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: Optics/Общая физика: оптика
major:	Biotechnology
specialization:	Biomedical Engineering/Биомедицинская инженерия
	Phystech School of Biological and Medical Physics
	Chair of General Physics
term:	3
qualification:	Bachelor

Semester, form of interim assessment: 5 (fall) - Exam

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

Independent work: 45 AH.

Exam preparation: 30 AH.

In total: 135 AH, credits in total: 3

Number of course papers, tasks: 2

Authors of the program:

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The program was discussed at the Chair of General Physics 04.06.2020

Annotation

The course examines the key concepts and methods of geometric and wave optics as part of the general physics course taught at MIPT. First, the elements of geometrical optics and photometry are considered, after which the main quantities, concepts and postulates of wave optics are introduced. The classical theory of dispersion is presented. The interference of monochromatic and quasi-monochromatic waves is considered. The concepts of temporal and spatial coherence are discussed. Restrictions on the permissible path difference are formulated, as well as on the permissible dimensions of the source and the interference aperture in two-beam interference schemes. Fresnel and Fraunhofer diffractions are studied. The main characteristics of spectral devices are analyzed using the example of a prism, a diffraction grating and a Fabry – Perot interferometer. The principles of Fourier optics are presented. The Rayleigh method for solving the diffraction problem (spatial Fourier expansion) is considered. Abbe's theory of the formation of an optical image (the principle of double diffraction) is studied. The principles of holography and elements of crystal optics in uniaxial crystals are discussed. The Faraday, Kerr and Pockels effects and their application are considered. Separate lectures are devoted to the theory of light scattering and propagation of electromagnetic waves in waveguides and light guides. In conclusion, nonlinear optical phenomena are considered: nonlinear polarization of the medium, second harmonic generation, phase synchronization, self-focusing phenomenon.

The course contains a discussion of basic physical processes, analysis of problems, demonstrations of physical experiments, without which a deep understanding of general physics is impossible. To successfully master the online course, the listener should know the general physics course: "Electricity and Magnetism" and master the basics of mathematical analysis, know the basics of linear algebra and be able to operate with complex numbers.

1. Study objective

Purpose of the course

Development of students ' basic knowledge in the field of optical phenomena for further study of other branches of physics and in-depth study of the fundamental principles of optics.

Tasks of the course

- Form the basic knowledge in the field of optics;
- develop skills and ability to apply the studied theoretical laws and mathematical tools in solution of various physical problems;
- cultivate the general culture in physics, i.e. the ability to focus on the essential physical phenomena and neglect non-essential ones; ability to assess physical quantities; skills to build the simplest theoretical models describing physical processes.

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

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

Code and the name of the competence	Competency indicators
UC-1 Search and identify, critically assess, and synthesize information, apply a systematic approach to problem-solving	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
Gen.Pro.C-3 Write scientific and/or technical (technological, innovative) reports (publications, projects)	Gen.Pro.C-3.1 Adopt the general criteria for submission of manuscripts, scientific and technical documentation, using relevant software applications
	Gen.Pro.C-3.2 Employ practical methodologies for preparing scientific and technical reports (projects)

(publications, projects)	Gen.Pro.C-3.3 Visually and graphically present scientific (scientific and technical, innovative technological) outcomes in the form of reports, scientific publications
Gen.Pro.C-4 Collect and process scientific and technical and/or technological data for fundamental and applied problem-solving	Gen.Pro.C-4.1 Apply scientific research and intellectual analysis methods for professional problem-solving
	Gen.Pro.C-4.2 Search for primary sources of scientific and technical and/or technological information in professional settings
	Gen.Pro.C-4.4 Use computer and network skills to obtain, store, and process scientific (technical, technological) information
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:

- Fermat's principle and the laws of geometric optics;
- wave equation, plane and spherical waves, superposition principle and interference of monochromatic waves;
- temporal and spatial coherence of the source;
- Huygens–Fresnel principle, Fresnel diffraction:
- Fraunhofer diffraction at the slit;
- spectral instruments and their main characteristics;
- principles of Fourier optics, spatial Fourier decomposition, the effect Zamora-production;
- Abbe theory of optical image formation, double diffraction principle;
- principles of holography, Bragg–Wolfe condition.
- light dispersion, phase and group velocities, classical dispersion theory;
- polarization of light, natural light, the phenomenon of Brewster;,
- dichroism, Polaroids, Malus law.
- double refraction in uniaxial crystals, interference phenomena in crystalline plates, Faraday effect and Kerr effect.
- nonlinear optical phenomena, nonlinear polarization of the medium, second harmonic generation (frequency doubling), phase synchronism, self-focusing.

be able to:

- apply the studied General physical laws to solve specific problems in optics:
- apply the laws of geometric optics in the construction of images in optical systems;
- solve Helmholtz equations for the cases of plane and spherical waves;
- use the concept of Fresnel zones and Fresnel spiral in solving diffraction problems on the screen with axial symmetry
- use of Rayleigh's method of solving the problem of diffraction: wave field as a superposition of plane waves of different directions (the spatial Fourier-decomposition);
- analyze physical problems, highlighting the essential and non-essential aspects of the phenomenon, and on the basis of the analysis to build a simplified theoretical model of physical phenomena;
- apply various mathematical tools to solve problems based on the formulated physical laws, and carry out the necessary analytical and numerical calculations/

master:

- the main methods of solving the problems of optics;
- basic mathematical tools typical for optics 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

		Types of training sessions, including independent work

№	Topic (section) of the course	Lectures	Seminars	Laboratory practical	Independent work
1	Fermat's principle. Geometric optics and photometry elements. Optical instruments.	2	2		3
2	Propagation of electromagnetic waves. Reflection laws, Fresnel for-mulas. Energy flow.	2	2		3
3	Dispersion. Phase and group veloci-ties	2	2		3
4	Interference of monochromatic waves. The width of the bands.	2	2		3
5	Non-monochromatic light, temporal coherence. Wave interference when using extended sources. Spatial coherence	2	2		3
6	Fresnel diffraction, zone plates.	2	2		3
7	Fraunhofer diffraction. Resolution of optical instruments.	2	2		3
8	Resolution of spectral instruments.	2	2		3
9	Intermediate test.	2	2		3
10	Feedback Session. Presentation of the first home assignment	2	2		3
11	Diffraction on sinusoidal gratings. Spatial Fourier transform.	2	2		3
12	Elements of Fourier optics and holography.	2	2		3
13	Light polarization. Elements of crystal optics.	2	2		3
14	Propagation of light in matter. Elements of nonlinear optics.	2	2		3
15	Presentation of the second home assignment.	2	2		3
AH in total		30	30		45
Exam preparation		30 AH.			
Total complexity		135 AH., credits in total 3			

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

Semester: 5 (Fall)

1. Fermat's principle. Geometric optics and photometry elements. Optical instruments.

Geometrical optics. Fermat's principle, laws of refraction and reflection, boundary conditions, Fresnel equations, Brewster’s angle. Geometric aberrations. Modern applications of geometrical optics in the short wavelength limit: X-ray microscopy, X-ray projection lithography, X-ray astronomy, spatial resolution microanalysis. Fundamentals of photometry.

2. Propagation of electromagnetic waves. Reflection laws, Fresnel for-mulas. Energy flow.

Wave optics. Wave equation, monochromatic waves, complex amplitude, Helmholtz equation, plane and spherical waves, refractive index, phase velocity of propagation, complex dielectric constant and complex refractive index, con-nection of the imaginary part with the absorption of light by the medium. Non-relativistic Doppler effect, search for exoplanets.

3. Dispersion. Phase and group veloci-ties

The refractive index dispersion, classical theory of dispersion, normal and anom-alous dispersions. Damped waves, Booger's law. Refractive index of plasma. Ra-dio waves in the ionosphere and long-distance radio communications. Metamate-rials - media with negative ε and μ, advances in the creation of metamaterials. Group speed. Various wavelength ranges, their features.

4. Interference of monochromatic waves. The width of the bands.

Principle of superposition and interference of monochromatic waves. Band visi-bility, band width. Antireflection coating. The statistical nature of emission of a quasi-monochromatic wave. Temporal coherence, temporal coherence function, relationship with spectral intensity (Wiener–Khinchin theorem) and visibility. Re-striction on the permissible path difference in two-beam interference schemes, uncertainty relation.

5. Non-monochromatic light, temporal coherence. Wave interference when using extended sources. Spatial coherence

Extended sources interference. Spatial coherence, radius of coherence, spatial coherence function, connection with the radiation intensity distribution over the source I(x) (Van Cittert–Zernike theorem). Limitations on the permissible size of a source and interference aperture in two-beam schemes. Lasers as sources of radi-ation with high temporal and spatial coherence.

6. Fresnel diffraction, zone plates.

Diffraction of waves. Huygens–Fresnel principle. Diffraction by thin screen. Kirchhoff's approximation. Wave parameter. Fresnel diffraction. Axial symmetry problems, Fresnel zones, Fresnel spiral. Zone plates, lens. The use of zone plates for focusing X-ray radiation. Diffraction by additional screen, Poisson spot. Dif-fraction by a system of additional screens, Babinet's theorem. Edge diffraction, the Cornu spiral.

7. Fraunhofer diffraction. Resolution of optical instruments.

Fraunhofer diffraction. Light field in the Fraunhofer zone as the Fourier trans-formation of boundary field. Fraunhofer diffraction by slit, diffraction diver-gence. Diffraction limit of resolution of telescope and microscope. Field in focal plane of lens, transverse and longitudinal dimensions of focal spot.

8. Resolution of spectral instruments.

Spectral instruments: prism, diffraction grating, Fabry–Perot interferometer. Characteristics of spectral devices: resolution, dispersion area, angular dispersion. Interference in thin films and multilayer structures, mirrors with a high reflectance. Artificial multilayer structures for soft X-ray reflection. Diffraction gratings for radio waves.

9. Intermediate test.

Principles of Fourier Optics. Rayleigh's method for solving the diffraction problem: wave field as a superposition of plane waves of different directions (spatial Fou-rier expansion), uncertainty relation. Fresnel diffraction by periodic structures (self-replication effect). Abbe's theory of optical imaging, the principle of double diffraction. Aperture, bandwidth of spatial frequencies of optical system, relation to resolution. Resolution for coherent and incoherent lighting.

10. Feedback Session. Presentation of the first home assignment

Principles of holography. Gabor's hologram. Hologram with an oblique reference beam. Resolution of hologram. Bragg–Wolfe condition. Volume hologram, vol-ume lattice in the recording medium. Concept of holographic microscopy of bio-objects and holographic interferometry.

11. Diffraction on sinusoidal gratings. Spatial Fourier transform.

Crystal optics: light polarization. Natural light. Dichroism, polaroids, Malus's law. Double refraction in uniaxial crystals, ordinary and extraordinary waves. Mutual orientation of vectors k, E, D, B, direction of Poynting vector, side drift of light beams in crystals. Interference phenomena in crystal plates. The concept of arti-ficial anisotropy. Faraday, Kerr and Pockels effects and their applications.

12. Elements of Fourier optics and holography.

Propagation of electromagnetic waves in waveguides and optical fiber. Gradient optical fiber and optical fiber with a sharp change in the refractive index. Permis-sible angular aperture. Types of waves. Singlemode and multimode optical fibers. Optical fiber application for high-speed communication. Zero dispersion area.

13. Light polarization. Elements of crystal optics.

Scattering of light. Effective scattering cross section, directional diagram, their dependence on wavelength and on the size of scattering particles, Rayleigh scat-tering (scattering on density fluctuations). The polarization of scattered light. Rayleigh scattering as the main cause of light wave attenuation in optical fibers.

14. Propagation of light in matter. Elements of nonlinear optics.

Nonlinear optical phenomena. Nonlinear polarization of medium. Estimates of intensity of a light wave at which non-linear effects are observed based on the values of intra-atomic fields. Induced birefringence. Second harmonic generation, phase matching. Symmetry factor, impossibility of generating a second harmonic in media with an inversion center. Self-focusing, critical self-focusing power, small-scale self-focusing.

15. Presentation of the second home assignment.

Extended sources interference. Spatial coherence, radius of coherence, spatial coherence function, connection with the radiation intensity distribution over the source I(x) (Van Cittert–Zernike theorem). Limitations on the permissible size of a source and interference aperture in two-beam schemes. Lasers as sources of radi-ation with high temporal and spatial coherence.

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

A student studying the course "General physics: Optics" should not only learn the General physical laws and concepts, but learn to apply them in practice.

Successful development of the course requires intensive independent work of the student. The program of the course provides the minimum necessary time for the student to work on those-my. Independent work includes:

– reading and note-taking recommended reading,
– study of educational material (on lecture notes, educational and scientific literature), preparation of answers to questions intended for self-study;
– solving problems offered to students in lectures and practical classes,
– preparation for practical classes, test work, assignment, exam.

Management and control over the independent work of the student is carried out in the form of individual consultations.

An indicator of material ownership is the ability to solve problems. To form the ability to apply theoretical knowledge in practice, the student needs to solve as many problems as possible. When solving problems, each action must be argued, referring to the known theoretical information and carry out all the necessary calculations, bringing the problem to the final answer.The problem is considered solved if it contains a General solution: references to the applicable physical laws and correct calculations, as well as the correct numerical answer (if the problem has numerical data).

In preparation for the practical training, it is necessary to familiarize yourself with the basic concepts and laws that will be devoted to the lesson, and to solve the problems provided for the preparation of the seminar.

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:	3
qualification:	Bachelor

Semester, form of interim assessment: 5 (fall) - Exam

Authors:

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

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
UC-1 Search and identify, critically assess, and synthesize information, apply a systematic approach to problem-solving	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
Gen.Pro.C-3 Write scientific and/or technical (technological, innovative) reports (publications, projects)	Gen.Pro.C-3.1 Adopt the general criteria for submission of manuscripts, scientific and technical documentation, using relevant software applications
	Gen.Pro.C-3.2 Employ practical methodologies for preparing scientific and technical reports (projects)
	Gen.Pro.C-3.3 Visually and graphically present scientific (scientific and technical, innovative technological) outcomes in the form of reports, scientific publications
Gen.Pro.C-4 Collect and process scientific and technical and/or technological data for fundamental and applied problem-solving	Gen.Pro.C-4.1 Apply scientific research and intellectual analysis methods for professional problem-solving
	Gen.Pro.C-4.2 Search for primary sources of scientific and technical and/or technological information in professional settings
	Gen.Pro.C-4.4 Use computer and network skills to obtain, store, and process scientific (technical, technological) information
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:

- Fermat's principle and the laws of geometric optics;
- wave equation, plane and spherical waves, superposition principle and interference of monochromatic waves;
- temporal and spatial coherence of the source;
- Huygens–Fresnel principle, Fresnel diffraction:
- Fraunhofer diffraction at the slit;
- spectral instruments and their main characteristics;
- principles of Fourier optics, spatial Fourier decomposition, the effect Zamora-production;
- Abbe theory of optical image formation, double diffraction principle;
- principles of holography, Bragg–Wolfe condition.
- light dispersion, phase and group velocities, classical dispersion theory;
- polarization of light, natural light, the phenomenon of Brewster;,
- dichroism, Polaroids, Malus law.
- double refraction in uniaxial crystals, interference phenomena in crystalline plates, Faraday effect and Kerr effect.
- nonlinear optical phenomena, nonlinear polarization of the medium, second harmonic generation (frequency doubling), phase synchronism, self-focusing.

be able to:

- apply the studied General physical laws to solve specific problems in optics:
- apply the laws of geometric optics in the construction of images in optical systems;
- solve Helmholtz equations for the cases of plane and spherical waves;
- use the concept of Fresnel zones and Fresnel spiral in solving diffraction problems on the screen with axial symmetry
- use of Rayleigh's method of solving the problem of diffraction: wave field as a superposition of plane waves of different directions (the spatial Fourier-decomposition);
- analyze physical problems, highlighting the essential and non-essential aspects of the phenomenon, and on the basis of the analysis to build a simplified theoretical model of physical phenomena;
- apply various mathematical tools to solve problems based on the formulated physical laws, and carry out the necessary analytical and numerical calculations/

master:

- the main methods of solving the problems of optics;
- basic mathematical tools typical for optics problems/

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

1. Find the focal length f of a biconvex thin lens bounded by spherical surfaces with radii R1 = 25mm and R2 = 40mm; refractive index of the glass lens n=1.5.
2. The position of the main optical axis of a thin lens LL' and the path of the beam ABC passing through it are shown in the Figure. Find by plotting the path of an arbitrary ray DE behind the lens.
3. A positive lens with a focal length F creates an image of the object on the screen. What condition for the distance from the object to the screen has to be satisfied for this to be possible?

1. Using constancy of an energy flux carried by a wave in a non-absorbing medium, establish the nature of the dependence of the intensity and amplitude of the cylindrical wave on the distance r to the axis x along which the wave source is located.
2. A plane electromagnetic wave is propagating in a non-magnetic me-dium with a refractive index n. Express its intensity through the amplitude of its electric field E0.
3. Do the coordinates of nodes and antinodes of vectors H and E coin-cide in space in a plane standing electromagnetic wave? Do the coordinates of maxima and minima of vectors H and E in a plane traveling electromag-netic wave coincide in space at an arbitrary moment of time?

4. Evaluation criteria

List of oral exam questions:

1. Wave equation. Monochromatic waves. Complex amplitude. Helmholtz equation.
2. Monochromatic waves. Complex amplitude. Equation of plane and spherical waves. Su-perposition principle, interference.
3. Interference of monochromatic waves. Interference of plane and spherical waves. The width of the interference fringes. Visibility of fringes.
4. Influence of non-monochromaticity of light on the visibility of interference fringes. Temporal coherence function. Relationship between the coherence time and the spectrum width. Wiener-Khinchin theorem. Uncertainty ratio.
5. Visibility of interference fringes and its relationship with the degree of coherence when using quasi-monochromatic light sources. Estimate of the maximum number of bands ob-served. Maximum allowable path difference in interference experiments.
6. The aperture of the interference scheme and the influence of the source size on the visi-bility of the interference fringes. Spatial coherence function. Radius of spatial coherence.
7. Relationship between the radius of spatial coherence and the angular size of an extended source. The Van-Zittert-Zernike theorem. Visibility of interference fringes when using ex-tended light sources. Michelson stellar interferometer.
8. Maximum permissible difference in wave paths in interference experiments and its rela-tionship with the coherence time.
9. The radius of spatial coherence and the limitation on the permissible size of the source in interference experiments.
10. The Huygens-Fresnel principle. Quantitative formulation of the Huygens-Fresnel prin-ciple. Wave parameter as a criterion for the similarity of diffraction phenomena.

11. Fresnel diffraction on a round hole. Fresnel spiral. Poisson spot and conditions of its observation.
12. Fresnel zone plate. Light intensity at the focus of the zone plate. Ideal lens. Focusing light.
13. Wave parameter. Observation condition for Fresnel and Fraunhofer diffraction. A crite-rion for geometric optics.
14. Fraunhofer diffraction. Connection with Fourier transform. Fraunhofer diffraction by a slit and a round hole. Field in the focal plane of the lens.
15. Fraunhofer diffraction in optical devices. Resolution of the telescope and microscope. Rayleigh criterion.
16. Diffraction grating as a spectral device. Resolution and area of dispersion. Resolution of the prism.
17. Fraunhofer diffraction on a grating: position and intensity of the main maxima, their width and maximum order.
18. Fabry-Perot interferometer as an optical resonator. Resolution of the interferometer, re-lationship with the quality factor.
19. Principles of Fourier optics: representation of an arbitrary wave as a superposition of plane waves of different directions. Spatial Fourier transformation. Spatial frequency. Ray-leigh method in diffraction problems.
20. Fresnel diffraction on periodic structures. Self-replication effect.
21. Abbe's theory of the formation of an optical image. Fourier plane of the optical system.
22. Principles of spatial filtering. Methods for observing phase structures.
23. Field in the focal plane of the lens. Connection with Fourier transformation.
24. Diffraction on the amplitude and phase sinusoidal grating.
25. Methods for observing transparent (phase) structures. Darkfield and phase contrast techniques.
26. Holography. Point source hologram (Gabor hologram). Resolution of the hologram. Hologram with an oblique reference beam.
27. Volume hologram. Image restoration with a volume hologram, the Bragg-Wolfe condi-tion.
28. Electromagnetic waves at the interface between two dielectrics. Brewster's phenome-non. Dependence of the energy reflection coefficients $R^{\perp}$ and R|| from the angle of inci-dence (qualitatively).
29. Methods for obtaining linearly polarized light. Dichroism. Polaroid. Malus' law.
30. Electromagnetic waves in uniaxial crystals. Ordinary and extraordinary waves. Crystal plates □/2 and □/4.
31. Birefringence. Interference of polarized waves.
32. Nonlinear polarization of the medium. Second harmonic generation. Phase matching condition. Optical rectification.
33. Nonlinear optical effects. Self-focusing. Threshold power.
34. Dispersion. Phase and group velocities. Rayleigh's formula. Classical theory of variance. Abnormal variance. Dispersion in the ionosphere and metals.

Examples of simple tasks that need to be done to get a satisfactory grade:
• Find the angle of incidence of light on the water/oil interface at which total reflection occurs. Refractive index of water nw=4/3, oil no=1.5. What environment should the light fall from?
• A thin segment of a glass sphere with a radius of cm is leaning against a thin diffusing lens with a focal length of cm. Find the focal length of the resulting composite lens, if the refractive index of the glass .
• Find the total intensity of two coherent, equally polarized light beams, if the intensity of the first is equal , the second - , and the path difference between them is .
• Find the distance from the slits to the screen in Young's experiment, if the width of the inter-ference fringes is mm, the spacing between the slits is mm, monochromatic light is used with λ = 500 nm.
• At what distances between the slits in Young's experiment can you see the interference on the screen, if the angular size of the source is equal to 10-4 rad. Light to be considered monochro-matic with λ = 500 nm.
• Find the number of fringes that can be observed in an interference experiment using a sodium doublet (wavelengths: 5890 and 5896 angstroms) as a light source.
• Find the radius of the third bright Newtonian ring, for light with λ = 500 nm, using a plano-convex lens with a radius of curvature m.
• A hole with a diameter D = 1 mm is illuminated with plane-parallel light with λ = 500 nm, cre-ating a diffraction spot on the screen, at a distance L = 0.1 m. Determine the number of open Fresnel zones.

• The hole with the lens attached to it is illuminated with a beam of light with intensity . The hole fits two and a half Fresnel zones when viewed from focus. Find the intensity of the light in it.

• Slit width l = 0.1 mm is illuminated with parallel light with λ = 500 nm. Attached to it is a lens with a focal length cm. Find the width of the brightest fringe on a screen located in the focal plane.

• The hole of the radius is illuminated by a beam of light with a long wavelength . At what distance should the observation point be in order for the diffraction to be considered Fraun-hofer? (the answer should be provided in the form " much more (less) of such characteristic size")

• When the crystal is rotated in a rotating X-ray spectrograph, the reflected maximum appears for the first time at a grazing angle . The lattice constant of the crystal is d = 0.2 nm. Find the wavelength of the studied X-ray.

TICKET 1

1. A question of choice.

2.Wave equation. Monochromatic waves. Complex amplitude. Helmholtz equation.

TICKET 2

1. A question of choice.

2. Monochromatic waves. Complex amplitude. Equation of plane and spherical waves. Superposition principle, interference.

TICKET 3

1. A question of choice.

2. Interference of monochromatic waves. Interference of plane and spherical waves. The width of the interference fringes. Visibility of fringes.

TICKET 4

1. A question of choice.

2. Influence of non-monochromatic light on the visibility of interference fringes. Tem-poral coherence function. Relationship between coherence time and spectrum width. Wiener-Khinchin theorem. Uncertainty ratio.

TICKET 5

1. A question of choice.

2. Visibility of interference fringes and its relationship with the degree of coherence when using quasi-monochromatic light sources. Estimation of the maximum number of ob-served bands. Maximum allowable path-length difference in interference experiments.

The mark "excellent (10)" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and beyond, as well as the ability to confidently apply them in prac-tice when solving complex non-standard problems.

The mark "excellent (9)" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems.

The mark "excellent (8)" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems, but who made some inaccuracies in the answer.

The mark "good (7)" is given to a student if he has demonstrated solid knowledge and confident understanding of the curriculum material and the ability to freely apply physical laws in practice in solving typical problems.

The mark "good (6)" is given to a student if he has demonstrated solid knowledge of the curricu-lum material and the ability to apply physical laws in practice when solving typical problems.

The mark "good (5)" is given to a student if he has demonstrated solid knowledge and under-standing of the curriculum material and the ability to apply physical laws in practice when solving typical problems, but made a number of gross inaccuracies in answering.

The mark "satisfactory (4)" is given to a student who has shown the fragmented nature of knowledge, who made inaccuracies in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The mark "satisfactory (3)" is given to a student who has shown a highly fragmented nature of knowledge, who made gross errors in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The grade "unsatisfactory (2)" or "unsatisfactory (1)" is given to a student who does not know a significant part of the main content of the program, systematically makes gross errors in the for-mulation of basic physical laws, or is unable to correctly apply physical laws even for solving simple problems.

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

The exam takes place in the traditional form of a teacher-student conversation on the top-ic of the exam ticket.

The student is given from 30 to 45 minutes to prepare for the answer on questions of the ticket. During the exam, the student is not allowed to use computers, literature, previously pre-pared own notes and other materials related to the subject, except for the examination program of the course.

In the process of answering the ticket question, the examiner can ask clarifying questions. After answering, the examiner has the right to ask the student any additional questions about the course program.

In total, the student's questioning for the oral examination should not exceed two astro-nomical hours.

3. The list of typical test items used to assess knowledge, abilities, skills

Interim attestation in the discipline "General Physics: Optics" is carried out in the form of an exam. The exam consists of two parts: written and oral.

On the written part of the exam, the student is asked to solve 5 problems. All proposed problems are original author's problems specially prepared for the exam.

The oral part of the exam is based on tickets. Each ticket contains a theoretical question from the list of exam questions below. In addition, the student is invited to present a prepared in advance "optional question", which can be either one of the items in the list below, or any question raised in the course being studied or directly related to it. As a question of choice, the results of the laboratory work done by the student can be presented.

List of oral exam questions:

1. Wave equation. Monochromatic waves. Complex amplitude. Helmholtz equation.
2. Monochromatic waves. Complex amplitude. Equation of plane and spherical waves. Superposition principle, interference.
3. Interference of monochromatic waves. Interference of plane and spherical waves. The width of the interference fringes. Visibility of fringes.
4. Influence of non-monochromaticity of light on the visibility of interference fringes. Temporal coherence function. Relationship between the coherence time and the spectrum width. Wiener-Khinchin theorem. Uncertainty ratio.
5. Visibility of interference fringes and its relationship with the degree of coherence when using quasi-monochromatic light sources. Estimate of the maximum number of bands observed. Maximum allowable path difference in interference experiments.
6. The aperture of the interference scheme and the influence of the source size on the visibility of the interference fringes. Spatial coherence function. Radius of spatial coherence.
7. Relationship between the radius of spatial coherence and the angular size of an extended source. The Van-Zittert-Zernike theorem. Visibility of interference fringes when using extended light sources. Michelson stellar interferometer.
8. Maximum permissible difference in wave paths in interference experiments and its relationship with the coherence time.
9. The radius of spatial coherence and the limitation on the permissible size of the source in interference experiments.
10. The Huygens-Fresnel principle. Quantitative formulation of the Huygens-Fresnel principle. Wave parameter as a criterion for the similarity of diffraction phenomena.
11. Fresnel diffraction on a round hole. Fresnel spiral. Poisson spot and conditions of its observation.
12. Fresnel zone plate. Light intensity at the focus of the zone plate. Ideal lens. Focusing light.
13. Wave parameter. Observation condition for Fresnel and Fraunhofer diffraction. A criterion for geometric optics.
14. Fraunhofer diffraction. Connection with Fourier transform. Fraunhofer diffraction by a slit and a round hole. Field in the focal plane of the lens.
15. Fraunhofer diffraction in optical devices. Resolution of the telescope and microscope. Rayleigh criterion.
16. Diffraction grating as a spectral device. Resolution and area of dispersion. Resolution of the prism.
17. Fraunhofer diffraction on a grating: position and intensity of the main maxima, their width and maximum order.

18. Fabry-Perot interferometer as an optical resonator. Resolution of the interferometer, relationship with the quality factor.
19. Principles of Fourier optics: representation of an arbitrary wave as a superposition of plane waves of different directions. Spatial Fourier transformation. Spatial frequency. Rayleigh method in diffraction problems.
20. Fresnel diffraction on periodic structures. Self-replication effect.
21. Abbe's theory of the formation of an optical image. Fourier plane of the optical system.
22. Principles of spatial filtering. Methods for observing phase structures.
23. Field in the focal plane of the lens. Connection with Fourier transformation.
24. Diffraction on the amplitude and phase sinusoidal grating.
25. Methods for observing transparent (phase) structures. Darkfield and phase contrast techniques.
26. Holography. Point source hologram (Gabor hologram). Resolution of the hologram. Hologram with an oblique reference beam.
27. Volume hologram. Image restoration with a volume hologram, the Bragg-Wolfe condition.
28. Electromagnetic waves at the interface between two dielectrics. Brewster's phenomenon. Dependence of the energy reflection coefficients $R_\perp$ and $R_{||}$ from the angle of incidence (qualitatively).
29. Methods for obtaining linearly polarized light. Dichroism. Polaroid. Malus' law.
30. Electromagnetic waves in uniaxial crystals. Ordinary and extraordinary waves. Crystal plates $\lambda/2$ and $\lambda/4$.
31. Birefringence. Interference of polarized waves.
32. Nonlinear polarization of the medium. Second harmonic generation. Phase matching condition. Optical rectification.
33. Nonlinear optical effects. Self-focusing. Threshold power.
34. Dispersion. Phase and group velocities. Rayleigh's formula. Classical theory of variance. Abnormal variance. Dispersion in the ionosphere and metals.

Examples of simple tasks that need to be done to get a satisfactory grade:
• Find the angle of incidence of light on the water/oil interface at which total reflection occurs. Refractive index of water n_w=4/3, oil n_o=1.5. What environment should the light fall from?
• A thin segment of a glass sphere with a radius of $R = 40$ cm is leaning against a thin diffusing lens with a focal length of $f = -120$ cm. Find the focal length of the resulting composite lens, if the refractive index of the glass $n = 1.5$.
• Find the total intensity of two coherent, equally polarized light beams, if the intensity of the first is equal I_0, the second - $4I_0$, and the path difference between them is $\lambda/6$.
• Find the distance from the slits to the screen in Young's experiment, if the width of the interference fringes is $\Delta x = 1$ mm, the spacing between the slits is $d = 1$ mm, monochromatic light is used with λ = 500 nm.
• At what distances between the slits in Young's experiment can you see the interference on the screen, if the angular size of the source is equal to 10^{-4} rad. Light to be considered monochromatic with λ = 500 nm.
• Find the number of fringes that can be observed in an interference experiment using a sodium doublet (wavelengths: 5890 and 5896 angstroms) as a light source.
• Find the radius of the third bright Newtonian ring, for light with λ = 500 nm, using a plano-convex lens with a radius of curvature $R = 1$ m.

• A hole with a diameter D = 1 mm is illuminated with plane-parallel light with λ = 500 nm, creating a diffraction spot on the screen, at a distance L = 0.1 m. Determine the number of open Fresnel zones.
• The hole with the lens attached to it is illuminated with a beam of light with intensity I_0. The hole fits two and a half Fresnel zones when viewed from focus. Find the intensity of the light in it.
• Slit width l = 0.1 mm is illuminated with parallel light with λ = 500 nm. Attached to it is a lens with a focal length $f = 30$ cm. Find the width of the brightest fringe on a screen located in the focal plane.
• The hole of the radius R is illuminated by a beam of light with a long wavelength λ. At what distance L should the observation point be in order for the diffraction to be considered Fraunhofer? (the answer should be provided in the form "L much more (less) of such characteristic size")
• When the crystal is rotated in a rotating X-ray spectrograph, the reflected maximum appears for the first time at a grazing angle 30°. The lattice constant of the crystal is d = 0.2 nm. Find the wavelength of the studied X-ray.

4. Assessment criteria

Based on the results of solving the problems of the written part of the exam, from 0 to 3 points are given for each problem according to the following criteria:

- 3 points: The problem was solved completely correctly (that is, the correct justified solution is given and answers to all questions of the problem are given). There may be minor flaws (clerical errors, minor arithmetic errors).
- 2 points: The problem is solved, the progress of solving the problem is generally correct, but there are significant shortcomings (errors in calculations, an absurd answer, etc.).
- 1 point: The problem has not been solved, but all the basic physical laws necessary for the solution are formulated correctly.
- 0 points: The problem has not been solved or solved incorrectly (the basic laws are written with errors, or not completely, the approach to solving the problem is fundamentally wrong, or the solution to the problem does not correspond to the condition).

The points obtained are summed up and the mark for the written part of the exam is given according to the following scheme

Grade	points	Sum of points
Excellent	10	15
	9	13-14
	8	12
Good	7	11
	6	9-10
	5	8
Satisfactory	4	6-7
	3	5
Unsatisfactory	2	2-4
	1	0-1

The grade for the written portion of the exam determines the maximum final grade for the exam. In exceptional cases, if on the oral part of the exam a student demonstrates excellent theoretical knowledge and level of understanding of the subject, the final grade can be increased, but not more than by 2 points (on a 10-point scale).

In the oral exam, the instructor assesses the student's overall response and gives a grade according to the criteria below and the comments above regarding the written part of the exam:

The mark "**excellent (10)**" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and beyond, as well as the ability to confidently apply them in practice when solving complex non-standard problems.

The mark "**excellent (9)**" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems.

The mark "**excellent (8)**" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems, but who made some inaccuracies in the answer.

The mark "**good (7)**" is given to a student if he has demonstrated solid knowledge and confident understanding of the curriculum material and the ability to freely apply physical laws in practice in solving typical problems.

The mark "**good (6)**" is given to a student if he has demonstrated solid knowledge of the curriculum material and the ability to apply physical laws in practice when solving typical problems.

The mark "**good (5)**" is given to a student if he has demonstrated solid knowledge and understanding of the curriculum material and the ability to apply physical laws in practice when solving typical problems, but made a number of gross inaccuracies in answering.

The mark "**satisfactory (4)**" is given to a student who has shown the fragmented nature of knowledge, who made inaccuracies in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The mark "**satisfactory (3)**" is given to a student who has shown a highly fragmented nature of knowledge, who made gross errors in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The grade "**unsatisfactory (2)**" or "**unsatisfactory (1)**" is given to a student who does not know a significant part of the main content of the program, systematically makes gross errors in the formulation of basic physical laws, or is unable to correctly apply physical laws even for solving simple problems.

5. Methodological materials defining procedures for assessing knowledge, skills, abilities and (or) experience

The procedure for conducting a written examination.
The time for the written part of the exam is 4 astronomical hours. The exam offers 5 original problems to solve. The topics correspond to the topics of the seminar classes. The problem is considered solved if it contains a reasonable solution: references to the applied physical laws and

correct calculations, as well as the correct numerical answer (if the problem contains numerical data). The exam is allowed to use any notes and study guides in paper form. It is strictly forbidden to turn on any devices that can serve as means of communication - laptops, media-pads, phones, etc. Violators are removed from the exam with an “unsatisfactory” mark. It is allowed to use calculators. Do not use calculators in mobile phones, laptops, etc.

The procedure for conducting an oral exam.

The exam takes place in the traditional form of a teacher-student conversation on the topic of the exam ticket.

The student is given from 30 to 45 minutes to prepare for the answer on questions of the ticket. During the exam, the student is not allowed to use computers, literature, previously prepared own notes and other materials related to the subject, except for the examination program of the course.

In the process of answering the ticket question, the examiner can ask clarifying questions. After answering, the examiner has the right to ask the student any additional questions about the course program.

In total, the student's questioning for the oral examination should not exceed two astronomical hours.

TICKET 1

1. A question of choice.

2.Wave equation. Monochromatic waves. Complex amplitude. Helmholtz equation.

TICKET 2

1. A question of choice.

2. Monochromatic waves. Complex amplitude. Equation of plane and spherical waves. Superposition principle, interference.

TICKET 3

1. A question of choice.

2. Interference of monochromatic waves. Interference of plane and spherical waves. The width of the interference fringes. Visibility of fringes.

TICKET 4

1. A question of choice.

2. Influence of non-monochromatic light on the visibility of interference fringes. Temporal coherence function. Relationship between coherence time and spectrum width. Wiener-Khinchin theorem. Uncertainty ratio.

TICKET 5

1. A question of choice.

2. Visibility of interference fringes and its relationship with the degree of coherence when using quasi-monochromatic light sources. Estimation of the maximum number of observed bands. Maximum allowable path-length difference in interference experiments.