct processing of the experimental data.

master:

- skills to work with modern instrumentation;
- basic mathematical tools typical of the mechanical problems.

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	Determination of systematic and random errors in measurement of specific resistance of nichrome			4	5

2	Measurement of radiation background intensity			4	5
3	Test 1.			4	5
4	Study of electronic oscilloscope			4	5
5	Determination of principal moments of inertia of rigid bodies by means of trifilar torsion suspension			4	5
6	Experimental verification of the dynamical law of rotational motion using the Oberbeck pendulum			4	5
7	Test 2			4	5
8	Measurement of gravitational acceleration by means of Kater's pendulum			4	5
9	Test 3			4	5
10	Determination of Young's modulus based on measurements of tensile and bending strain			4	5
11	Study of gyroscope precession			4	5
12	Study of string oscillations			4	5
13	Study of oscillations of coupled pendulums			4	5
14	Determination of pellet velocity by means of ballistic pendulum			4	5
15	Test 4			4	5
16	Study of stationary flow of liquid through pipe			4	5
17	Determination of activation energy of liquid via temperature dependence of its viscosity			4	5
18	Test 1			4	5
19	Creation and measurement of vacuum			4	5
20	Experimental study of molecular diffusion of gases			4	5
21	Measurement of thermal conductivity of air at various pressures			4	5
22	Experimental study of ion pump			4	5
23	Test 2			4	5
24	Determination of Cp/Cv ratio of gas by measuring the speed of sound in it			4	5
25	Phase Transitions: measurement of vaporization heat of liquid			4	5
26	Test 3			4	5
27	Real Gases: The Joule-Thomson effect			4	5
28	Measurement of surface tension of liquid			4	5
29	Measurement of specific heat of solids			4	5
30	Test 4			4	5
31	Magnetometer. Absolute voltmeter. Modeling of electric fields.			4	5
32	Spectra of electrical signals. Waveguide. Synthesis of electrical signals.			4	5
33	Test 1			4	5
34	Magnetron (and focusing). Law three second. Milliken's Experience.			4	5
35	Phase shift in the AC circuit. The voltage resonance. A resonance of currents.			4	5

36	Hall effect in semiconductors. Hall effect in metals. Magnetoresistance of semiconductors.			4	5
37	Test 2			4	5
38	Free vibrations. Forced oscillations. Shot noise. Oscillatory circuit with nonlinear capacitance.			4	5
39	Dia - and paramagnetic. Skin-effect.			4	5
40	Test 3			4	5
41	Ballistic galvanometer.			4	5
42	Relaxation generator. Glow discharge. High-frequency discharge.			4	5
43	Defense of Lab Results			4	5
44	Hysteresis loop (dynamic method). Hysteresis loop (static method). Parametron. Double yoke.			4	5
45	Test 4			4	5
46	Newton's Rings. The Jamin Interferometer. The Rayleigh Interferometer.			4	5
47	Centered optical systems. Modeling of optical devices. The Abbe Refractometer.			4	5
48	Laser study.			4	5
49	Test 1			4	5
50	Diffraction of light.			4	5
51	Polarization.			4	5
52	Interference of microwave waves.			4	5
53	Test 2			4	5
54	Diffraction gratings (goniometer).			4	5
55	Birefringence.			4	5
56	Test 3			4	5
57	Diffraction on ultrasonic waves.			4	5
58	Resolution of the microscope (Abbe method).			4	5
59	Pockels effect			4	5
60	Test 4			4	5
61	Resonant absorption of gamma-quanta (The Moessbauer effect).			4	5
62	The Compton effect.			4	5
63	Measurement of total activity of a sample of Co-60 by method of gamma-gamma coincidence.			4	5
64	Determination of energy of alpha-particles by measuring their range in air.			4	5
65	Measurement of angular distribution of hard component of cosmic rays.			4	5
66	Test 1			4	5
67	Study of cosmic ray showers.			4	5
68	Experimental verification of Einstein's equations for photoelectric effect and measurement of Planck's constant.			4	5
69	Spectra of hydrogen and deuterium.			4	5
70	Scattering of slow electrons by atoms of noble gas (the Ramsauer-Townsend effect).			4	5
71	Test 2			4	5

72	Measurement of flux attenuation coefficient of gamma-rays in medium and determination of their energy.			4	5
73	Measurement of energy spectrum of beta-particles and their end-point energy by means of magnetic spectrometer.			4	5
74	Franck-Hertz experiment.			4	5
75	Measurement of cross-section of electron-positron pair production on lead nuclei.			4	5
AH in total				300	375
Exam preparation		0 AH.			
Total complexity		675 AH., credits in total 15			

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

Semester: 2 (Spring)

1. Determination of systematic and random errors in measurement of specific resistance of nichrome

Systematic and random errors are studied on the example of nichrome wire resistivity measurement. The lab assignment includes studies of instrumental errors of analog and digital devices, laws of error addition, and errors in direct line parameters obtained by the least square method.

2. Measurement of radiation background intensity

Using the cosmic background radiation recorded by a Geiger counter as an example, this lab investigates the main methods of statistical data processing. Basic properties of normal distribution and Poisson distribution are studied. The dependence of the RMS deviation of data on the number of measurements is studied.

3. Test 1.

Test 1.

4. Study of electronic oscilloscope

The principle of operation of electronic oscilloscope is studied. Parameters of simplest oscillations, like amplitude, phase, and frequency, are measured. The influence of amplitude-frequency and phase-frequency characteristics on the result of measurements with the oscilloscope is underlined.

5. Determination of principal moments of inertia of rigid bodies by means of trifilar torsion suspension

Torsional oscillation periods of rigid bodies of different shape are measured with the aid of trifilar suspension. The measured periods are used to calculate the moments of inertia of the bodies, which are compared with those obtained by calculations based on geometric dimensions of the studied bodies. The additivity of inertia moments and the Huygens-Steiner theorem are checked experimentally.

6. Experimental verification of the dynamical law of rotational motion using the Oberbeck pendulum

With the help of a cross-shaped pendulum, the basic law of rotational motion is studied. The cylinder moments of inertia and the relationship between inertia moments and the distance to the axis of rotation are checked experimentally. The influence of air drag on the distortion of experimental results is studied.

7. Test 2

Test #2

8. Measurement of gravitational acceleration by means of Kater's pendulum

Basic laws of oscillatory motion are investigated with a long rod-shaped physical pendulum and a revolving pendulum with movable loads. Pendulum oscillation periods are measured, and the dependence of the period on the amplitude of oscillation and attenuation is studied. The measured period of oscillation is used to calculate the acceleration of free fall with high accuracy.

9. Test 3

Test 3

10. Determination of Young's modulus based on measurements of tensile and bending strain

Small elastic deformations of tension/compression, bending and torsion of different materials, like steel, brass, different types of wood, etc. are studied. The deformation value is used to calculate the Young's modulus of corresponding material using different calculation methods.

11. Study of gyroscope precession

Laws of motion of a fast rotating axisymmetric top (i.e. a gyroscope) are studied. The top rotation speed is determined by the precession rate under the influence of constant torque. The moment of inertia of the top is determined by the method of comparison of the top torsional oscillation period with the period of reference body oscillation. The friction torque in the gyroscope axis is measured by the tilting rate of the gyroscope axis.

12. Study of string oscillations

This lab investigates the excitation of standing waves in a stretched steel string with fixed ends. Resonance frequencies are measured as functions of the force of string tension, from which the speed of wave propagation in the string and its linear density are determined. Oscillations are recorded by means of an electromagnetic sensor connected to an electronic oscilloscope. The resonance width measures the quality factor of the oscillating system.

13. Study of oscillations of coupled pendulums

The oscillation pattern in a system consisting of two coupled pendulums is investigated. The natural frequencies of oscillations are measured and the natural modes of oscillation are investigated. The dependence of oscillation pattern on the coupling constant of pendulums is studied.

14. Determination of pellet velocity by means of ballistic pendulum

The flight velocity of a pellet fired from a pneumatic gun is measured using the ballistic pendulum method. The velocities are calculated from the amplitude of deviation of ballistic and torsional pendulums using the laws of conservation of momentum, energy and angular momentum.

15. Test 4

Test #4

16. Study of stationary flow of liquid through pipe

Properties of stationary flow of liquids and gases are studied. Liquid flow rate is measured by Pitot and Venturi flowmeters. Gas viscosity is measured based on the dependence of gas flow rate on the pressure drop in the pipe section. The deviation from Poiseil law determines the critical value of Reynolds number corresponding to the transition from laminar flow to turbulent flow.

17. Determination of activation energy of liquid via temperature dependence of its viscosity

The viscosity coefficient of liquid as a function of temperature is measured by dropping the test balls in a vertical flask filled with glycerol. The Stokes formula for the viscosity of liquid is checked at a constant rate of falldown. The temperature dependence of viscosity determines the activation energy for the liquid molecules. The activation energy is compared to the bonding energy, evaporation heat and surface tension energy.

18. Test 1

test 1

19. Creation and measurement of vacuum

Basic methods of obtaining and measuring vacuum are studied. The law of viscous mode pumping and the law of pumping in Knudsen mode at high vacuum (with the help of diffusion oil or turbo-molecular pumps) are studied. Low vacuum measurement is performed with oil, thermocouple and thermoresistor vacuum gauges. High vacuum is measured with ionization and magnetron vacuum gauges.

20. Experimental study of molecular diffusion of gases

Mutual diffusion of air and helium through a thin tube connecting two vessels is investigated. The concentrations of gases are measured by a thermistor sensor by the difference in thermal conductivity of gas mixture. The applicability of Fick law and the dependence of mutual diffusion coefficient on pressure are studied.

21. Measurement of thermal conductivity of air at various pressures

This lab is designed to investigate the dependence of heat conductivity coefficient of air on temperature and pressure. Measurements are carried out by the heating of wire, enclosed in a cylindrical air shell. The temperature of the outer jacket is controlled by a thermostat while the temperature of the wire is determined by the dependence of wire resistance on temperature. The phenomenon of temperature jump near the wire surface is investigated at low pressure.

22. Experimental study of ion pump

Molecular processes in low-pressure gases are investigated. The process of electric pumping, i.e. absorption of gas particles by anode as a result of ionization by electron impact, is studied. The pressure of saturated vapor of refractory metals is measured by the pressure change when heating a metal sample in vacuum by electric current.

23. Test 2

Test #2

24. Determination of Cp/Cv ratio of gas by measuring the speed of sound in it

The adiabatic index is measured by an acoustic resonance method and Kleman-Desorm method. The value of sound velocity is calculated. Adiabatic parameters and their dependence on temperature for air and carbon dioxide are measured in this lab.

25. Phase Transitions: measurement of vaporization heat of liquid

The dependence of saturated vapor pressure on temperature of water or alcohol is measured using a mercury pressure gauge and thermostat. The vaporization heat of the corresponding liquid is calculated on the basis of the obtained dependence.

26. Test 3

Test #3

27. Real Gases: The Joule-Thomson effect

The Joule-Thomson effect in gas diffusion through a porous membrane for carbon dioxide is studied. The temperature difference is measured by a thermocouple. Joule-Thomson coefficients and Van-der-Waals gas parameters are calculated. The measured parameters are used to assess critical gas parameters and the temperature of effect inversion.

28. Measurement of surface tension of liquid

The surface tension coefficient of different liquids (water and alcohol) is measured as a function of temperature by the Rebinder method. The total free energy and the heat of surface formation are determined.

29. Measurement of specific heat of solids

The heat capacity of solids is measured, as well as the heat capacity of gases at constant pressure for different flow rates. The temperature of the solid body is measured by the dependence of the heater resistance on temperature. The gas temperature is measured by a thermocouple.

30. Test 4

Test #4.

Semester: 4 (Spring)

31. Magnetometer. Absolute voltmeter. Modeling of electric fields.

Measurement of the Earth's magnetic field horizontal component and establishment of a quantitative ratio between the units of measurement of electric current and voltage in the SI and CGS systems of units. Observation of electrostatic fields of rectangular cable, flat capacitor, four charged cylinders on conductive paper.

32. Spectra of electrical signals. Waveguide. Synthesis of electrical signals.

Study of spectral composition of periodic electrical signals. Synthesis of periodic signals using a limited set of spectral components. Electromagnetic wave propagation in a waveguide, equipment and methods of measuring the main characteristics of processes that take place in this case.

33. Test 1

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

34. Magnetron (and focusing). Law three second. Milliken's Experience.

Determination of the ratio of electron charge to its mass by magnetic focusing and magnetron methods. Determination of the specific charge of the electron on the basis of three-halves-power law for a vacuum diode. Measurement of elementary charge by the method of oil droplets movement in air under the influence of gravity and vertical electric field.

35. Phase shift in the AC circuit. The voltage resonance. A resonance of currents.

Investigate how the resistance, inductance and capacitance influence the phase shift between current and voltage in the AC circuit. Study of voltage and current resonances in the serial and parallel oscillation circuits with variable capacitance. Obtaining the amplitude-frequency and phase-frequency characteristics, determining the basic parameters of the circuits.

36. Hall effect in semiconductors. Hall effect in metals. Magnetoresistance of semiconductors.

Investigation of the Hall EMF dependence on the magnitude of magnetic field at different currents through the sample to determine the Hall constant. Measurement of mobility and concentration of charge carriers in semiconductors and metals. Measurement of resistance of semiconductor samples of different shapes as a function of magnetic field induction.

37. Test 2

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

38. Free vibrations. Forced oscillations. Shot noise. Oscillatory circuit with nonlinear capacitance.

Investigation of free and forced oscillations in the oscillating circuit. Electron charge measurement by shot noise. Study of resonance properties of the nonlinear oscillatory circuit.

39. Dia - and paramagnetic. Skin-effect.

Measurement of magnetic susceptibility of diamagnetic and paramagnetic samples. Study of temperature dependence of magnetic susceptibility of ferromagnetic materials above the Curie point. Study of penetration of a variable magnetic field into a copper hollow cylinder.

40. Test 3

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

41. Ballistic galvanometer.

Study of operation of a highly sensitive mirror galvanometer of magneto-electric system in the modes of measuring direct current and electric charge.

42. Relaxation generator. Glow discharge. High-frequency discharge.

Research of relaxation generator on voltage-stabilizing tube. Study of volt-ampere characteristic of normal glow discharge. Study of high-frequency gas discharge plasma properties in the air by probe characteristics.

43. Defense of Lab Results

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

44. Hysteresis loop (dynamic method). Hysteresis loop (static method). Parametron. Double yoke.

Study of hysteresis loops of different ferromagnetic materials in variable fields. Measurement of the initial magnetization curve of ferromagnetic materials and the final hysteresis loop for toroidal specimens made of pure iron or steel. Investigation of parametric oscillations in the electrical circuit.

45. Test 4

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

Semester: 5 (Fall)

46. Newton's Rings. The Jamin Interferometer. The Rayleigh Interferometer.

Measurement of glass surface curvature using interference in the form of Newton rings. Interference measurements of refractive index of gases by means of Jamin interferometer and Rayleigh interferometer.

47. Centered optical systems. Modeling of optical devices. The Abbe Refractometer.

Study of methods for determining the focal length of a lens or complex optical system. Determination of characteristics of optical system consisting of thin lenses. Study of spherical and chromatic aberrations. Study of Kepler telescope and Galileo telescope, as well as microscope models. Measurement of refractive indices of solid and liquid bodies in monochromatic light by means of Abbe refractometer.

48. Laser study.

Studying the basic principles of helium-neon laser operation, laser radiation properties and laser tube gain measurement. Investigation of polarization state of laser radiation. Observation of modal structure of laser radiation.

49. Test 1

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

50. Diffraction of light.

Investigation of Fresnel and Fraunhofer diffraction phenomena by slits. Study of diffraction influence on the resolution of optical instruments.

51. Polarization.

Familiarization with the methods of obtaining and analyzing polarized light. Determination of refractive index of ebonite by measuring the Brewster angle. Investigation of the nature of light polarization in the refracted and reflected beams. Investigation of interference of polarized rays. Determination of the direction of rotation of field vector in an elliptically polarized wave.

52. Interference of microwave waves.

Study of interference of electromagnetic waves in millimeter range using two optical interference schemes. Experimental determination of radiation wavelength and dielectric refractive index. Experimental check of Malus Law.

53. Test 2

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

54. Diffraction gratings (goniometer).

Study of operation and adjustment of goniometer and determination of spectral characteristics of amplitude grating. Investigation of radiation spectrum of mercury lamp. Determination of spectral characteristics of phase lattice (echelette).

55. Birefringence.

Measurement of the refractive index of extraordinary wave as a function of propagation direction in the birefringent crystal. Determination of main refractive indices of the crystal.

56. Test 3

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

57. Diffraction on ultrasonic waves.

Study of light diffraction on sinusoidal acoustic grating and observation of phase grating by dark field method.

58. Resolution of the microscope (Abbe method).

Determination of diffraction limit of resolution of the microscope lens by the Abbe method. Determination of lattice period using its spatial spectrum, or its image magnified by a microscope model, or using the microscope resolution estimate. Spatial filtration and multiplication.

59. Pockels effect

Study of interference of scattered light that has passed through the crystal. Observation of changes in the character of light polarization when applying an electric field to the crystal.

60. Test 4

Processing of experimental data obtained. Error analysis and calculation of measurement errors. Presentation of work in the form of a scientific report. Defense of the obtained results. Discussion of question of choice.

Semester: 6 (Spring)

61. Resonant absorption of gamma-quanta (The Moessbauer effect).

Using the Doppler shift method in the Moessbauer absorption line, the resonance absorption of gamma-quanta emitted by tin nuclei is investigated. Students determine the position of maximum resonant absorption, its value, as well as the experimental line width of gamma-radiation.

62. The Compton effect.

With the help of a scintillation spectrometer, the energy spectrum of gamma-quanta scattered on graphite is studied. The energy of quanta depending on the scattering angle is determined, as well as the rest energy of the particles on which the Compton scattering takes place.

63. Measurement of total activity of a sample of Co-60 by method of gamma-gamma coincidence.

Absolute activity of Co-60 is measured by gamma-gamma coincidence method. After that, the energy of gamma-quanta emitted by the unknown radioactive specimen is determined.

64. Determination of energy of alpha-particles by measuring their range in air.

There are two ways to measure the alpha-particle range in the air: using a scintillation counter and a Geiger counter. The energy of alpha-particles is determined based on the measured range in the air.

65. Measurement of angular distribution of hard component of cosmic rays.

A telescope consisting of two scintillation counters measures the angular distribution of the hard component of cosmic radiation. Based on the data obtained, the muon's lifetime is estimated.

66. Test 1

Test #1

67. Study of cosmic ray showers.

The probability of formation of showers of secondary charged particles in lead is measured as a function of the observation level depth (cascade curve). The results are used to estimate the average particle energy in a shower.

68. Experimental verification of Einstein's equations for photoelectric effect and measurement of Planck's constant.

The photocurrent is measured as a function of the reverse potential and the frequency of incident radiation. Based on the results, the Planck constant is calculated.

69. Spectra of hydrogen and deuterium.

The optical spectrum of hydrogen atom radiation is investigated. The results are used to calculate the Rydberg constant for two isotopes, their ionization potentials, and isotopic line shifts.

70. Scattering of slow electrons by atoms of noble gas (the Ramsauer-Townsend effect).

The energy dependence of probability of scattering of slow electrons by xenon atoms is studied. The size of the outer electron shell of xenon atom is estimated based on the results of measurements.

71. Test 2

Test #2

72. Measurement of flux attenuation coefficient of gamma-rays in medium and determination of their energy.

Linear coefficients of flux attenuation of gamma-rays in lead, iron, and aluminum are measured with the help of a scintillation counter. The results are used to determine the energy of gamma-quanta.

73. Measurement of energy spectrum of beta-particles and their end-point energy by means of magnetic spectrometer.

A magnetic spectrometer is used to study the energy spectrum of beta-particles produced in the decay of caesium nuclei. The spectrometer is calibrated by the energy of electrons of internal conversion.

74. Franck-Hertz experiment.

The electron excitation method is used to measure the energy of the first level in helium atom. The results obtained in dynamic and static modes are compared.

75. Measurement of cross-section of electron-positron pair production on lead nuclei.

With the help of a telescope consisting of two scintillators and a Cherenkov detector, the cross section of electron-positron pair production in lead is measured. Radiation length and absorption length are measured.

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 List of Informational Resources:
1. Methodical section of the Department of General Physics website: http://mipt.ru/education/chair/physics/S_I/method/.

2. MIPT electronic library, the General Physics section: http://lib.mipt.ru/catalogue/1412/?t=750.

Lecture halls are equipped with multimedia and presentation facilities.

The recommended literature is available in electronic form (see paragraphs [1, 2] of the list of Internet resources necessary for mastering the discipline modules) so that the students may read textbooks using 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: 1
qualification: Bachelor

Semesters, forms of interim assessment:

2 (spring) - Grading test
3 (fall) - Grading test
4 (spring) - Grading test
5 (fall) - Grading test
6 (spring) - Grading test

Authors:

V.V. Uskov, associate professor
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
Gen.Pro.C-1 Apply knowledge of mathematical, physical, chemical, biological laws, patterns, and interrelation to study, analyze, and utilize biological objects and processes	Gen.Pro.C-1.1 Analyze the task in hand, outline the ways to complete it
Pro.C-1 Plan and conduct scientific experiments (in a selected subject area) and/or theoretical (analytical and simulation) research	Pro.C-1.1 Understand the fundamental concepts, laws, and theories of modern physics and biology

2. Competency assessment indicators

As a result of studying the course the student should:

know:
- methodology of the experiment;
- methods of processing the results.

be able to:
- work with modern measuring equipment;
- correct processing of the experimental data.

master:
- skills to work with modern instrumentation;
- basic mathematical tools typical of the mechanical problems.

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

Intermediate certification of students in General Physics: Laboratory Practicum is carried out in the form of a graded test. To pass the end-of-semester test, the student must complete a given number of laboratory works. To complete each lab assignment, the student must prepare for the work, pass a preliminary quest to the instructor, perform the experimental part of the work, conduct necessary calculations, and pass the lab test. Obtaining a credit for each lab requires passing control test that consists of a number of questions:

4. Evaluation criteria

Lab 1.1.2 Measurement of linear expansion coefficient of a rod with the aid of microscope

Test questions:

1. For a given accuracy of AL determine the required accuracy of the rod length and the thermometer resistance.
2. Determine the contributions to the error of a: due to calibration of the ocular scale, due to determination of the mark position, due to measurement of the room temperature, and due to the error of the temperature coefficient of resistance.
3. Near-sighted and far-sighted observers adjust the microscope so that the image h is either at small or at large distance, respectively, from the observer’s eye. Is it linear or angular magnification that changes less?

Lab 1.1.5 Study of elastic proton-electron collisions

Test questions:

1. Derive equations relating electron scattering angle and its momentum in relativistic and non-relativistic mechanics.
2. Derive the formula relating velocity of a relativistic particle with its momentum and energy.
3. Derive the equation relating electron momentum and the radius of its trajectory in magnetic field. Show that this equation is valid both in relativistic and non-relativistic mechanics.

Lab 1.2.1 Determination of pellet velocity by means of ballistic pendulum

I. Pellet-velocity measurement setup

Test questions:

1. Give a definition of ballistic pendulum and describe where it can be used.
2. When is initial momentum of ballistic pendulum equal to pellet momentum?
3. Why is it necessary to use inelastic collision between pellet and pendulum?
4. Estimate the time of pellet-pendulum collision in the experiment.
5. What factors are responsible for non-conservation of momentum during the collision?
6. What are the specific requirements for rifle installation?
7. What factors contribute to swing attenuation?
8. Which assumptions made in derivation of eq. (5) can be checked experimentally?
9. Why the suspension threads are not parallel (see Fig. 1)?

II. Method of torsion ballistic pendulum

Test questions:

1. How does a deviation of the pellet-target impact angle from 90 degrees affect the validity of the method employed in the experiment?
2. At which amplitudes of pendulum swing should the periods be measured?
3. How does pellet momentum affect pendulum swing?

Lab 1.2.2 Experimental verification of the dynamical law of rotational motion using the Oberbeck pendulum

Test questions:

1. Why must the torque due to friction in the shaft bearings be reduced as much as possible? It appears that Eq. (6) is valid for any value of Mfr.
2. What is the role of the thread thickness and elasticity?
3. Which quantity has to be measured with the greatest accuracy in this experiment?
4. State and prove Huygens-Steiner theorem.

Lab 1.2.3 Determination of principal moments of inertia of rigid bodies by means of trifilar torsion suspension

Test questions:

1. What are the assumptions used in the derivation of Eq. (10)?
2. Can the method of measuring the moments of inertia suggested in the lab be used if the axis of rotation of the platform does not pass through the center of mass?
3. Prove the Huygens-Steiner theorem.

Lab 1.2.4 Determination of principal moments of inertia of rigid bodies by means of torsional oscillations

Test questions:

1. What are the principal moments of inertia of a rigid body?
2. What does the inertia ellipsoid of a cube look like?
3. Describe the state of free (torqueless) rotation of a rigid body.

Lab 1.2.5 Study of gyroscope precession

Test questions:

1. What is gyroscope and what are its major properties?
2. What factors does the velocity of regular precession depend on?
3. What is the dimensionality of the torsion modulus in Eq. (9)?
4. Derive Eq. (8) from Eq. (7).
5. Can you explain that a rolling coin is turning in the direction of its tilt?

Lab 1.3.1 Determination of Young's modulus based on measurements of tensile and bending strain

Test questions:

1. What are the main sources of measurement errors? How can the measurement error be reduced?
2. Estimate the maximum accuracy of measurement of wire elongation and beam deflection which is reasonable in this experiment.

3. What is the difference between the state of normal stress and the state of normal deformation?
4. For which stress and strain does Hooke's law hold?
5. Which deviations from Hooke's law are possible in deformation of solids?
6. What is Poisson's ratio?
7. Which assumptions are made to obtain the relation between the maximum beam deflection and Young's modulus?
8. What function y(x) describes the shape of the middle line of beam under perfect bending?
9. What is the use of platform M in Lermant's machine?

Lab 1.3.2 Determination of torsional rigidity

Test questions:

1. How does friction in the axes of blocks B affect the results of static measurements? How can one minimize this influence?
2. How does the oscillation period change when damping is increased?
3. Which method of measurement of shear modulus is preferable in practice: the static or dynamic one?
4. How can one estimate the error of shear modulus from the plot in (I2,T2)-coordinates?

Lab 1.3.3 Determination of air viscosity by measuring a rate of gas flow in thin pipes

Test questions:

1. Write the equation which describes the radial distribution of laminar flow velocity in a circular pipe. What is the ratio of the average and maximum velocities?
2. How is the Reynolds number defined? How can it be determined experimentally?
3. Describe the method of graphical treatment of the experimental data (see 8) that allows one to clearly distinguish the regions of formed and non-formed flow.

Lab 1.3.4 Study of stationary flow of liquid through pipe

Test questions:

1. Specify the assumptions used to derive Bernouilli's equation.
2. How does viscosity affect the readings of Venturi and Pitot flow meters?
3. Which water levels in reservoir 1 correspond to laminar or turbulent flow in tube T?
4. Suppose there is a laminar fluid flow through a tube and the viscosity decreases gradually while other flow parameters remain constant. How does the flow change?
5. Which flow regime, laminar or turbulent, provides a better agreement between the values of flow velocity determined by Venturi and Pitot tubes and that one obtained by using reservoir II?
6. Derive Torricelli's equation and use it to estimate the velocity of liquid flowing out a very short pipe for different levels H. Why are the experimental values of the velocities of water flowing out a long pipe sufficiently less?

Lab 1.4.1 Compound pendulum

Test questions:

1. What simplifying assumptions are used to obtain Eq. (4)?
2. What distance between the pivot point and the center of mass corresponds to the minimum period of oscillations?
3. Describe the behavior of the compound pendulum whose pivot point and the center of mass coincide.
4. Why is the simple gravity pendulum suspended on two wires?
5. Formulate and prove the Huygens-Steiner theorem.

Lab 1.4.3 Study of non-linear oscillations of a long-period pendulum

Test questions:

1. How does the pendulum oscillation period depend on damping?
2. Discuss the design of a moderate size pendulum which has a large oscillation period. Could a conventional pendulum be used in the lab instead?
3. Discuss the dependence of the pendulum oscillation period on the amplitude.

Lab 1.4.4 Study of oscillations of coupled pendulums

Test questions:

1. Give some examples of oscillators with two degrees of freedom.
2. What are normal oscillations (normal modes)?
3. What are partial oscillations?
4. At which initial condition does the swinging of pendulums occur in turn?
5. Derive the equation (17).

Lab 1.4.5 Study of string oscillations

Test questions:

1. What are longitudinal and transverse waves? Write down the wave equation.
2. Derive the wave equation. Give a definition of node and antinode of a standing wave. Describe the energy propagation along an oscillating string.
3. Derive a formula for the velocity of transverse wave on a string. Compare the value calculated with the velocity obtained in the experiment.
4. Describe the reflection of a wave from the fixed end and from the end which moves freely in a plane orthogonal to the direction of the string tension. What is the value of a phase shift between the incident and reflected waves?
5. What condition must be satisfied for a traveling wave not to affect the oscillation pattern? How can one check the condition experimentally?

Lab 1.4.6 Measurement of speed of ultrasound in liquid by means of ultrasound interferometer

Test questions:

1. Which mechanical oscillations are called ultrasonic?
2. What are longitudinal and transverse waves? In which media can the waves propagate?
3. Write down a mathematical expression for a plane wave.
4. What conditions should be met to make wave interference possible?
5. Derive an equation which specifies the condition of resonance in the interferometer. How does the equation depend on boundary conditions?
6. What conditions should be met to create a standing wave? Give definitions of node and anti-node. How is energy transferred in the wave?
7. Why is the speed of ultrasound greater in a solution of electrolyte than in the pure liquid?
8. Suppose the open surface of liquid is used instead of the metallic reflector. The height of the liquid column can be gradually varied by slowly emptying the container. What is the phase difference between the incident and reflected waves on the air-liquid boundary?
9. How should the interferometer be modified in order to do the same measurements with gases?

Lab 1.4.7 Determination of elastic constants of liquids and solids via measurement of speed of ultrasound

Test questions:

1. When measuring the speed of ultrasound by means of the ultrasound sensor one can see ghost pulses on the screen in addition to sequentially reflected pulses. Why are these pulses seen? How can one get rid of them?
2. When measuring the ultrasound speed using the prism probe, a systematic error is introduced because there is a wedge-shaped part of the plexiglass probe between the emitter and the material under study. Evaluate this error for given sizes of the probe and the sample.
3. Show that the reflection coefficient of the ultrasound wave on the interface between two media does not depend on the direction of wave propagation.

Lab 2.1.2 Measurement of Cp/Cv ratio of gas by the method of adiabatic expansion

Test questions:

1. Does γ depend on temperature in the chosen temperature interval?
2. What are the values of Cp, Cv, and γ for an ideal gas according to the equipartition theorem?
3. Why does the gas temperature increase when the container is being filled?
4. Evaluate the time of gas outflow using the Poiseuille equation.

Lab 2.1.3 Determination of Cp/Cv ratio of gas by measuring the speed of sound in it

Test questions:

1. Derive equations (1.16) and (1.17).
2. Does the value of γ depend on temperature in the considered temperature range?
3. Is there such dependence in the range from very small temperatures to 1000 ◦C?

Lab 2.1.4 Measurement of specific heat of solids

Test questions:

1. Give the definition of specific and molar heat capacity.
2. What is the molar heat capacity of a metal according to the classical theory? What is the molar heat capacity of a chemical compound?
3. Describe the method used to reduce the error related to heat losses.

Lab 2.1.5 Experimental study of thermal effects caused by elastic deformations

Test questions:

1. What conditions must be met to ensure that a deformation process is reversible?
2. Show that Eq. (15) gives ordinary expressions for elastic stretching and thermal expansion at small values of λ and ΔT.
3. Is a rubber deformation without a thermal effect possible?

Lab 2.1.6 The Joule-Thomson effect

Test questions:

1. What is the difference between real and ideal gases?
2. Plot the interaction force and the potential energy of two molecules versus the distance between them. Using the curves explain the Joule-Thomson effect.
3. Give the definition of critical temperature. What is the inversion temperature?
4. Explain the sign of Joule-Thomson effect for $a = 0, b \neq 0$ and for $a \neq 0, b = 0$.

Lab 2.2.1 Experimental study of molecular diffusion of gases

Test questions:

1. Show that in the installation the concentration of gases can be considered uniform in the whole volume of V1 (and V2).
2. Why is the dependence of D on 1/P expected to be a straight line?

Lab 2.2.2 Measurement of thermal conductivity of air at various pressures

Test questions:

1. Why does the heat transfer from the filament to the ambient air drop when the pressure decreases from several torr to several decitorr?
2. Does the heat transfer depend on pressure at higher pressures? (Discuss also the mechanisms different from thermal conductivity.)

Lab 2.2.3 Measurement of thermal conductivity of air at atmospheric pressure

Test questions:

1. According to kinetic theory of gases the mean free path λ depends on concentration n as $\lambda = 1/\sigma n$. What can you say about the temperature dependence of σ using the results of item 6?
2. Why does the installation for measurement of thermal conductivity of gas have the shape of a long thin vertical cylinder?
3. Estimate the heat losses through the wire ends.
4. A thermal e.m.f. is usually several microvolts per kelvin. Estimate the current through the wire for which a thermal e.m.f. in the voltmeter circuit would significantly affect the results.
5. What is the temperature difference between the wire and the tube at 150 mA? Compare the result with the experimental value.
6. Equation (1) was derived under the assumption that the thermal conductivity is independent of temperature, therefore the equation is valid if $\Delta T \ll T$. Assume that the coefficient of thermal conductivity depends on temperature as ϰ ~ Tβ and calculate the exact relation. Estimate the corresponding error of x.

Lab 2.2.4 Measurement of thermal conductivity of solids
Test questions:
1. What is the definition of coefficient of thermal conductivity and what is its dimension?
2. Derive an equation similar to Eq. (3) which would take into account a change in the heat flow area, say, from S1 to S2.
3. Derive Eq. (6) which takes into account a difference in thermocouple sensitivity.
4. Can the dependence of thermal conductivity coefficient of ebonite be measured using this particular installation? Are the heat losses through the lateral surface significant enough to prevent the measurement?
5. Using the experimental points of the radial temperature dependence plot isotherms and sketch the lines of heat flow (there should be at least three isotherms and flow lines which span the whole plate area).

Lab 2.2.5 Determination of viscosity of liquid by its outflow through capillary
Test questions:
1. Why is it recommended to determine the viscosity of water by a graphical method in the first experiment? Wouldn't it be better to determine the viscosity directly for different tube heights? It seems that averaging the results one could accurately find the viscosity and estimate reliably the experimental error by the dispersion of the results. What is wrong with this approach?
2. The pressure difference that must be applied to force a liquid through a pipe at a given velocity (assuming laminar flow) depends on liquid viscosity. Does viscosity matter if the flow is turbulent? What parameters of the liquid are required in this case?

Lab 2.2.6 Determination of activation energy of liquid via temperature dependence of its viscosity
Test questions:
1. The model of liquid considered in this lab implies that moving a molecule to a neighboring “hole” requires disrupting its bonds with the neighboring molecules. The bond disruption also occurs during evaporation of liquid, so one could expect that the activation energy would be close to the vaporization heat per molecule. Does the experiment verify this conclusion? Take the tabulated value for the vaporization heat.
2. Steel spheres of different diameters are used in the measurement of liquid viscosity by Stokes' method. Which spheres, small or large, are better suited for the experiment?

Lab 2.2.7 Experimental study of gas diffusion through porous medium
Test questions:
1. Prove that the gas concentration is almost uniform in the installation in our experiment.
2. What is the difference between the Knudsen and viscous regimes of diffusion?

Lab 2.3.1 Creation and measurement of vacuum
Test questions:
1. At which circumstances are the thermal conductivity and viscosity of gases independent of pressure?
2. Why are the readings of the thermocouple vacuum gauge almost constant at pressures below 10^{-4} torr?
3. For which purpose do the electrons execute the oscillatory motion in the ionization gauge?
4. Why is the flow capacity of pipes in Knudsen regime independent of the size of molecules?

Lab 2.3.2 Experimental study of ion pump
Test questions:
1. What is the highest vacuum obtained in the LM-2 tube in this experiment?
2. Would the vacuum increase or decrease if the ion pumping were accompanied by cooling of the collector?

Lab 2.3.3 Measurement of osmotic pressure
Test questions:

1. Estimate the influence of the capillary effects on the results of the measurements.
2. For which concentration of the solution is Eq. (1) valid?

Lab 2.3.4 Scattering slow electrons on mercury atoms
Test questions:
1. What is scattering cross-section? What cross-section is called elastic, inelastic?
2. How are cross-section and free path connected? Derive Eq. (5).
3. What law determines the dependence of the pressure of saturated vapor of a liquid on temperature?
4. Why should the installation be immersed in liquid completely, i.e. with all its projected parts?

Lab 2.4.1 Measurement of vaporization heat of liquid
Test questions:
1. A reference manual gives the heat of vaporization measured at the pressure of 760 mm Hg. Does the tabulated value correspond to your result? Which value is greater? Estimate the difference between them.
2. Argue how the value of heat of vaporization changes when temperature increases.

Lab 2.5.1 Measurement of surface tension of liquid
Test questions:
1. If several bubbles are produced per second the manometer readings are practically constant. Does it make sense to measure it?
2. Why should one measure just the peak pressure?
3. Why can a thermal expansion effect be reduced by submerging the needle?
4. Why should the bubbles not touch the bottom?
5. Is it possible to determine σ by measuring maximum and minimum pressures during the bubble gurgling if the needle immersion depth is unknown?
6. Using the obtained results estimate the critical temperature of aniline.
7. Does the experiment accuracy allow one to notice a nonlinearity of the σ(T) dependence?
8. Which errors dominate in the experiment: random or systematic?
9. Which value should be substituted into the formula for the height of the liquid column in the capillary: σwater-air or σwater-glass?

Lab 3.1.1 Magnetometer
Test questions:
1. Write the expression for the field of magnetic dipole.
2. Derive the expression for the magnetic field at the center of a circular current loop.
3. What must the internal resistance of the power source be in order for the capacitance to have time to discharge between the oscillator short-circuitings?
4. Actually we measure the magnetic field inside the building rather than the field of the Earth. Is the accuracy of measurement of Weber’s constant affected?
5. Find relations between oersted and ampere per meter, gauss and tesla, and maxwell and weber.

Lab 3.1.2 Absolute voltmeter
Test questions:
1. Estimate the error arising due to the fact that the beam is equilibrated at a small separation between the contact screws and the beds while the measurements are done at zero separation.
2. Explain how the electrostatic voltmeter can be used for measuring both direct and alternating voltage.
3. Explain how by measuring an alternating voltage one obtains the effective volt¬age value.
4. What determines a frequency range in which an alternating voltage can be measured by means of electrostatic voltmeter?

Lab 3.2.1 Phase shift in alternating current circuit
Test questions:
1. What is the impedance of electrical circuit?

2. What is the total impedance of elements connected in series? And in parallel?

Lab 3.2.2 Voltage resonance
Test questions:
1. Why is the voltmeter reading VR+L not equal to the sum of readings VR and VL? In our case VR+L < ER+VL. Is the opposite inequality possible?
2. Why does the ellipse on the oscilloscope screen transform into a straight line at resonance in the circuit shown in Fig. 2?
3. What contributes to the active resistance of coil with a core?
4. Explain the principle of wattmeter operation.
5. Are the currents in the studied circuit quasi-stationary? Why?
6. At which frequency does the coil hum?

Lab 3.2.3 Current resonance
Test questions:
1. Give all definitions of resonance which you know.
2. How to detect resonance in a circuit? Specify all criteria which you know.
3. Derive the formula relating Q-factor and resistance.
4. What effects are behind energy loss in the circuit?
5. Do energy losses depend on the current frequency?
6. Derive the relation between Rres and rL.

Lab 3.2.4 Free oscillations in electrical circuit
Test questions:
1. What are the natural frequency, Q-factor, and logarithmic decrement of oscillator circuit?
2. What is the phase plane of oscillations?
3. How to determine logarithmic decrement with the aid of oscillation pattern on the phase plane?

Lab 3.2.5 Driven oscillations in electrical circuit
Test questions:
1. Derive Eq. (2.57).
2. Find a real solution of Eq. (2.44). Hint: look for a solution of Eq. (2.44) in the form Ai sin fit + Ai cos fit.
3. Derive all equations (2.28) that define the Q-factor. What is the physical meaning of Q-factor?
4. In what cases an oscillator circuit is weakly coupled to other circuit elements?

Lab 3.2.6 Ballistic mirror galvanometer
Test questions:
1. What is the dynamical constant of galvanometer? What parameters does it depend on and in what units is it specified in the galvanometer manual?
2. Which modes of frame motion are possible when the galvanometer operates in stationary regime? What regimes are suitable for measurement of direct current?
3. How does the damping ratio of the galvanometer frame change when ohmic resistance of its circuit increases?
4. Why does the galvanometer frame stops quickly after closing key K1 (see Fig. 2)?
5. What are cylindrical cuts in the poles of magnet designed for (see Fig. 1)?
6. What is the main operation principle of ballistic regime? What is the ballistic constant of galvanometer?
7. What conditions should be met to ensure the maximal first light-spot deflection for the galvanometer operating in the ballistic regime?
8. Derive Eq. (30).
9. For R > 10 Rcr the curve 1/θ2 = f[(Ro + R)2] can deviate from a straight line. How can this deviation be explained?

Lab 3.3.1 Measurement of electron specific charge by magnetic focusing and by magnetron

Test questions:

1. Sketch and explain the setups for measuring the electron specific charge by means of magnetic focusing and magnetron.
2. Explain the operating principle of CRT.
3. Explain the operating principle of millifluxmeter.
4. Why does the anode used in the magnetron method consist of three cylinders rather than of one?

Lab 3.3.2 Study of current-voltage characteristics of vacuum diode

Test questions:

1. Sketch the potential distribution V(r) between cathode and anode: a) at zero potential difference between cathode and anode; b) at a large potential difference (the diode current saturation mode). Explain the distributions.
2. Sketch the diode current as a function of anode voltage Va in the range from a negative to a large positive value. Show the voltage area where the three-half power law is observed. How can we explain the deviations from this law at small and large anode voltages?
3. How does the cathode heating current affect the diode current at a constant anode voltage? Does it bring an error to the measured value of e/m?

Lab 3.3.3 Millikan's experiment

Test questions:

1. Why should one avoid using too big and too small droplets for the measurement?
2. What voltage range is optimal for the experiment? Evaluate it (see item 1).
3. Sketch the time dependence of drop velocity in free fall and indicate the settling time and path.
4. Using the installation parameters estimate the capacitance C and the time of discharge through the resistor R (the plate area is ~20 cm2).

5* What other methods of measuring electron charge do you know?

Lab 3.3.4 The Hall effect in semiconductors

Test questions:

1. What substances are called dielectrics, conductors, and semiconductors? How can the difference in their electrical properties be explained? How does the metal and semiconductor conductivity depend on temperature?
2. What is the Hall constant? How does the Hall constant depend on temperature in metals and semiconductors?
3. Does the measured value of the Hall constant depend on sample geometry?
4. What is the principal design of a millifluxmeter? Do its readings depend on the test coil resistance? Should this resistance be small or large compared to the resistance of the meter coil?
5. Derive the expression for the Hall constant for materials with two types of charge carriers. Hint: the transverse current must vanish.

Lab 3.3.5 Hall effect in metals

Test questions:

1. What substances are called dielectrics, conductors, and semiconductors? How can the difference in their electrical properties be explained? How does metal and semiconductor conductivity depend on temperature?
2. What is the Hall constant? How does the Hall constant depend on temperature in metals and semiconductors?
3. Does the measured value of the Hall constant depend on sample geometry?
4. What is the principal design of a millifluxmeter? Do its readings depend on the test coil resistance? Should this resistance be small or large compared to the resistance of the meter coil?

Lab 3.3.6 Effect of magnetic field on semiconductor conductivity

Test questions:

1. Study equations of electron motion in a rectangular sample. Does the sample resistance depend on the magnetic field induction?
2. Explain qualitatively (without formulas) why the sample resistance depends on magnetic field.

Lab 3.4.1 Dia- and paramagnets

Test questions:

1. Explain the method of measurement of magnetic susceptibility.
2. Write down the expression for the force acting on a sample in a non-uniform magnetic field
3. How can one verify whether the magnetic field in the gap of electromagnet is uniform?
4. How can one experimentally verify whether the magnetic susceptibility of the scale affects the results?

Lab 3.4.2 The Curie-Weiss law

Test questions:

1. Explain dia- and paramagnetism from the atomic theory perspective.
2. What is the difference between dia- and paramagnets in the absence of magnetic field?
3. What is the general principle which explains diamagnetism?
4. Sketch the curve B(H) for dia- and paramagnets on the same plot.
5. What is the contribution to magnetic susceptibility due to gadolinium conductivity? Find a relation between the bit size, the frequency, and the conductivity? Does the contribution depend on temperature? Estimate the contribution for bits of 0.5 mm in size.

Lab 3.4.3 The Curie point

Test questions:

1. What is the difference in magnetic properties of atoms of dia- and paramagnets in the absence of magnetic field?
2. How do the properties of a material change under first- and second-order phase transitions?
3. What two competitive interactions between atoms are typical for a ferromagnet?
4. On the same plot sketch three initial magnetization curves B(H) of a ferromagnet corresponding to room temperature, a temperature above the Curie point, and a temperature in-between. Show the region of H corresponding to this experiment.

Lab 3.4.4 Hysteresis loop (static method)

Test questions:

1. Why is it recommended to start going around the loop from the saturation?
2. Derive the relation between a spotlight deflection and the corresponding increment of magnetization. What are the validity conditions for this relation?
3. Using Stokes' theorem, derive the expression for magnetic field inside a long solenoid.

Lab 3.4.5 Hysteresis loop (dynamical method)

Test questions:

1. What shape of a sample placed in a uniform magnetic field ensures uniform magnetization of the sample?
2. Why is the sample used for observation of hysteresis loop shaped as a toroid rather than a rod?
3. Why should the magnetizing coil be disconnected when calibrating the horizontal axis of oscilloscope?
4. Estimate the accuracy of measurement of induction B if the measurement coil is loosely wound around a sample, e.g. if the sample occupies only a half of the coil cross-section.

Lab 3.4.6 Parametric resonance

Test questions:

1. Derive the condition of parametric oscillations (3) assuming that the inductance varies periodically: $L = L0[1 — m \sin(2\omega0t)]$.
Write down the oscillator current as a function of time.
2. Why is the inductance in the experiment proportional to differential magnetic susceptibility?
3. Sketch the dependence of μ-diff on magnetizing current for the hysteresis loop shown in Fig. 1.
4. What other frequencies of parametric oscillations could be induced at large inductance variations?

Lab 3.5.3 Relaxation oscillations

Test questions:

1. What oscillations are called relaxation oscillations?
2. Which gas parameters determine the ignition potential of VR tube?
3. Why is the quenching potential significantly less than the ignition potential?
4. How can one determine the steady current of VR tube using its I-V curve and the generator parameters?
5. What is the critical resistance of relaxation generator? What does it depend on?
6. Why does the critical resistance depend on the value of U at the generator input? Examine Fig. 3.
7. Why are there no oscillations at a small capacitance (the tube does not go out) even at $R > R_{cr}$? Estimate the capacitance by comparing the relaxation time and the time of de-ionization.

Lab 3.6.1 Spectral analysis of electric signals

Test questions:

1. Plot the frequency spectrum $F(\omega)$ of

a) an infinite sinusoid;

b) a finite sinusoid;

c) a repeating sequence of trains;

d) a repeating sequence of rectangular pulses;

e) a single train;

f) a single rectangular pulse.

2. How does the spectrum of a repeating sequence of rectangular trains change if every second pulse is removed? How does the spectrum look if the procedure is repeated until a single pulse is left?
3. Find the spectrum of the following phase-modulated signal,

$f(t) = A_o \cos(\omega t + m \cos \Omega t)$, providing $m < 1$.

Compare it to the spectrum of an amplitude modulated sinusoid.

Lab 4.1.1 Centered optical systems

Test questions:

1. Show that if a distance between an object and a source exceeds 4f then the image on the screen can be obtained for two different lens positions.
2. Describe a method of measurement of the focal length of a negative lens.
3. Give definitions of principal focuses, focal length, and principal planes of a compound centered optical system.
4. Using graphical method locate principal planes of a system composed of two thin lenses, positive and negative, providing their focal length and a distance between them are known.
5. Give definitions of spherical and chromatic aberrations.
6. Explain why spherical aberration depends on a side of plane-convex lens facing the source.

Lab 4.1.2 Modeling of optical instruments and measurement of their magnification

Test questions:

1. What is the purpose of an auxiliary spotting scope used in these experiments?
2. Evaluate a linear, angular, and longitudinal telescope magnification if the front focal length of its objective $f_1 = 40$ cm and focal length of the eyepiece $f_2 = —2$ cm?
3. Under what condition are angular and linear magnifications of microscope equal?
4. Derive Eq. (4) and explain the corresponding method of measurement of microscope magnification.

Lab 4.1.3 Abbe refractometer

Test questions:

1. What is the total internal reflection?
2. Why are the faces ab and ed of prisms P1 and P2 grounded?
3. Under what condition the layer of liquid between a solid specimen and the prism P2 does not affect the measured value of refractive index?
4. What is atomic refraction? and molecular refraction? State the rule of additivity of refraction.

Lab 4.2.1 Newton's Rings

Test questions:

1. In the center of Newton’s rings observed in reflected light the dark spot is located. Why?
2. How does the pattern of Newton's rings look like in transmitted light?
3. Why does the ring width decrease with increasing the ring radius?
4. Why is the light reflected from the front (plane) surface of the lens rendered irrelevant in calculating the interference pattern?
5. Derive the formula relating the period of beats expressed via the number of rings and the wavelengths of spectral lines.
6. Why does the ring visibility increase if the beam entering the dark-window illuminator passes through an aperture?
7. Why do the interference rings of large number seem fuzzy?

Lab 4.2.2 Jamin interferometer

Test questions:

1. Why should the plates P1 and P2 of Jamin interferometer be sufficiently thick (not less than 2-3 cm)?
2. Can these plates differ significantly in thickness?
3. Explain why the number of observable interference fringes grows if the light beam goes through an optical filter.

Lab 4.2.3 Rayleigh interferometer

Test questions:

1. Explain why the diffraction pattern does not move when one of the slits D is obstructed.
2. Why must a width of collimator slit S be small enough? Estimate the maximal width if a collimator focal length and a distance between the slits are known.
3. Is it possible to obtain a sharp zero band if the dispersion $n = n(\lambda)$ of a studied fluid is strong? Do the corresponding estimates.

Lab 4.2.4 Michelson interferometer

Test questions:

1. What is the relation between the speed of interference bands and the speed of mobile mirror?
2. What factor restricts the maximal and minimal speed which can be measured by the Doppler frequency shift on our installation?
3. What determines the accuracy of measurement of the laser wavelength? How does the accuracy depend on the mirror speed?
4. What configuration of interference pattern corresponds to an arbitrary arrangement of sources S1 and S2?

Lab 4.2.5 Coherence of light

Test questions:

1. What is the relationship between the coherence and visibility functions?
2. How can the coherence length and coherence radius be measured?
3. What is the efficiency of an incandescent light bulb used in a regular light fixture?
4. How does the coherence radius depend on a slit width and a distance between the slit and the input interferometer plane?
5. How does the number of visible interference bands change if there is an optical filter placed between an eye and the microscope?

Lab 4.3.1 Diffraction of light

Test questions:

1. Explain why a pattern of Fresnel diffraction obtained with a circular opening can have either dark or bright spot at the center while the diffraction by a circular screen always produces a bright central spot (the Poisson spot).

2. Explain why a lateral displacement of slit S2 in the setup shown in Fig. 4 does not result in a displacement of the diffraction pattern. Does a longitudinal shift of the slit result in a pattern displacement?
3. Derive the intensity distribution of the pattern of Fraunhofer diffraction by two parallel slits.
4. Derive Eq. (10). Explain the concept of spatial coherence by using the blurring of an interference pattern caused by a wide light source as an example.
5. What is the relationship between the visibility of interference pattern and spatial coherence of a light source? What is the difference between visibility curves corresponding to discrete and continuous variation of the source parameters? Explain the same for temporal coherence.
6. Explain the Babinet's principle.

Lab 4.3.2 Diffraction of light on ultrasound wave in liquid
Test questions:
1. Show that the period of acoustic grating equals the wavelength of ultrasound wave both for a propagating and standing wave. Show that Eq. (8) is valid for any amplitude and/or phase periodic grating.
2. How does the light intensity change over time in diffraction maximums of different order in the diffraction of light on traveling and standing ultrasound waves?
3. What is the difference between the method of dark field and the method of phase contrast?
4. How can one experimentally check whether an acoustic grating is a purely phase grating?

Lab 4.3.3 Study of microscope resolution by the Abbe method
Test questions:
1. What condition must be imposed on the distance between the grid and the screen in order to obtain the pattern of Fraunhofer diffraction on the screen?
2. Why do the diffraction maxima overlap when diffraction on the remote screen is produced by a coarse grid?
3. Why should the object be placed near the front focal plane of the microscope lens?
4. Why does the primary image remain at rest while the secondary image shifts when the grid is moved transversely?
5. Which spatial filter must be placed at the back focal plane of objective in order to form the grid image with the cells reduced by half at the plane P2?

Lab 4.3.4 Method of Fourier transform in optics
Test questions:
1. What is the relationship between the images observed at the planes P1 and P2?
2. What common features are observed in the spectra of a single slit and a periodic array of the same slits?
3. What is the relationship between the slit width and its spectrum width?
4. What grid parameters can be determined from the pattern of Fraunhofer diffraction obtained with the help of this grid?
5. What common and what different features can be observed in the spatial spectrum of a slit and of a hair obtained by Fraunhofer diffraction?

Lab 4.3.5 Study of hologram
Test questions:
1. What do they have in common and what is different about a hologram of point source, a Fresnel zone plate, and a photograph of Newton's rings?
2. How will the perception of the hologram of point source reconstructed as in Fig. (1) change if one blocks the point source O'1 by placing a small opaque screen at the focal point of lens L?
3. How will the focal length of a hologram of point source be changed if it is recorded by using one wavelength and reconstructed by using another one?
4. What determines the minimal size of a hologram, so that image reconstruction is still possible?
5. How are the dimensions of real and virtual image changed when a hologram is illuminated by a diverging or converging wave?
6. How does the range of angles at which the virtual image can be viewed depend on film granularity and on the spectral width of the light source?

Lab 4.3.6 Diffraction of light by periodic structure (the Talbot effect)

Test questions:

1. Estimate a distance between the screen and the grid at which Fraunhofer diffraction can be observed.
2. Why do we get only a few sharp repeated images of the grid in the experiment?
3. Derive the formula for directions to diffraction maxima.
4. Explain why the image of a wire grid is repeated and the image of a single wire is not.

Lab 4.4.1 Amplitude diffraction grating

Test questions:

1. Define the main spectral parameters of diffraction grating.
2. Formulate the Rayleigh criterion.
3. How do the angular parameters of the spectra change when the grating period, groove width, and the grating size are varied?
4. Is it possible to determine a dispersion range by the spectrum of mercury lamp in this experiment?
5. Which physical and technical factors limit the number of large-sized diffraction grating lines that work effectively?

Lab 4.4.2 Phase diffraction grating

Test questions:

1. Define the main spectral parameters of echelette.
2. What is the advantage of echelette as compared to an amplitude diffraction grating?
3. Which element of the spectrometer, echelette, goniometer, or your eye (sensitivity and visual acuity) mostly affects the accuracy of evaluating the spectral resolution?
4. Sketch an optical setup for determination of the echelette working order and its wavelength.
5. Sketch the intensity as a function of angle in the far field region for the working wavelength. Assume that echelette operates in the auto-collimation mode.

Lab 4.4.3 Study of prism with the aid of goniometer

Test questions:

1. Define spectral parameters of prism. What is its dispersion region equal to?
2. Derive a relation between the least deviation angle and refractive index.
3. Explain the dependence between refractive index of glass and optical wavelength.
4. Estimate the maximal period of amplitude grating for which its angular dispersion at the first order approximately equals the angular dispersion of the studied prism. Estimate the period of grating for which its resolution at the first spectral order is comparable to the prism resolution.

Lab 4.4.4 Fabry-Perot interferometer

Test questions:

1. Give definitions and formulas for calculating the spectral parameters of the Fabry-Perot interferometer.
2. Would it be possible to study the yellow lines of mercury by this interferometer if instead of being narrow the lines overlapped, i.e. their width were 21 ˚A?
3. Estimate the minimal diameter of interferometer mirrors which makes it possible to resolve the sodium yellow doublet.
4. Estimate the pulse duration of sodium lamp for which the interferometer cannot resolve the yellow doublet. To do this, estimate the path travelled by light in the interferometer and compare it with the interferometer base.

Lab 4.5.1 Helium-neon laser

Test questions:

1. Why is it impossible to achieve a large gain in the He-Ne laser tube by increasing the discharge current?
2. Why are the exit windows in laser tube glued at some angle with their outward surface facing down rather than up or sidewise?

3. Why is a helium admixture added to neon (the working substance) in the laser tube?
4. Why is the studied beam modulated in our experiment? Is it possible to do without the modulation in this setup?

Lab 4.5.2 Interference of laser radiation

Test questions:

1. Explain the operating principle of Fresnel rhomb.
2. Determine the visibility of an interference pattern produced by waves of equal intensity if one wave is linearly polarized and the other is circular.
3. How does the curve V2(ℓ) change if one varies the distance between mirrors of laser resonator?
4. What factors should be taken into account when choosing the width of the photodetector input slit?
5. Sketch the V(ℓ)-dependence for a single mode and for two modes.

Lab 4.5.3 Tunable Fabry-Perot interferometer

Test questions:

1. Explain basic processes leading to population inversion of energy levels in neon.
2. The ends of helium-neon working tube are covered by two plane-parallel plates. Why are these plates tilted at the Brewster angle?
3. What is the radiation mode? Derive Eq. (2) for the inter-mode separation.
4. What is the condition for laser excitation?
5. Derive Eq. (6) for the finesse of Fabry-Perot interferometer.
6. What is the operation principle of optical isolator?
7. What is the length of He-Ne-laser resonator for which the generation is possible on no more than one mode regardless of the pumping level (the single-mode laser generation)?

Lab 4.6.1 Interference of microwaves

Test questions:

1. How can one check that the microwave generated by a transducer antenna is linearly polarized?
2. How can the direction of electric field vector of a microwave be determined?
3. What is Malus' law and how can it be experimentally verified?
4. What are the necessary conditions for observation of interference of EM waves?
5. Estimate the length and radius of coherence in the mirror and grid experiment.
6. Give plausible explanations of the discrepancy in the values of the same quantities measured in this experiment by various methods and tabulated values of these quantities?

Lab 4.7.1 Birefringence

Test questions:

1. How are vectors D and E related in anisotropic medium?
2. How is the optical axis of a uniaxial crystal oriented with respect to the principal axes of the dielectric permittivity ellipsoid?
3. What are the principal refractive coefficients?
4. Give an example when the wave propagating in the crystal is ordinary and when it is extraordinary.
5. Derive Eq. (8) from Eq. (7).
6. How does the electromagnetic theory explain emergence of two refracted rays when a plane wave is incident on a surface of uniaxial crystal?
7. How do the refractive indices of ordinary and extraordinary rays depend on the angle between the crystal axis and the normal to the wave front?
8. How does the refractive index of ordinary (extraordinary) ray depend on the angle of refraction if the crystal axis is parallel to the prism rotation axis?
9. Explain how E is directed in the rays exiting the prism.

Lab 4.7.2 The Pockels effect

Test questions:

1. Is it possible to observe the Pockels effect in liquid?

2. Why does the interference pattern on the screen switch from positive to negative under 900 rotation of the polarizer?
3. What is the half-wave voltage $U\lambda/2$? How does it depend on λ?
4. Why is the beam exiting the crystal circularly polarized at $U = 0.5\ U\lambda/2$?
5. Evaluate the relative change of refractive index of the crystal when a voltage of $U = U\lambda/2$ is applied.
6. Derive Eq. (5).

Lab 4.7.3 Polarization

Test questions:

1. Show that under Brewster's condition the refracted and reflected rays are perpendicular.
2. How can one distinguish right-hand and left-hand polarization of light?
3. Unpolarized light is incident on a $\lambda/4$-waveplate. What can be said about polarization of the transmitted light?
4. How can one identify natural light, a circularly polarized light, and mix of natural light with a circularly polarized light?
5. Explain variation of intensity and color observed in experiments with polarized light.
6. Why is the light from the night sky polarized?

Lab 4.7.4 Polarization rotation

Test questions:

1. What is the difference between optical activity and birefringence?
2. How does Fresnel's theory explain the rotation of the polarization plane in optically active materials?
3. What is a specific rotation?
4. How does a Nicol prism work?
5. Describe the operation principle and design of a polarimeter.
6. Sometimes a polarimeter is designed so that a light beam travels multiple times along the magnetic field in opposite directions. Explain why the rotation angle of plane polarization in this case is accumulated.

Lab 5.1.1 Experimental verification of Einstein's equations for photoelectric effect and measurement of Planck's constant

Test questions:

1. What is the external photo effect? Write down and explain the Einstein equation.
2. What facts testify to the presence of initial kinetic energy of photoelectrons?
3. Why do photoelectrons come out of the metal at different velocities? What defines the maximum speed of photoelectrons?
4. On what and how does the flow of photoelectrons depend (i.e. the number of electrons pulled out by light per time unit)?
5. What is the photoemission threshold of photo effect and what does it depend on?
6. Plot a general view of current-voltage characteristic of photocell and explain this curve including the dependence of $I(U)$ in the region of reverse voltage $U > 0$. What is the stopping potential U_o and what is its value at a given light frequency?
7. Write down a formula for the stopping potential U_o expressed in terms of the wavelength λ for a photocathode with work function A.
8. Plot a family of I-V characteristics of a photocell when illuminated by light of constant intensity I and frequency $\nu 1 = \nu 0$, $\nu 2 = 2\nu 0$, $\nu 3 = 3\nu 0$, where $\nu 0$ is the frequency corresponding to the photoemission threshold.
9. Plot a graph of the stopping potential dependence on frequency of illumining light. How Planck constant h can be determined from this graph?
10. How can we show from the $U0(\nu)$ graph that the photo-effect is impossible at light frequencies $\nu < \nu 0$?
11. What determines the saturation current at a given light intensity?
12. Plot a family of current-voltage characteristics of photocell when it is illuminated by light of constant frequency v with intensities $I1 = I$, $I2 = 2I$, $I3 = 3I$.

13. Two photocells have electrodes in the form of a small ball and a concentric sphere around it. The sphere in one of the photocells serves as a photocathode, and in the other it serves as anode. Photocells are illuminated with light of the same frequency v so that saturation currents are the same. Plot in one figure approximate I-V characteristics of the photocells and explain their difference.

14. According to the concepts of classical physics, light is a continuous electromagnetic wave, the electric field of which in a given point of space changes according to a harmonic law. From this point of view, answer the following questions and compare your answers with the experimental results:

- Is it possible to predict the photoelectric effect in classical physics?
- What should the kinetic energy of photoelectrons depend on?
- What should the number of electrons emitted per time unit depend on?
- Should there be a photoemission threshold in photo effect?
- Should the photo effect be possible at very low intensity of illuminating light?

Lab 5.1.2 The Compton effect

Test questions:

1. Which processes of γ-quanta interaction with matter result in weakening of the primary quanta flow?
2. What is the Compton scattering effect? At what energies of γ-quanta does this process make a significant contribution to the weakening of the primary quanta flow?
3. How do the cross-sections of Thompson and Compton scattering depend on the atomic number of the scattering atoms Z?
4. By using the conservation laws, obtain a formula describing the dependence of energy loss on the scattering angle of γ-quanta due to Compton-effect.
5. Explain the principle of scintillation spectrometer operation.
6. Describe how the energy of incident γ-quantum is converted into an electrical pulse at the photomultiplier output?
7. Why does a lead diaphragm have to be inserted into the collimator when measuring at a zero-degree scattering angle?
8. It is well known that the photo-peak is separated from the Compton distribution by the area in which the count rate is greatly reduced. How wide is this interval? Why does it occur?

Lab 5.1.3 Scattering of slow electrons by atoms of noble gas
(the Ramsauer-Townsend effect)

Test questions:

1. What is the Ramsauer effect and how can it be observed experimentally?
2. Describe the "classical" mechanism of electron scattering on atom and explain how the probability of electron scattering should depend on electron velocity in this approach? What is this dependence in reality?
3. What is the fundamental difference between the quantum mechanical method of describing scattering of electrons on atoms and the classical method?
4. What is the meaning of de Broglie formula?
5. Derive the index of refraction of atom for de Broglie waves?
6. Write down the condition of quenching the de Broglie waves reflected from the atom.
7. At what kinetic energy E of electron the transmitted de Broglie wave quenching will be observed?
8. Plot the thyratron current-voltage characteristic observed in the experiment and the theoretical characteristic resulting from the classical theory of electron scattering. What is the reason behind their difference?
9. How can we determine the energy of electrons, at which the Ramsauer effect is observed, from the experimental I-V characteristic?
10. Explain the origin of the force acting from the atom on the passing electron and changing its kinetic energy. Why is this force not acting outside the atom?
11. Explain the change in potential energy of electron when it flies through the atom? What does the term "potential well" mean?
12. Write down the Schroedinger equation for the motion of electron over the potential well, and obtain its general solution.
13. Find the transmission coefficient of particle moving over the rectangular potential well (the ratio of squared amplitudes of transmitted and reflected waves).

14. The voltmeter reading does not give the true value of accelerating voltage in thyratron. Why? And how can it be determined?
15. How do you explain that on the current-voltage characteristic there is only one maximum of current flowing through the thyratron?
16. How do you direct the external magnetic field to make the thyratron's I-V characteristic more distorted?
17. Does the Earth magnetic field affect the thyratron I-V characteristic?
18. How can we determine from the I-V characteristic what inert gas is in the thyratron?
19. Which characteristic, dynamic or static, should be used for calculations and why?

Lab 5.2.1 Franck-Hertz experiment

Test questions:

1. Can the atom be a stable system from the point of view of classical physics? Explain your answer.
2. Formulate the Bohr postulates.
3. Demonstrate by direct calculation that in the experiment it is possible to neglect the thermal motion of helium atoms in the bulb.
4. Which impacts of particles are called absolutely elastic, and which are inelastic? Write down the law of energy conservation for absolutely elastic and inelastic impact of two particles.
5. Under what condition do only elastic collisions with gas atoms occur in the bulb and under what condition are inelastic collisions possible?
6. Show by direct calculation that when considering the collisions of electrons with atoms in this lab it is possible not to take into account the change in kinetic energy of the atom.
7. Draw a schematic diagram of measurement of current-voltage characteristics of the bulb in the Frank-Hertz experiment in static mode. Explain the purpose of each circuit element and how the installation works.
8. The same for dynamic mode.
9. Show that the curve observed on the oscilloscope screen represents a certain (which?) scale of function $I = I(U)$.
10. Plot and explain the I-V characteristic of the bulb when atoms are excited by electrons. Why is there a second drop in the current?
11. What is the resonance excitation potential? How is it measured in this work?
12. How can the resonance potential of atom be determined if only one minimum of the I-V characteristic is observed in the experiment? What will be the systematic error in this case?
13. Explain how the contact-potential difference between the cathode and accelerating grid can be determined from the I-V characteristic measurement.
14. What is the first ionization potential of atom? At what accelerating voltage will ions appear in the bulb?
15. What should be done to ionize helium in the bulb? What will the microammeter show in this case?

1. What is the nature of molecular spectra?
2. Plot the diagram of energy levels of two-atomic molecule.
3. What types of molecular spectra do you know?
   a. Which type is the absorption spectrum of iodine molecule in the visible region?
4. Which series are called the Delander series? Why are only two Delander series observed in the absorption spectrum?
5. What are the zero and first Delander series in the iodine absorption spectrum? What is the general view of absorption spectrum in the visible region?
6. What is the energy of zero-point and first Delander series absorption lines?
7. What parameters of the iodine molecule energy scheme can be determined by the absorption spectrum?
8. Plot the optical scheme of the installation used to study the iodine vapor absorption spectrum.
9. Plot the scheme of УМ-2 monochromator. How did you obtain the calibration curve of the spectral device?
10. What does the width of absorption lines observed this work depend on? How can the contrast of the observed spectrum be increased?

11. Why is the iodine cell heated in this experiment?
12. Does the spectrum clarity depend on the degree of cell heating?

Lab 5.4.1 Determination of energy of alpha-particles by measuring their range in air
Test questions:
1. Formulate the Geiger-Nuttoll law. What physical reasons are behind the sharp dependence of half-life on the energy of alpha-particles?
2. Why do the alpha-particle spectra consist of separate lines while the beta-particle spectra are continuous?
3. What is the mechanism of interaction of heavy charged particles with matter (explain the formula for ionization losses dE/dx)?
4. Which dependence is called the Bragg curve? How do ionization losses depend on the velocity of particles, on the properties of the medium?
5. What is the difference between the deceleration processes of alpha-particles and electrons in matter?
6. What is the relation between the energy of alpha-particles and their range?
7. What experimental methods are used to measure the range of alpha-particles in gas?
8. Which alpha-particle source is used in this work? What is the pipe collimator used for?
9. Explain the operation of ionization chamber, scintillation counter and Geiger counter. Describe their construction. How are the operating modes of these devices selected? How does the output signal of the Geiger counter and ionization chamber change with a small (~50 V) increase in the supply voltage around the operation point?
10. Which physical quantities are measured directly in this work?
11. Compare different methods to measure the range of alpha-particles. Estimate the accuracy of these methods of measurement. What systematic errors are possible in the measurement methods used in this work (what are their values and sources)?

Lab 5.4.2 Measurement of energy spectrum of beta-particles and their end-point energy by means of magnetic spectrometer
Test questions:
1. Which particles are emitted by the nuclei in beta-decay? Explain why the spectrum of alpha-particles emitted by the nuclei is always discrete while the spectrum of electrons is continuous. Derive the probability density for an electron in beta-decay to have a certain momentum Pe.
2. Show that the energy transmitted in beta-decay to the daughter nucleus is very small compared to the energy carried away by the electron and the antineutrino.
3. What is the end-point energy of beta-spectrum?
4. What is the phenomenon of internal electron conversion?
5. Name the main elements of experimental setup and explain their purpose. What is the principle of operation of a magnetic spectrometer with a longitudinal magnetic field? Explain the formula for the focal length of the spectrometer.
6. What is the resolution of beta-spectrometer? What does it depend on? How do you determine the resolution of the device by the shape of the peak of internal conversion electrons?
7. How does a Geiger counter operate? With what efficiency does it register electrons with energy of ~1 MeV? How are conventional counters and end-window counters arranged? How does the thickness of the end-window affect the experimental form of beta-spectrum?
8. Explain qualitatively how the residual gas affects the spectrometer's performance?
9. How should the installation be prepared for measurements with beta-spectrometer? What is the beta-spectrum measurement procedure? How is the energy scale of spectrometer graded?
10. Which experimental points should be used to draw the Fermi graph in order to determine the maximal electron energy in beta-spectrum?
11. What is the energy resolution of beta-spectrometer? Analyze possible errors in measuring the maximal spectrum energy (random and systematic).
12. Estimate the distance between the K- and L-lines in beta-spectrum.

Lab 5.4.3 Measurement of total activity of a sample of Co-60 by method of gamma-gamma coincidence
Test questions:
1. Explain the dipole, quadrupole, and octupole transitions in nuclei.

2. What quantum laws should be applied to electromagnetic transitions in nuclei?
3. What is an electric and magnetic photon?
4. What is the cascading nature of radioactive decay of Co-60 related to? How does the probability of transition depend on the multipolarity of radiation?
5. What is the specimen activity and in which units is it measured?
6. Explain the principle of measuring absolute activity by coincidence method.
7. Describe the principle of operation and construction of the photomultiplier tube.
8. Explain why organic and inorganic scintillators vary greatly in sensitivity to gamma-rays. Explain how the scintillator works.
9. How does the coincidence scheme work? What is the "resolution time"?
10. Does the accuracy of absolute activity measurement depend on the counter efficiency in this lab?

Lab 5.5.1 Measurement of flux attenuation coefficient of gamma-rays in medium and determination of their energy

Test questions:

1. What is the gamma-radiation of nuclei?
2. What are the processes of interaction of gamma-rays with matter?
3. Show that no photoelectric effect on a free electron is possible.
4. Using the conservation laws obtain a formula linking the loss of energy with the scattering angle of gamma-quanta under the Compton effect.
5. Does the energy of gamma-quantum change as it propagates through the medium? Compare the propagation of gamma-quanta through the medium with the propagation of a charged particle.
6. Obtain a formula describing the attenuation of gamma-ray during its propagation in the medium.
7. What is called the cross section of interaction? What does it have to do with the linear coefficient of attenuation of gamma-quantum flow in the medium?
8. What is the interaction cross-section? What is the dependence of cross-section of photo-effect, Compton scattering, and electron-positron pair production on the energy of gamma-quanta and on the serial number Z of atoms of the medium?
9. Describe the principle of operation and construction of the photomultiplier tube.
10. Describe the operating principle of scintillation counters using organic and inorganic scintillators.
11. Does the interaction of gamma-quanta with the absorber (for example, Al) differ from its interaction with the scintillator NaI(Tl)?
12. Why the source and detector are placed very far apart in this work?
13. Describe the order of conducting measurements. How can the instrumental drift be taken into account? How is the background noise evaluated?
14. What statistical accuracy of experimental results was obtained in this work and how large are the errors associated with the instrumental drift. Compare the results of different series of measurements. Does the difference between the results lie within the expected range?
15. Compare the experimentally obtained coefficients of absorption of gamma-quanta in Al, Fe, and Pb. Explain the obtained results. Estimate with their help the energy of gamma-quanta emitted by the source.

Lab 5.5.3 Determination of gamma-quanta energy by means of scintillation spectrometer

Test questions:

1. What is gamma-radiation? What conservation laws apply to electromagnetic transitions in nuclei?
2. What effects are behind the attenuation of gamma-quanta flow in the medium?
3. Show that no photo-effect is possible on a free electron.
4. What is the energy distribution of electrons in photo-effect and Compton scattering?
5. What is the energy of electrons in Compton scattering of gamma quanta by 180°?
6. What is the interaction cross-section? What is the dependence of cross-section of photo-effect, Compton scattering, and electron-positron pair production on the energy of gamma-quanta and on the serial number Z of atoms of the medium?
7. Why do many gamma-transitions in nuclei follow each other, forming a cascade rather than a "single jump" from the upper to the lower state? What is the multipolarity of transitions in Co-60?
8. Describe the operation principle and construction of the photomultiplier tube.

9. What is the NaI(Tl) crystal used for? Why is the crystal activated by thallium used in this work rather than pure NaI crystals?
10. Explain the operation principle of scintillation spectrometer. Describe how the energy of incident gamma-quantum is converted into an electrical pulse at the output of the PMT spectrometer.
11. What is the differential spectrum of a radioactive source emitting one gamma-line (e.g. Mn-54 with gamma-radiation energy 0.83 MeV)? What is the contribution of photo-effect and Compton effect to the spectrum?
12. How can you verify that the radiation detected by the detector is actually a gamma-radiation?
13. How do you calibrate the energy scale of the amplitude analyzer?
14. Will the Co-60 spectrum change if an organic crystal is used instead of NaI(Tl)?

Lab 5.6.1 Resonant absorption of gamma-quanta (the Moessbauer effect)
Test questions:
1. What kind of nuclear radiation is called gamma-radiation? How does it differ from X-ray radiation?
2. What effects are behind the attenuation of gamma-quantum flow in a medium?
3. What is the resonant absorption of gamma-rays? Under what conditions does this effect become observable?
4. What determines the natural width of the gamma-ray line?
5. How does the Doppler effect influence the shape of the lines?
6. What determines the probability of resonant absorption of gamma-quanta? What energy range of gamma-quanta and specimen temperature can be used to observe the Moessbauer effect?
7. Explain why does a chemical shift of gamma-line occur?
8. What source of gamma-quanta is used in this work? Plot its decay scheme. Which substance is used as an absorber?
9. For what purpose is the amplitude spectrum of radiation measured? Why is a "thin" NaI(Tl) crystal used for measurements?
10. How are gamma-quanta with energy E = 23.8 keV selected and registered? How is the working "window" of differential analyzer selected?
11. Why is a palladium filter used in this work?
12. What is the Doppler shift method for the emission and absorption lines of gamma-rays?
13. What sequence of operations is used to observe the spectrum of resonant absorption?
14. In the installation, the absorber moves relative to the source. Is it possible to move the source and leave the absorber at rest?
15. Does the thickness of absorber affect the width of resonant line measured in the experiment?
16. How do the processes of gamma-quanta absorption due to the photo effect and Compton effect influence the amplitude of resonant (nuclear) absorption of gamma-quanta in the absorber?
17. What do you know about the applications of Moessbauer effect in various scientific and technical fields?

Lab 5.7.1 (Measurement of angular distribution of hard component of cosmic rays),
Lab 5.7.2 (Study of cosmic ray showers), and
Lab 5.7.3 (Measurement of cross-section of electron-positron pair production on lead nuclei)
Test questions:
1. What is the composition of primary cosmic radiation? Why are there no neutrons in cosmic radiation?
2. What is the composition of cosmic radiation at the Earth surface? Which particles are found in the soft and hard components of cosmic radiation? What is their origin?
3. What physical processes are behind the energy loss by particles that make up the soft and hard radiation components when passing through the medium? Which of these processes are dominant?
4. Qualitatively explain the angular distribution of cosmic rays.
5. Explain the operation principles of a telescope that makes use of Geiger (scintillation) counters.

Based on the results of student's work, a score is set from 0 to 10 points according to the level of the prepared report and knowledge of the student. From the points received for each work, an average score is calculated, which determines the credit mark for the work in physics laboratory according to the following table:

Score	Mark
10	Excellent
9	
8	
7	Good
6	
5	
4	Satisfactory
3	
2	Unsatisfactory
1	

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 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 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 syllabus required for further education.

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

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

The credit in semesters 2-6 is given to a student based on the results of his/her current performance (results of work in physics laboratory).

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: Laboratory Practicum* is carried out in the form of a graded test.

To pass the end-of-semester test, the student must complete a given number of laboratory works. To complete each lab assignment, the student must prepare for the work, pass a preliminary quest to the instructor, perform the experimental part of the work, conduct necessary calculations, and pass the lab test. Obtaining a credit for each lab requires passing control test that consists of a number of questions:

Examples of Test Questions for Laboratory Works:

Lab 1.1.2 Measurement of linear expansion coefficient of a rod with the aid of microscope

Test questions:

1. For a given accuracy of AL determine the required accuracy of the rod length and the thermometer resistance.
2. Determine the contributions to the error of a: due to calibration of the ocular scale, due to determination of the mark position, due to measurement of the room temperature, and due to the error of the temperature coefficient of resistance.
3. Near-sighted and far-sighted observers adjust the microscope so that the image h is either at small or at large distance, respectively, from the observer’s eye. Is it linear or angular magnification that changes less?

Lab 1.1.5 Study of elastic proton-electron collisions

Test questions:

1. Derive equations relating electron scattering angle and its momentum in relativistic and non-relativistic mechanics.
2. Derive the formula relating velocity of a relativistic particle with its momentum and energy.
3. Derive the equation relating electron momentum and the radius of its trajectory in magnetic field. Show that this equation is valid both in relativistic and non-relativistic mechanics.

Lab 1.2.1 Determination of pellet velocity by means of ballistic pendulum

I. Pellet-velocity measurement setup

Test questions:

1. Give a definition of ballistic pendulum and describe where it can be used.
2. When is initial momentum of ballistic pendulum equal to pellet momentum?
3. Why is it necessary to use inelastic collision between pellet and pendulum?
4. Estimate the time of pellet-pendulum collision in the experiment.
5. What factors are responsible for non-conservation of momentum during the collision?
6. What are the specific requirements for rifle installation?
7. What factors contribute to swing attenuation?

8. Which assumptions made in derivation of eq. (5) can be checked experimentally?
9. Why the suspension threads are not parallel (see Fig. 1)?

II. Method of torsion ballistic pendulum

Test questions:

1. How does a deviation of the pellet-target impact angle from 90 degrees affect the validity of the method employed in the experiment?
2. At which amplitudes of pendulum swing should the periods be measured?
3. How does pellet momentum affect pendulum swing?

Lab 1.2.2 <u>Experimental verification of the dynamical law of rotational motion using the Oberbeck pendulum</u>

Test questions:

1. Why must the torque due to friction in the shaft bearings be reduced as much as possible? It appears that Eq. (6) is valid for any value of M_{fr}.

2. What is the role of the thread thickness and elasticity?

3. Which quantity has to be measured with the greatest accuracy in this experiment?

4. State and prove Huygens-Steiner theorem.

Lab 1.2.3 <u>Determination of principal moments of inertia of rigid bodies by means of trifilar torsion suspension</u>

Test questions:

1. What are the assumptions used in the derivation of Eq. (10)?

2. Can the method of measuring the moments of inertia suggested in the lab be used if the axis of rotation of the platform does not pass through the center of mass?

3. Prove the Huygens-Steiner theorem.

Lab 1.2.4 <u>Determination of principal moments of inertia of rigid bodies by means of torsional oscillations</u>

Test questions:

1. What are the principal moments of inertia of a rigid body?

2. What does the inertia ellipsoid of a cube look like?

3. Describe the state of free (torqueless) rotation of a rigid body.

Lab 1.2.5 <u>Study of gyroscope precession</u>

Test questions:

1. What is gyroscope and what are its major properties?

2. What factors does the velocity of regular precession depend on?

3. What is the dimensionality of the torsion modulus in Eq. (9)?

4. Derive Eq. (8) from Eq. (7).

5. Can you explain that a rolling coin is turning in the direction of its tilt?

Lab 1.3.1 Determination of Young's modulus based on measurements of tensile and bending strain

Test questions:

1. What are the main sources of measurement errors? How can the measurement error be reduced?

2. Estimate the maximum accuracy of measurement of wire elongation and beam deflection which is reasonable in this experiment.

3. What is the difference between the state of normal stress and the state of normal deformation?

4. For which stress and strain does Hooke's law hold?

5. Which deviations from Hooke's law are possible in deformation of solids?

6. What is Poisson's ratio?

7. Which assumptions are made to obtain the relation between the maximum beam deflection and Young's modulus?

8. What function $y(x)$ describes the shape of the middle line of beam under perfect bending?

9. What is the use of platform M in Lermant's machine?

Lab 1.3.2 Determination of torsional rigidity

Test questions:

1. How does friction in the axes of blocks B affect the results of static measurements? How can one minimize this influence?

2. How does the oscillation period change when damping is increased?

3. Which method of measurement of shear modulus is preferable in practice: the static or dynamic one?

4. How can one estimate the error of shear modulus from the plot in (I^2,T^2)-coordinates?

Lab 1.3.3 Determination of air viscosity by measuring a rate of gas flow in thin pipes

Test questions:

1. Write the equation which describes the radial distribution of laminar flow velocity in a circular pipe. What is the ratio of the average and maximum velocities?

2. How is the Reynolds number defined? How can it be determined experimentally?

3. Describe the method of graphical treatment of the experimental data (see 8) that allows one to clearly distinguish the regions of formed and non-formed flow.

Lab 1.3.4 Study of stationary flow of liquid through pipe

Test questions:

1. Specify the assumptions used to derive Bernouilli's equation.
2. How does viscosity affect the readings of Venturi and Pitot flow meters?
3. Which water levels in reservoir 1 correspond to laminar or turbulent flow in tube T?

4. Suppose there is a laminar fluid flow through a tube and the viscosity decreases gradually while other flow parameters remain constant. How does the flow change?
5. Which flow regime, laminar or turbulent, provides a better agreement between the values of flow velocity determined by Venturi and Pitot tubes and that one obtained by using reservoir II?
6. Derive Torricelli's equation and use it to estimate the velocity of liquid flowing out a very short pipe for different levels H. Why are the experimental values of the velocities of water flowing out a long pipe sufficiently less?

Lab 1.4.1 Compound pendulum

Test questions:

1. What simplifying assumptions are used to obtain Eq. (4)?
2. What distance between the pivot point and the center of mass corresponds to the minimum period of oscillations?
3. Describe the behavior of the compound pendulum whose pivot point and the center of mass coincide.
4. Why is the simple gravity pendulum suspended on two wires?
5. Formulate and prove the Huygens-Steiner theorem.

Lab 1.4.3 Study of non-linear oscillations of a long-period pendulum

Test questions:

1. How does the pendulum oscillation period depend on damping?
2. Discuss the design of a moderate size pendulum which has a large oscillation period. Could a conventional pendulum be used in the lab instead?
3. Discuss the dependence of the pendulum oscillation period on the amplitude.

Lab 1.4.4 Study of oscillations of coupled pendulums

Test questions:

1. Give some examples of oscillators with two degrees of freedom.
2. What are normal oscillations (normal modes)?
3. What are partial oscillations?
4. At which initial condition does the swinging of pendulums occur in turn?
5. Derive the equation (17).

Lab 1.4.5 Study of string oscillations

Test questions:

1. What are longitudinal and transverse waves? Write down the wave equation.
2. Derive the wave equation. Give a definition of node and antinode of a standing wave. Describe the energy propagation along an oscillating string.
3. Derive a formula for the velocity of transverse wave on a string. Compare the value calculated with the velocity obtained in the experiment.

4. Describe the reflection of a wave from the fixed end and from the end which moves freely in a plane orthogonal to the direction of the string tension. What is the value of a phase shift between the incident and reflected waves?

5. What condition must be satisfied for a traveling wave not to affect the oscillation pattern? How can one check the condition experimentally?

Lab 1.4.6 Measurement of speed of ultrasound in liquid by means of ultrasound interferometer

Test questions:

1. Which mechanical oscillations are called ultrasonic?

2. What are longitudinal and transverse waves? In which media can the waves propagate?

3. Write down a mathematical expression for a plane wave.

4. What conditions should be met to make wave interference possible?

5. Derive an equation which specifies the condition of resonance in the interferometer. How does the equation depend on boundary conditions?

6. What conditions should be met to create a standing wave? Give definitions of node and anti-node. How is energy transferred in the wave?

7. Why is the speed of ultrasound greater in a solution of electrolyte than in the pure liquid?

8. Suppose the open surface of liquid is used instead of the metallic reflector. The height of the liquid column can be gradually varied by slowly emptying the container. What is the phase difference between the incident and reflected waves on the air-liquid boundary?

9. How should the interferometer be modified in order to do the same measurements with gases?

Lab 1.4.7 Determination of elastic constants of liquids and solids via measurement of speed of ultrasound

Test questions:

1. When measuring the speed of ultrasound by means of the ultrasound sensor one can see ghost pulses on the screen in addition to sequentially reflected pulses. Why are these pulses seen? How can one get rid of them?

2. When measuring the ultrasound speed using the prism probe, a systematic error is introduced because there is a wedge-shaped part of the plexiglass probe between the emitter and the material under study. Evaluate this error for given sizes of the probe and the sample.

3. Show that the reflection coefficient of the ultrasound wave on the interface between two media does not depend on the direction of wave propagation.

Lab 2.1.2 Measurement of C_p/C_v ratio of gas by the method of adiabatic expansion

Test questions:

1. Does γ depend on temperature in the chosen temperature interval?

2. What are the values of C_p, C_v, and γ for an ideal gas according to the equipartition theorem?

3. Why does the gas temperature increase when the container is being filled?

4. Evaluate the time of gas outflow using the Poiseuille equation.

Lab 2.1.3 <u>Determination of C_p/C_v ratio of gas by measuring the speed of sound in it</u>

Test questions:

1. Derive equations (1.16) and (1.17).
2. Does the value of γ depend on temperature in the considered temperature range?
3. Is there such dependence in the range from very small temperatures to 1000 ◦C?

Lab 2.1.4 <u>Measurement of specific heat of solids</u>

Test questions:

1. Give the definition of specific and molar heat capacity.
2. What is the molar heat capacity of a metal according to the classical theory? What is the molar heat capacity of a chemical compound?
3. Describe the method used to reduce the error related to heat losses.

Lab 2.1.5 <u>Experimental study of thermal effects caused by elastic deformations</u>

Test questions:

1. What conditions must be met to ensure that a deformation process is reversible?
2. Show that Eq. (15) gives ordinary expressions for elastic stretching and thermal expansion at small values of λ and ΔT.
3. Is a rubber deformation without a thermal effect possible?

Lab 2.1.6 <u>The Joule-Thomson effect</u>

Test questions:

1. What is the difference between real and ideal gases?
2. Plot the interaction force and the potential energy of two molecules versus the distance between them. Using the curves explain the Joule-Thomson effect.
3. Give the definition of critical temperature. What is the inversion temperature?
4. Explain the sign of Joule-Thomson effect for $a = 0$, $b \neq 0$ and for $a \neq 0$, $b = 0$.

Lab 2.2.1 <u>Experimental study of molecular diffusion of gases</u>

Test questions:

1. Show that in the installation the concentration of gases can be considered uniform in the whole volume of V_1 (and V_2).
2. Why is the dependence of D on $1/P$ expected to be a straight line?

Lab 2.2.2 <u>Measurement of thermal conductivity of air at various pressures</u>

Test questions:

1. Why does the heat transfer from the filament to the ambient air drop when the pressure decreases from several torr to several decitorr?

2. Does the heat transfer depend on pressure at higher pressures? (Discuss also the mechanisms different from thermal conductivity.)

Lab 2.2.3 <u>Measurement of thermal conductivity of air at atmospheric pressure</u>

Test questions:

1. According to kinetic theory of gases the mean free path λ depends on concentration n as $\lambda = 1/\sigma n$. What can you say about the temperature dependence of σ using the results of item 6?
2. Why does the installation for measurement of thermal conductivity of gas have the shape of a long thin vertical cylinder?
3. Estimate the heat losses through the wire ends.
4. A thermal e.m.f. is usually several microvolts per kelvin. Estimate the current through the wire for which a thermal e.m.f. in the voltmeter circuit would significantly affect the results.
5. What is the temperature difference between the wire and the tube at 150 mA? Compare the result with the experimental value.
6. Equation (1) was derived under the assumption that the thermal conductivity is independent of temperature, therefore the equation is valid if $\Delta T \ll T$. Assume that the coefficient of thermal conductivity depends on temperature as $\varkappa \sim T\beta$ and calculate the exact relation. Estimate the corresponding error of x.

Lab 2.2.4 <u>Measurement of thermal conductivity of solids</u>

Test questions:

1. What is the definition of coefficient of thermal conductivity and what is its dimension?
2. Derive an equation similar to Eq. (3) which would take into account a change in the heat flow area, say, from S_1 to S_2.
3. Derive Eq. (6) which takes into account a difference in thermocouple sensitivity.
4. Can the dependence of thermal conductivity coefficient of ebonite be measured using this particular installation? Are the heat losses through the lateral surface significant enough to prevent the measurement?
5. Using the experimental points of the radial temperature dependence plot isotherms and sketch the lines of heat flow (there should be at least three isotherms and flow lines which span the whole plate area).

Lab 2.2.5 <u>Determination of viscosity of liquid by its outflow through capillary</u>

Test questions:

1. Why is it recommended to determine the viscosity of water by a graphical method in the first experiment? Wouldn't it be better to determine the viscosity directly for different tube heights? It seems that averaging the results one could accurately find the viscosity and estimate reliably the experimental error by the dispersion of the results. What is wrong with this approach?
2. The pressure difference that must be applied to force a liquid through a pipe at a given velocity (assuming laminar flow) depends on liquid viscosity. Does viscosity

matter if the flow is turbulent? What parameters of the liquid are required in this case?

Lab 2.2.6 Determination of activation energy of liquid via temperature dependence of its viscosity

Test questions:

1. The model of liquid considered in this lab implies that moving a molecule to a neighboring “hole” requires disrupting its bonds with the neighboring molecules. The bond disruption also occurs during evaporation of liquid, so one could expect that the activation energy would be close to the vaporization heat per molecule. Does the experiment verify this conclusion? Take the tabulated value for the vaporization heat.

2. Steel spheres of different diameters are used in the measurement of liquid viscosity by Stokes' method. Which spheres, small or large, are better suited for the experiment?

Lab 2.2.7 Experimental study of gas diffusion through porous medium

Test questions:

1. Prove that the gas concentration is almost uniform in the installation in our experiment.

2. What is the difference between the Knudsen and viscous regimes of diffusion?

Lab 2.3.1 Creation and measurement of vacuum

Test questions:

1. At which circumstances are the thermal conductivity and viscosity of gases independent of pressure?

2. Why are the readings of the thermocouple vacuum gauge almost constant at pressures below 10^{-4} torr?

3. For which purpose do the electrons execute the oscillatory motion in the ionization gauge?

4. Why is the flow capacity of pipes in Knudsen regime independent of the size of molecules?

Lab 2.3.2 Experimental study of ion pump

Test questions:

1. What is the highest vacuum obtained in the LM-2 tube in this experiment?

2. Would the vacuum increase or decrease if the ion pumping were accompanied by cooling of the collector?

Lab 2.3.3 Measurement of osmotic pressure

Test questions:

1. Estimate the influence of the capillary effects on the results of the measurements.

2. For which concentration of the solution is Eq. (1) valid?

Lab 2.3.4 Scattering slow electrons on mercury atoms

Test questions:

1. What is scattering cross-section? What cross-section is called elastic, inelastic?
2. How are cross-section and free path connected? Derive Eq. (5).
3. What law determines the dependence of the pressure of saturated vapor of a liquid on temperature?
4. Why should the installation be immersed in liquid completely, i.e. with all its projected parts?

Lab 2.4.1 Measurement of vaporization heat of liquid

Test questions:

1. A reference manual gives the heat of vaporization measured at the pressure of 760 mm Hg. Does the tabulated value correspond to your result? Which value is greater? Estimate the difference between them.
2. Argue how the value of heat of vaporization changes when temperature increases.

Lab 2.5.1 Measurement of surface tension of liquid

Test questions:

1. If several bubbles are produced per second the manometer readings are practically constant. Does it make sense to measure it?
2. Why should one measure just the peak pressure?
3. Why can a thermal expansion effect be reduced by submerging the needle?
4. Why should the bubbles not touch the bottom?
5. Is it possible to determine σ by measuring maximum and minimum pressures during the bubble gurgling if the needle immersion depth is unknown?
6. Using the obtained results estimate the critical temperature of aniline.
7. Does the experiment accuracy allow one to notice a nonlinearity of the $\sigma(T)$ dependence?
8. Which errors dominate in the experiment: random or systematic?
9. Which value should be substituted into the formula for the height of the liquid column in the capillary: $\sigma_{water\text{-}air}$ or $\sigma_{water\text{-}glass}$?

Lab 3.1.1 Magnetometer

Test questions:

1. Write the expression for the field of magnetic dipole.
2. Derive the expression for the magnetic field at the center of a circular current loop.
3. What must the internal resistance of the power source be in order for the capacitance to have time to discharge between the oscillator short-circuitings?
4. Actually we measure the magnetic field inside the building rather than the field of the Earth. Is the accuracy of measurement of Weber’s constant affected?

5. Find relations between oersted and ampere per meter, gauss and tesla, and maxwell and weber.

Lab 3.1.2 <u>Absolute voltmeter</u>

Test questions:

1. Estimate the error arising due to the fact that the beam is equilibrated at a small separation between the contact screws and the beds while the measurements are done at zero separation.
2. Explain how the electrostatic voltmeter can be used for measuring both direct and alternating voltage.
3. Explain how by measuring an alternating voltage one obtains the effective voltage value.
4. What determines a frequency range in which an alternating voltage can be measured by means of electrostatic voltmeter?

Lab 3.2.1 <u>Phase shift in alternating current circuit</u>

Test questions:

1. What is the impedance of electrical circuit?
2. What is the total impedance of elements connected in series? And in parallel?

Lab 3.2.2 <u>Voltage resonance</u>

Test questions:

1. Why is the voltmeter reading $VR+L$ not equal to the sum of readings VR and VL? In our case $VR+L < ER+VL$. Is the opposite inequality possible?
2. Why does the ellipse on the oscilloscope screen transform into a straight line at resonance in the circuit shown in Fig. 2?
3. What contributes to the active resistance of coil with a core?
4. Explain the principle of wattmeter operation.
5. Are the currents in the studied circuit quasi-stationary? Why?
6. At which frequency does the coil hum?

Lab 3.2.3 <u>Current resonance</u>

Test questions:

1. Give all definitions of resonance which you know.
2. How to detect resonance in a circuit? Specify all criteria which you know.
3. Derive the formula relating Q-factor and resistance.
4. What effects are behind energy loss in the circuit?
5. Do energy losses depend on the current frequency?
6. Derive the relation between R_{res} and rL.

Lab 3.2.4 <u>Free oscillations in electrical circuit</u>

Test questions:

1. What are the natural frequency, Q-factor, and logarithmic decrement of oscillator circuit?

2. What is the phase plane of oscillations?

3. How to determine logarithmic decrement with the aid of oscillation pattern on the phase plane?

Lab 3.2.5 Driven oscillations in electrical circuit

Test questions:

1. Derive Eq. (2.57).

2. Find a real solution of Eq. (2.44). Hint: look for a solution of Eq. (2.44) in the form A_i sin fit + A_i cos fit.

3. Derive all equations (2.28) that define the Q-factor. What is the physical meaning of Q-factor?

4. In what cases an oscillator circuit is weakly coupled to other circuit elements?

Lab 3.2.6 Ballistic mirror galvanometer

Test questions:

1. What is the dynamical constant of galvanometer? What parameters does it depend on and in what units is it specified in the galvanometer manual?

2. Which modes of frame motion are possible when the galvanometer operates in stationary regime? What regimes are suitable for measurement of direct current?

3. How does the damping ratio of the galvanometer frame change when ohmic resistance of its circuit increases?

4. Why does the galvanometer frame stops quickly after closing key K1 (see Fig. 2)?

5. What are cylindrical cuts in the poles of magnet designed for (see Fig. 1)?

6. What is the main operation principle of ballistic regime? What is the ballistic constant of galvanometer?

7. What conditions should be met to ensure the maximal first light-spot deflection for the galvanometer operating in the ballistic regime?

8. Derive Eq. (30).

9. For $R > 10\,R_{cr}$ the curve $1/\theta 2 = f[(Ro + R)2]$ can deviate from a straight line. How can this deviation be explained?

Lab 3.3.1 Measurement of electron specific charge by magnetic focusing and by magnetron

Test questions:

1. Sketch and explain the setups for measuring the electron specific charge by means of magnetic focusing and magnetron.

2. Explain the operating principle of CRT.

3. Explain the operating principle of millifluxmeter.

4. Why does the anode used in the magnetron method consist of three cylinders rather than of one?

Lab 3.3.2 Study of current-voltage characteristics of vacuum diode

Test questions:

1. Sketch the potential distribution $V(r)$ between cathode and anode: a) at zero potential difference between cathode and anode; b) at a large potential difference (the diode current saturation mode). Explain the distributions.

2. Sketch the diode current as a function of anode voltage Va in the range from a negative to a large positive value. Show the voltage area where the three-half power law is observed. How can we explain the deviations from this law at small and large anode voltages?

3. How does the cathode heating current affect the diode current at a constant anode voltage? Does it bring an error to the measured value of e/m?

Lab 3.3.3 Millikan's experiment

Test questions:

1. Why should one avoid using too big and too small droplets for the measurement?

2. What voltage range is optimal for the experiment? Evaluate it (see item 1).

3. Sketch the time dependence of drop velocity in free fall and indicate the settling time and path.

4. Using the installation parameters estimate the capacitance C and the time of discharge through the resistor R (the plate area is ~20 cm^2).

5* What other methods of measuring electron charge do you know?

Lab 3.3.4 The Hall effect in semiconductors

Test questions:

1. What substances are called dielectrics, conductors, and semiconductors? How can the difference in their electrical properties be explained? How does the metal and semiconductor conductivity depend on temperature?

2. What is the Hall constant? How does the Hall constant depend on temperature in metals and semiconductors?

3. Does the measured value of the Hall constant depend on sample geometry?

4. What is the principal design of a millifluxmeter? Do its readings depend on the test coil resistance? Should this resistance be small or large compared to the resistance of the meter coil?

5. Derive the expression for the Hall constant for materials with two types of charge carriers. Hint: the transverse current must vanish.

Lab 3.3.5 Hall effect in metals

Test questions:

1. What substances are called dielectrics, conductors, and semiconductors? How can the difference in their electrical properties be explained? How does metal and semiconductor conductivity depend on temperature?

2. What is the Hall constant? How does the Hall constant depend on temperature in metals and semiconductors?

3. Does the measured value of the Hall constant depend on sample geometry?

4. What is the principal design of a millifluxmeter? Do its readings depend on the test coil resistance? Should this resistance be small or large compared to the resistance of the meter coil?

Lab 3.3.6 Effect of magnetic field on semiconductor conductivity

Test questions:

1. Study equations of electron motion in a rectangular sample. Does the sample resistance depend on the magnetic field induction?

2. Explain qualitatively (without formulas) why the sample resistance depends on magnetic field.

Lab 3.4.1 Dia- and paramagnets

Test questions:

1. Explain the method of measurement of magnetic susceptibility.

2. Write down the expression for the force acting on a sample in a non-uniform magnetic field

3. How can one verify whether the magnetic field in the gap of electromagnet is uniform?

4. How can one experimentally verify whether the magnetic susceptibility of the scale affects the results?

Lab 3.4.2 The Curie-Weiss law

Test questions:

1. Explain dia- and paramagnetism from the atomic theory perspective.

2. What is the difference between dia- and paramagnets in the absence of magnetic field?

3. What is the general principle which explains diamagnetism?

4. Sketch the curve $B(H)$ for dia- and paramagnets on the same plot.

5. What is the contribution to magnetic susceptibility due to gadolinium conductivity? Find a relation between the bit size, the frequency, and the conductivity? Does the contribution depend on temperature? Estimate the contribution for bits of 0.5 mm in size.

Lab 3.4.3 The Curie point

Test questions:

1. What is the difference in magnetic properties of atoms of dia- and paramagnets in the absence of magnetic field?

2. How do the properties of a material change under first- and second-order phase transitions?

3. What two competitive interactions between atoms are typical for a ferromagnet?

4. On the same plot sketch three initial magnetization curves $B(H)$ of a ferromagnet corresponding to room temperature, a temperature above the Curie point, and a temperature in-between. Show the region of H corresponding to this experiment.

Lab 3.4.4 Hysteresis loop (static method)

Test questions:

1. Why is it recommended to start going around the loop from the saturation?
2. Derive the relation between a spotlight deflection and the corresponding increment of magnetization. What are the validity conditions for this relation?
3. Using Stokes' theorem, derive the expression for magnetic field inside a long solenoid.

Lab 3.4.5 Hysteresis loop (dynamical method)

Test questions:

1. What shape of a sample placed in a uniform magnetic field ensures uniform magnetization of the sample?
2. Why is the sample used for observation of hysteresis loop shaped as a toroid rather than a rod?
3. Why should the magnetizing coil be disconnected when calibrating the horizontal axis of oscilloscope?
4. Estimate the accuracy of measurement of induction B if the measurement coil is loosely wound around a sample, e.g. if the sample occupies only a half of the coil cross-section.

Lab 3.4.6 Parametric resonance

Test questions:

1. Derive the condition of parametric oscillations (3) assuming that the inductance varies periodically: $L = L_0[1 — m \sin(2\omega_0 t)]$.

   Write down the oscillator current as a function of time.
2. Why is the inductance in the experiment proportional to differential magnetic susceptibility?
3. Sketch the dependence of μ-diff on magnetizing current for the hysteresis loop shown in Fig. 1.
4. What other frequencies of parametric oscillations could be induced at large inductance variations?

Lab 3.5.3 Relaxation oscillations

Test questions:

1. What oscillations are called relaxation oscillations?
2. Which gas parameters determine the ignition potential of VR tube?
3. Why is the quenching potential significantly less than the ignition potential?
4. How can one determine the steady current of VR tube using its I-V curve and the generator parameters?

5. What is the critical resistance of relaxation generator? What does it depend on?

6. Why does the critical resistance depend on the value of U at the generator input? Examine Fig. 3.

7. Why are there no oscillations at a small capacitance (the tube does not go out) even at $R > R_{cr}$? Estimate the capacitance by comparing the relaxation time and the time of de-ionization.

Lab 3.6.1 Spectral analysis of electric signals

Test questions:

1. Plot the frequency spectrum $F(\omega)$ of

   a) an infinite sinusoid;

   b) a finite sinusoid;

   c) a repeating sequence of trains;

   d) a repeating sequence of rectangular pulses;

   e) a single train;

   f) a single rectangular pulse.

2. How does the spectrum of a repeating sequence of rectangular trains change if every second pulse is removed? How does the spectrum look if the procedure is repeated until a single pulse is left?

3. Find the spectrum of the following phase-modulated signal,

   $f(t) = A_o \cos(\omega t + m \cos \Omega t)$, providing $m < 1$.

   Compare it to the spectrum of an amplitude modulated sinusoid.

Lab 4.1.1 Centered optical systems

Test questions:

1. Show that if a distance between an object and a source exceeds $4f$ then the image on the screen can be obtained for two different lens positions.

2. Describe a method of measurement of the focal length of a negative lens.

3. Give definitions of principal focuses, focal length, and principal planes of a compound centered optical system.

4. Using graphical method locate principal planes of a system composed of two thin lenses, positive and negative, providing their focal length and a distance between them are known.

5. Give definitions of spherical and chromatic aberrations.

6. Explain why spherical aberration depends on a side of plane-convex lens facing the source.

Lab 4.1.2 Modeling of optical instruments and measurement of their magnification

Test questions:

1. What is the purpose of an auxiliary spotting scope used in these experiments?

2. Evaluate a linear, angular, and longitudinal telescope magnification if the front focal length of its objective f_1 = 40 cm and focal length of the eyepiece f_2 = —2 cm?

3. Under what condition are angular and linear magnifications of microscope equal?

4. Derive Eq. (4) and explain the corresponding method of measurement of microscope magnification.

Lab 4.1.3 Abbe refractometer

Test questions:

1. What is the total internal reflection?

2. Why are the faces *ab* and *ed* of prisms P1 and P2 grounded?

3. Under what condition the layer of liquid between a solid specimen and the prism P2 does not affect the measured value of refractive index?

4. What is atomic refraction? and molecular refraction? State the rule of additivity of refraction.

Lab 4.2.1 Newton's Rings

Test questions:

1. In the center of Newton’s rings observed in reflected light the dark spot is located. Why?

2. How does the pattern of Newton's rings look like in transmitted light?

3. Why does the ring width decrease with increasing the ring radius?

4. Why is the light reflected from the front (plane) surface of the lens rendered irrelevant in calculating the interference pattern?

5. Derive the formula relating the period of beats expressed via the number of rings and the wavelengths of spectral lines.

6. Why does the ring visibility increase if the beam entering the dark-window illuminator passes through an aperture?

7. Why do the interference rings of large number seem fuzzy?

Lab 4.2.2 Jamin interferometer

Test questions:

1. Why should the plates *P1* and *P2* of Jamin interferometer be sufficiently thick (not less than 2-3 cm)?

2. Can these plates differ significantly in thickness?

3. Explain why the number of observable interference fringes grows if the light beam goes through an optical filter.

Lab 4.2.3 Rayleigh interferometer

Test questions:

1. Explain why the diffraction pattern does not move when one of the slits *D* is obstructed.

2. Why must a width of collimator slit *S* be small enough? Estimate the maximal width if a collimator focal length and a distance between the slits are known.

3. Is it possible to obtain a sharp zero band if the dispersion $n = n(\lambda)$ of a studied fluid is strong? Do the corresponding estimates.

Lab 4.2.4 <u>Michelson interferometer</u>

Test questions:

1. What is the relation between the speed of interference bands and the speed of mobile mirror?

2. What factor restricts the maximal and minimal speed which can be measured by the Doppler frequency shift on our installation?

3. What determines the accuracy of measurement of the laser wavelength? How does the accuracy depend on the mirror speed?

4. What configuration of interference pattern corresponds to an arbitrary arrangement of sources *S1* and *S2*?

Lab 4.2.5 <u>Coherence of light</u>

Test questions:

1. What is the relationship between the coherence and visibility functions?

2. How can the coherence length and coherence radius be measured?

3. What is the efficiency of an incandescent light bulb used in a regular light fixture?

4. How does the coherence radius depend on a slit width and a distance between the slit and the input interferometer plane?

5. How does the number of visible interference bands change if there is an optical filter placed between an eye and the microscope?

Lab 4.3.1 <u>Diffraction of light</u>

Test questions:

1. Explain why a pattern of Fresnel diffraction obtained with a circular opening can have either dark or bright spot at the center while the diffraction by a circular screen always produces a bright central spot (the Poisson spot).

2. Explain why a lateral displacement of slit *S2* in the setup shown in Fig. 4 does not result in a displacement of the diffraction pattern. Does a longitudinal shift of the slit result in a pattern displacement?

3. Derive the intensity distribution of the pattern of Fraunhofer diffraction by two parallel slits.

4. Derive Eq. (10). Explain the concept of spatial coherence by using the blurring of an interference pattern caused by a wide light source as an example.

5. What is the relationship between the visibility of interference pattern and spatial coherence of a light source? What is the difference between visibility curves corresponding to discrete and continuous variation of the source parameters? Explain the same for temporal coherence.

6. Explain the Babinet's principle.

Lab 4.3.2 Diffraction of light on ultrasound wave in liquid

Test questions:

1. Show that the period of acoustic grating equals the wavelength of ultrasound wave both for a propagating and standing wave. Show that Eq. (8) is valid for any amplitude and/or phase periodic grating.

2. How does the light intensity change over time in diffraction maximums of different order in the diffraction of light on traveling and standing ultrasound waves?

3. What is the difference between the method of dark field and the method of phase contrast?

4. How can one experimentally check whether an acoustic grating is a purely phase grating?

Lab 4.3.3 Study of microscope resolution by the Abbe method

Test questions:

1. What condition must be imposed on the distance between the grid and the screen in order to obtain the pattern of Fraunhofer diffraction on the screen?

2. Why do the diffraction maxima overlap when diffraction on the remote screen is produced by a coarse grid?

3. Why should the object be placed near the front focal plane of the microscope lens?

4. Why does the primary image remain at rest while the secondary image shifts when the grid is moved transversely?

5. Which spatial filter must be placed at the back focal plane of objective in order to form the grid image with the cells reduced by half at the plane *P2*?

Lab 4.3.4 Method of Fourier transform in optics

Test questions:

1. What is the relationship between the images observed at the planes P1 and P2?

2. What common features are observed in the spectra of a single slit and a periodic array of the same slits?

3. What is the relationship between the slit width and its spectrum width?

4. What grid parameters can be determined from the pattern of Fraunhofer diffraction obtained with the help of this grid?

5. What common and what different features can be observed in the spatial spectrum of a slit and of a hair obtained by Fraunhofer diffraction?

Lab 4.3.5 Study of hologram

Test questions:

1. What do they have in common and what is different about a hologram of point source, a Fresnel zone plate, and a photograph of Newton's rings?

2. How will the perception of the hologram of point source reconstructed as in Fig. (1) change if one blocks the point source O'1 by placing a small opaque screen at the focal point of lens *L*?

3. How will the focal length of a hologram of point source be changed if it is recorded by using one wavelength and reconstructed by using another one?

4. What determines the minimal size of a hologram, so that image reconstruction is still possible?

5. How are the dimensions of real and virtual image changed when a hologram is illuminated by a diverging or converging wave?

6. How does the range of angles at which the virtual image can be viewed depend on film granularity and on the spectral width of the light source?

Lab 4.3.6 <u>Diffraction of light by periodic structure (the Talbot effect)</u>

Test questions:

1. Estimate a distance between the screen and the grid at which Fraunhofer diffraction can be observed.

2. Why do we get only a few sharp repeated images of the grid in the experiment?

3. Derive the formula for directions to diffraction maxima.

4. Explain why the image of a wire grid is repeated and the image of a single wire is not.

Lab 4.4.1 <u>Amplitude diffraction grating</u>

Test questions:

1. Define the main spectral parameters of diffraction grating.

2. Formulate the Rayleigh criterion.

3. How do the angular parameters of the spectra change when the grating period, groove width, and the grating size are varied?

4. Is it possible to determine a dispersion range by the spectrum of mercury lamp in this experiment?

5. Which physical and technical factors limit the number of large-sized diffraction grating lines that work effectively?

Lab 4.4.2 <u>Phase diffraction grating</u>

Test questions:

1. Define the main spectral parameters of echelette.

2. What is the advantage of echelette as compared to an amplitude diffraction grating?

3. Which element of the spectrometer, echelette, goniometer, or your eye (sensitivity and visual acuity) mostly affects the accuracy of evaluating the spectral resolution?

4. Sketch an optical setup for determination of the echelette working order and its wavelength.

5. Sketch the intensity as a function of angle in the far field region for the working wavelength. Assume that echelette operates in the auto-collimation mode.

Lab 4.4.3 Study of prism with the aid of goniometer

Test questions:

1. Define spectral parameters of prism. What is its dispersion region equal to?
2. Derive a relation between the least deviation angle and refractive index.
3. Explain the dependence between refractive index of glass and optical wavelength.
4. Estimate the maximal period of amplitude grating for which its angular dispersion at the first order approximately equals the angular dispersion of the studied prism. Estimate the period of grating for which its resolution at the first spectral order is comparable to the prism resolution.

Lab 4.4.4 Fabry-Perot interferometer

Test questions:

1. Give definitions and formulas for calculating the spectral parameters of the Fabry-Perot interferometer.
2. Would it be possible to study the yellow lines of mercury by this interferometer if instead of being narrow the lines overlapped, i.e. their width were 21 ˚A?
3. Estimate the minimal diameter of interferometer mirrors which makes it possible to resolve the sodium yellow doublet.
4. Estimate the pulse duration of sodium lamp for which the interferometer cannot resolve the yellow doublet. To do this, estimate the path travelled by light in the interferometer and compare it with the interferometer base.

Lab 4.5.1 Helium-neon laser

Test questions:

1. Why is it impossible to achieve a large gain in the He-Ne laser tube by increasing the discharge current?
2. Why are the exit windows in laser tube glued at some angle with their outward surface facing down rather than up or sidewise?
3. Why is a helium admixture added to neon (the working substance) in the laser tube?
4. Why is the studied beam modulated in our experiment? Is it possible to do without the modulation in this setup?

Lab 4.5.2 Interference of laser radiation

Test questions:

1. Explain the operating principle of Fresnel rhomb.
2. Determine the visibility of an interference pattern produced by waves of equal intensity if one wave is linearly polarized and the other is circular.
3. How does the curve $V2(\ell)$ change if one varies the distance between mirrors of laser resonator?
4. What factors should be taken into account when choosing the width of the photodetector input slit?

5. Sketch the $V(\ell)$-dependence for a single mode and for two modes.

Lab 4.5.3 Tunable Fabry-Perot interferometer

Test questions:

1. Explain basic processes leading to population inversion of energy levels in neon.

2. The ends of helium-neon working tube are covered by two plane-parallel plates. Why are these plates tilted at the Brewster angle?

3. What is the radiation mode? Derive Eq. (2) for the inter-mode separation.

4. What is the condition for laser excitation?

5. Derive Eq. (6) for the finesse of Fabry-Perot interferometer.

6. What is the operation principle of optical isolator?

7. What is the length of He-Ne-laser resonator for which the generation is possible on no more than one mode regardless of the pumping level (the single-mode laser generation)?

Lab 4.6.1 Interference of microwaves

Test questions:

1. How can one check that the microwave generated by a transducer antenna is linearly polarized?

2. How can the direction of electric field vector of a microwave be determined?

3. What is Malus' law and how can it be experimentally verified?

4. What are the necessary conditions for observation of interference of EM waves?

5. Estimate the length and radius of coherence in the mirror and grid experiment.

6. Give plausible explanations of the discrepancy in the values of the same quantities measured in this experiment by various methods and tabulated values of these quantities?

Lab 4.7.1 Birefringence

Test questions:

1. How are vectors **D** and **E** related in anisotropic medium?

2. How is the optical axis of a uniaxial crystal oriented with respect to the principal axes of the dielectric permittivity ellipsoid?

3. What are the principal refractive coefficients?

4. Give an example when the wave propagating in the crystal is ordinary and when it is extraordinary.

5. Derive Eq. (8) from Eq. (7).

6. How does the electromagnetic theory explain emergence of two refracted rays when a plane wave is incident on a surface of uniaxial crystal?

7. How do the refractive indices of ordinary and extraordinary rays depend on the angle between the crystal axis and the normal to the wave front?

8. How does the refractive index of ordinary (extraordinary) ray depend on the angle of refraction if the crystal axis is parallel to the prism rotation axis?

9. Explain how **E** is directed in the rays exiting the prism.

Lab 4.7.2 <u>The Pockels effect</u>

Test questions:

1. Is it possible to observe the Pockels effect in liquid?
2. Why does the interference pattern on the screen switch from positive to negative under 90^0 rotation of the polarizer?
3. What is the half-wave voltage $U_{\lambda/2}$? How does it depend on λ?
4. Why is the beam exiting the crystal circularly polarized at $U = 0.5\,U_{\lambda/2}$?
5. Evaluate the relative change of refractive index of the crystal when a voltage of $U = U_{\lambda/2}$ is applied.
6. Derive Eq. (5).

Lab 4.7.3 <u>Polarization</u>

Test questions:

1. Show that under Brewster's condition the refracted and reflected rays are perpendicular.
2. How can one distinguish right-hand and left-hand polarization of light?
3. Unpolarized light is incident on a λ/4-waveplate. What can be said about polarization of the transmitted light?
4. How can one identify natural light, a circularly polarized light, and mix of natural light with a circularly polarized light?
5. Explain variation of intensity and color observed in experiments with polarized light.
6. Why is the light from the night sky polarized?

Lab 4.7.4 <u>Polarization rotation</u>

Test questions:

1. What is the difference between optical activity and birefringence?
2. How does Fresnel's theory explain the rotation of the polarization plane in optically active materials?
3. What is a specific rotation?
4. How does a Nicol prism work?
5. Describe the operation principle and design of a polarimeter.
6. Sometimes a polarimeter is designed so that a light beam travels multiple times along the magnetic field in opposite directions. Explain why the rotation angle of plane polarization in this case is accumulated.

Lab 5.1.1 <u>Experimental verification of Einstein's equations for photoelectric effect and measurement of Planck's constant</u>

Test questions:

1. What is the external photo effect? Write down and explain the Einstein equation.

2. What facts testify to the presence of initial kinetic energy of photoelectrons?

3. Why do photoelectrons come out of the metal at different velocities? What defines the maximum speed of photoelectrons?

4. On what and how does the flow of photoelectrons depend (i.e. the number of electrons pulled out by light per time unit)?

5. What is the photoemission threshold of photo effect and what does it depend on?

6. Plot a general view of current-voltage characteristic of photocell and explain this curve including the dependence of $I(U)$ in the region of reverse voltage $U > 0$. What is the stopping potential $\underline{U}_o$ and what is its value at a given light frequency?

7. Write down a formula for the stopping potential U_o expressed in terms of the wavelength λ for a photocathode with work function A.

8. Plot a family of I-V characteristics of a photocell when illuminated by light of constant intensity I and frequency $\nu_1 = \nu_0$, $\nu_2 = 2\nu_0$, $\nu 3 = 3\nu_0$, where ν_0 is the frequency corresponding to the photoemission threshold.

9. Plot a graph of the stopping potential dependence on frequency of illumining light. How Planck constant h can be determined from this graph?

10. How can we show from the $U_0(\nu)$ graph that the photo-effect is impossible at light frequencies $\nu < \nu_0$?

11. What determines the saturation current at a given light intensity?

12. Plot a family of current-voltage characteristics of photocell when it is illuminated by light of constant frequency v with intensities $I_1 = \mathrm{I}$, $I_2 = 2I$, $I_3 = 3I$.

13. Two photocells have electrodes in the form of a small ball and a concentric sphere around it. The sphere in one of the photocells serves as a photocathode, and in the other it serves as anode. Photocells are illuminated with light of the same frequency v so that saturation currents are the same. Plot in one figure approximate I-V characteristics of the photocells and explain their difference.

14. According to the concepts of classical physics, light is a continuous electromagnetic wave, the electric field of which in a given point of space changes according to a harmonic law. From this point of view, answer the following questions and compare your answers with the experimental results:

- Is it possible to predict the photoelectric effect in classical physics?
- What should the kinetic energy of photoelectrons depend on?
- What should the number of electrons emitted per time unit depend on?
- Should there be a photoemission threshold in photo effect?
- Should the photo effect be possible at very low intensity of illuminating light?

Lab 5.1.2 <u>The Compton effect</u>

Test questions:

1. Which processes of γ-quanta interaction with matter result in weakening of the primary quanta flow?

2. What is the Compton scattering effect? At what energies of γ-quanta does this process make a significant contribution to the weakening of the primary quanta flow?

3. How do the cross-sections of Thompson and Compton scattering depend on the atomic number of the scattering atoms Z?

4. By using the conservation laws, obtain a formula describing the dependence of energy loss on the scattering angle of γ-quanta due to Compton-effect.

5. Explain the principle of scintillation spectrometer operation.

6. Describe how the energy of incident γ-quantum is converted into an electrical pulse at the photomultiplier output?

7. Why does a lead diaphragm have to be inserted into the collimator when measuring at a zero-degree scattering angle?

8. It is well known that the photo-peak is separated from the Compton distribution by the area in which the count rate is greatly reduced. How wide is this interval? Why does it occur?

Lab 5.1.3 <u>Scattering of slow electrons by atoms of noble gas</u>
<u>(the Ramsauer-Townsend effect)</u>

Test questions:

1. What is the Ramsauer effect and how can it be observed experimentally?

2. Describe the "classical" mechanism of electron scattering on atom and explain how the probability of electron scattering should depend on electron velocity in this approach? What is this dependence in reality?

3. What is the fundamental difference between the quantum mechanical method of describing scattering of electrons on atoms and the classical method?

4. What is the meaning of de Broglie formula?

5. Derive the index of refraction of atom for de Broglie waves?

6. Write down the condition of quenching the de Broglie waves reflected from the atom.

7. At what kinetic energy *E* of electron the transmitted de Broglie wave quenching will be observed?

8. Plot the thyratron current-voltage characteristic observed in the experiment and the theoretical characteristic resulting from the classical theory of electron scattering. What is the reason behind their difference?

9. How can we determine the energy of electrons, at which the Ramsauer effect is observed, from the experimental I-V characteristic?

10. Explain the origin of the force acting from the atom on the passing electron and changing its kinetic energy. Why is this force not acting outside the atom?

11. Explain the change in potential energy of electron when it flies through the atom? What does the term "potential well" mean?

12. Write down the Schroedinger equation for the motion of electron over the potential well, and obtain its general solution.

13. Find the transmission coefficient of particle moving over the rectangular potential well (the ratio of squared amplitudes of transmitted and reflected waves).

14. The voltmeter reading does not give the true value of accelerating voltage in thyratron. Why? And how can it be determined?

15. How do you explain that on the current-voltage characteristic there is only one maximum of current flowing through the thyratron?

16. How do you direct the external magnetic field to make the thyratron's I-V characteristic more distorted?

17. Does the Earth magnetic field affect the thyratron I-V characteristic?

18. How can we determine from the I-V characteristic what inert gas is in the thyratron?

19. Which characteristic, dynamic or static, should be used for calculations and why?

Lab 5.2.1 <u>Franck-Hertz experiment</u>

Test questions:

1. Can the atom be a stable system from the point of view of classical physics? Explain your answer.

2. Formulate the Bohr postulates.

3. Demonstrate by direct calculation that in the experiment it is possible to neglect the thermal motion of helium atoms in the bulb.

4. Which impacts of particles are called absolutely elastic, and which are inelastic? Write down the law of energy conservation for absolutely elastic and inelastic impact of two particles.

5. Under what condition do only elastic collisions with gas atoms occur in the bulb and under what condition are inelastic collisions possible?

6. Show by direct calculation that when considering the collisions of electrons with atoms in this lab it is possible not to take into account the change in kinetic energy of the atom.

7. Draw a schematic diagram of measurement of current-voltage characteristics of the bulb in the Frank-Hertz experiment in *static mode*. Explain the purpose of each circuit element and how the installation works.

8. The same for *dynamic mode*.

9. Show that the curve observed on the oscilloscope screen represents a certain (which?) scale of function $I = I(U)$.

10. Plot and explain the I-V characteristic of the bulb when atoms are excited by electrons. Why is there a second drop in the current?

11. What is the resonance excitation potential? How is it measured in this work?

12. How can the resonance potential of atom be determined if only one minimum of the I-V characteristic is observed in the experiment? What will be the systematic error in this case?

13. Explain how the contact-potential difference between the cathode and accelerating grid can be determined from the I-V characteristic measurement.

14. What is the first ionization potential of atom? At what accelerating voltage will ions appear in the bulb?

15. What should be done to ionize helium in the bulb? What will the microammeter show in this case?

Lab 5.2.2 <u>Spectra of hydrogen and deuterium</u>

Test questions:

1. Describe the energy spectrum of hydrogen atom. In which states is the energy of electron $E < 0$, and in which $E > 0$? Write down the formula for energy of discrete levels in hydrogen atom, and calculate the ionization energy of hydrogen atom using this formula.

2. Why do atoms have discrete radiation spectra? Get a generalized Ballmer formula and a theoretical expression for the Rydberg constant from the formula for hydrogen energy levels.

3. What is a spectral series? Write down the general formula for frequencies of an arbitrary series of hydrogen spectrum. Plot the relative position of the series lines versus the wavelength (i.e. as viewed in the monochromator eyepiece).

4. Write down the formulas for frequencies and the boundaries of spectral series. Calculate these frequencies for the first three series. Do these series overlap?

5. Which series of atomic hydrogen spectrum can be observed visually? What is the (theoretical) number of observed lines (count visible lines with $\lambda > 4{,}000$ A)?

6. Picture the optical scheme of monochromator and explain its operation.

7. What is called the angular dispersion of spectral device?

8. What does the reverse linear dispersion show? What does it depend on in the case of a prism monochromator?

9. What is the resolution power of spectral device and what does it depend on in the case of a prism monochromator?

10. What does the expression "two spectral lines are resolved" mean? And what is "spectral lines are not resolved?" Formulate the Rayleigh criterion.

11. What is the isotopic shift? Is it possible to observe an isotopic shift in a mixture of deuterium (D) and tritium (T)?

Lab 5.2.3 <u>Molecular spectrum of iodine</u>

Test questions:

1. What is the nature of molecular spectra?

2. Plot the diagram of energy levels of two-atomic molecule.

3. What types of molecular spectra do you know?

    a. Which type is the absorption spectrum of iodine molecule in the visible region?

4. Which series are called the Delander series? Why are only two Delander series observed in the absorption spectrum?

5. What are the zero and first Delander series in the iodine absorption spectrum? What is the general view of absorption spectrum in the visible region?

6. What is the energy of zero-point and first Delander series absorption lines?

7. What parameters of the iodine molecule energy scheme can be determined by the absorption spectrum?

8. Plot the optical scheme of the installation used to study the iodine vapor absorption spectrum.

9. Plot the scheme of УМ-2 monochromator. How did you obtain the calibration curve of the spectral device?

10. What does the width of absorption lines observed this work depend on? How can the contrast of the observed spectrum be increased?

11. Why is the iodine cell heated in this experiment?

12. Does the spectrum clarity depend on the degree of cell heating?

Lab 5.4.1 Determination of energy of alpha-particles by measuring their range in air

Test questions:

1. Formulate the Geiger-Nuttoll law. What physical reasons are behind the sharp dependence of half-life on the energy of alpha-particles?

2. Why do the alpha-particle spectra consist of separate lines while the beta-particle spectra are continuous?

3. What is the mechanism of interaction of heavy charged particles with matter (explain the formula for ionization losses dE/dx)?

4. Which dependence is called the Bragg curve? How do ionization losses depend on the velocity of particles, on the properties of the medium?

5. What is the difference between the deceleration processes of alpha-particles and electrons in matter?

6. What is the relation between the energy of alpha-particles and their range?

7. What experimental methods are used to measure the range of alpha-particles in gas?

8. Which alpha-particle source is used in this work? What is the pipe collimator used for?

9. Explain the operation of ionization chamber, scintillation counter and Geiger counter. Describe their construction. How are the operating modes of these devices selected? How does the output signal of the Geiger counter and ionization chamber change with a small (~50 V) increase in the supply voltage around the operation point?

10. Which physical quantities are measured directly in this work?

11. Compare different methods to measure the range of alpha-particles. Estimate the accuracy of these methods of measurement. What systematic errors are possible in the measurement methods used in this work (what are their values and sources)?

Lab 5.4.2 Measurement of energy spectrum of beta-particles and their end-point energy by means of magnetic spectrometer

Test questions:

1. Which particles are emitted by the nuclei in beta-decay? Explain why the spectrum of alpha-particles emitted by the nuclei is always discrete while the spectrum of electrons is continuous. Derive the probability density for an electron in beta-decay to have a certain momentum P_e.

2. Show that the energy transmitted in beta-decay to the daughter nucleus is very small compared to the energy carried away by the electron and the antineutrino.

3. What is the end-point energy of beta-spectrum?

4. What is the phenomenon of internal electron conversion?

5. Name the main elements of experimental setup and explain their purpose. What is the principle of operation of a magnetic spectrometer with a longitudinal magnetic field? Explain the formula for the focal length of the spectrometer.

6. What is the resolution of beta-spectrometer? What does it depend on? How do you determine the resolution of the device by the shape of the peak of internal conversion electrons?

7. How does a Geiger counter operate? With what efficiency does it register electrons with energy of ~1 MeV? How are conventional counters and end-window counters arranged? How does the thickness of the end-window affect the experimental form of beta-spectrum?

8. Explain qualitatively how the residual gas affects the spectrometer's performance?

9. How should the installation be prepared for measurements with beta-spectrometer? What is the beta-spectrum measurement procedure? How is the energy scale of spectrometer graded?

10. Which experimental points should be used to draw the Fermi graph in order to determine the maximal electron energy in beta-spectrum?

11. What is the energy resolution of beta-spectrometer? Analyze possible errors in measuring the maximal spectrum energy (random and systematic).

12. Estimate the distance between the K- and L-lines in beta-spectrum.

Lab 5.4.3 <u>Measurement of total activity of a sample of Co-60 by method of gamma-gamma coincidence</u>

Test questions:

1. Explain the dipole, quadrupole, and octupole transitions in nuclei.

2. What quantum laws should be applied to electromagnetic transitions in nuclei?

3. What is an electric and magnetic photon?

4. What is the cascading nature of radioactive decay of Co-60 related to? How does the probability of transition depend on the multipolarity of radiation?

5. What is the specimen activity and in which units is it measured?

6. Explain the principle of measuring absolute activity by coincidence method.

7. Describe the principle of operation and construction of the photomultiplier tube.

8. Explain why organic and inorganic scintillators vary greatly in sensitivity to gamma-rays. Explain how the scintillator works.

9. How does the coincidence scheme work? What is the "resolution time"?

10. Does the accuracy of absolute activity measurement depend on the counter efficiency in this lab?

Lab 5.5.1 <u>Measurement of flux attenuation coefficient of gamma-rays in medium and determination of their energy</u>

Test questions:

1. What is the gamma-radiation of nuclei?

2. What are the processes of interaction of gamma-rays with matter?

3. Show that no photoelectric effect on a free electron is possible.

4. Using the conservation laws obtain a formula linking the loss of energy with the scattering angle of gamma-quanta under the Compton effect.

5. Does the energy of gamma-quantum change as it propagates through the medium? Compare the propagation of gamma-quanta through the medium with the propagation of a charged particle.

6. Obtain a formula describing the attenuation of gamma-ray during its propagation in the medium.

7. What is called the cross section of interaction? What does it have to do with the linear coefficient of attenuation of gamma-quantum flow in the medium?

8. What is the interaction cross-section? What is the dependence of cross-section of photo-effect, Compton scattering, and electron-positron pair production on the energy of gamma-quanta and on the serial number Z of atoms of the medium?

9. Describe the principle of operation and construction of the photomultiplier tube.

10. Describe the operating principle of scintillation counters using organic and inorganic scintillators.

11. Does the interaction of gamma-quanta with the absorber (for example, Al) differ from its interaction with the scintillator NaI(Tl)?

12. Why the source and detector are placed very far apart in this work?

13. Describe the order of conducting measurements. How can the instrumental drift be taken into account? How is the background noise evaluated?

14. What statistical accuracy of experimental results was obtained in this work and how large are the errors associated with the instrumental drift. Compare the results of different series of measurements. Does the difference between the results lie within the expected range?

15. Compare the experimentally obtained coefficients of absorption of gamma-quanta in Al, Fe, and Pb. Explain the obtained results. Estimate with their help the energy of gamma-quanta emitted by the source.

Lab 5.5.3 <u>Determination of gamma-quanta energy by means of scintillation spectrometer</u>

Test questions:

1. What is gamma-radiation? What conservation laws apply to electromagnetic transitions in nuclei?

2. What effects are behind the attenuation of gamma-quanta flow in the medium?

3. Show that no photo-effect is possible on a free electron.

4. What is the energy distribution of electrons in photo-effect and Compton scattering?

5. What is the energy of electrons in Compton scattering of gamma quanta by 180°?

6. What is the interaction cross-section? What is the dependence of cross-section of photo-effect, Compton scattering, and electron-positron pair production on the energy of gamma-quanta and on the serial number Z of atoms of the medium?

7. Why do many gamma-transitions in nuclei follow each other, forming a cascade rather than a "single jump" from the upper to the lower state? What is the multipolarity of transitions in Co-60?

8. Describe the operation principle and construction of the photomultiplier tube.

9. What is the NaI(Tl) crystal used for? Why is the crystal activated by thallium used in this work rather than pure NaI crystals?

10. Explain the operation principle of scintillation spectrometer. Describe how the energy of incident gamma-quantum is converted into an electrical pulse at the output of the PMT spectrometer.

11. What is the differential spectrum of a radioactive source emitting one gamma-line (e.g. Mn-54 with gamma-radiation energy 0.83 MeV)? What is the contribution of photo-effect and Compton effect to the spectrum?

12. How can you verify that the radiation detected by the detector is actually a gamma-radiation?

13. How do you calibrate the energy scale of the amplitude analyzer?

14. Will the Co-60 spectrum change if an organic crystal is used instead of NaI(Tl)?

Lab 5.6.1 <u>Resonant absorption of gamma-quanta (the Moessbauer effect)</u>

Test questions:

1. What kind of nuclear radiation is called gamma-radiation? How does it differ from X-ray radiation?

2. What effects are behind the attenuation of gamma-quantum flow in a medium?

3. What is the resonant absorption of gamma-rays? Under what conditions does this effect become observable?

4. What determines the natural width of the gamma-ray line?

5. How does the Doppler effect influence the shape of the lines?

6. What determines the probability of resonant absorption of gamma-quanta? What energy range of gamma-quanta and specimen temperature can be used to observe the Moessbauer effect?

7. Explain why does a chemical shift of gamma-line occur?

8. What source of gamma-quanta is used in this work? Plot its decay scheme. Which substance is used as an absorber?

9. For what purpose is the amplitude spectrum of radiation measured? Why is a "thin" NaI(Tl) crystal used for measurements?

10. How are gamma-quanta with energy E = 23.8 keV selected and registered? How is the working "window" of differential analyzer selected?

11. Why is a palladium filter used in this work?

12. What is the Doppler shift method for the emission and absorption lines of gamma-rays?

13. What sequence of operations is used to observe the spectrum of resonant absorption?

14. In the installation, the absorber moves relative to the source. Is it possible to move the source and leave the absorber at rest?

15. Does the thickness of absorber affect the width of resonant line measured in the experiment?

16. How do the processes of gamma-quanta absorption due to the photo effect and Compton effect influence the amplitude of resonant (nuclear) absorption of gamma-quanta in the absorber?

17. What do you know about the applications of Moessbauer effect in various scientific and technical fields?

Lab 5.7.1 (Measurement of angular distribution of hard component of cosmic rays),
Lab 5.7.2 (Study of cosmic ray showers), and
Lab 5.7.3 (Measurement of cross-section of electron-positron pair production on lead nuclei)

Test questions:

1. What is the composition of primary cosmic radiation? Why are there no neutrons in cosmic radiation?

2. What is the composition of cosmic radiation at the Earth surface? Which particles are found in the soft and hard components of cosmic radiation? What is their origin?

3. What physical processes are behind the energy loss by particles that make up the soft and hard radiation components when passing through the medium? Which of these processes are dominant?

4. Qualitatively explain the angular distribution of cosmic rays.

5. Explain the operation principles of a telescope that makes use of Geiger (scintillation) counters.

4. Evaluation Criteria

Based on the results of student's work, a score is set from 0 to 10 points according to the level of the prepared report and knowledge of the student. From the points received for each work, an average score is calculated, which determines the credit mark for the work in physics laboratory according to the following table:

Score	Mark
10	Excellent
9	
8	
7	Good
6	
5	
4	Satisfactory
3	
2	Unsatisfactory
1	

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 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 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 syllabus required for further education.

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

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

The credit in semesters 2-6 is given to a student based on the results of his/her current performance (results of work in physics laboratory).