Syllabus
Course Program

Physics

Specialty
113 Applied mathematics

Institute
Institute of Computer Modeling, Applied Physics and Mathematics.

Educational program
Intelligent Data Analysis

Department
Physics.

Level of education
Bachelor's level

Course type
General, Mandatory.

Semester
2,3

Language of instruction
Ukrainian

Lecturers and course developers

Alla Savchenko

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PhD (Physics&Mathematics), Associate Professor, Associate Professor of the Department of Physics.

Work experience – 15 years. The author of many scientific, educational, and methodological works. Lecturer in the "Physics" cours.

Google Scholar: https://scholar.google.com/citations?user=LA7iMC0AAAAJ&hl=ru&authuser=1
ORCID: https://orcid.org/my-orcid?orcid=0000-0001-9309-1797
Scopus: https://www.scopus.com/authid/detail.uri?authorId=56637062400
More about the lecturer on the department's website

General information

Summary

The physics course introduces fundamental concepts, laws, and theories of classical and modern physics, the main methods of solving physics problems, and the characteristics of fundamental physical processes. This ensures effective mastery of specialized subjects and the subsequent ability to apply physical principles in data analysis.

Course objectives and goals

- Providing future engineers with a foundation of experimental and theoretical training in fundamental physics;
- Developing students' skills in understanding the physical content of problems;
- Enhancing students' ability to practically apply fundamental knowledge of physics in intellectual data analysis.

Format of classes

Lectures, laboratory classes, consultations, self-study. Final control in the form of an exam.

Competencies

SC 3. Ability to choose and apply mathematical methods for solving applied problems, modelling, analysis, design, management, forecasting, decision-making.
SC 13. Ability to search, systematically study and analyse scientific and technical information, domestic and foreign experience related to the use of mathematical methods to study various processes, phenomena and systems.
SC 14. Ability to understand the task statement formulated in the language of a particular subject area, to search and collect the necessary initial data.
SC 15. Ability to formulate a mathematical statement of a problem, based on the statement in the language of the subject area, and choose a method of solving it that ensures the required accuracy and reliability of the result.

Learning outcomes

LO 3. Formalize tasks formulated in the language of a particular subject fields; formulate their mathematical formulation and choose rational method of solution; solve the resulting problems with analytical and numerical methods, evaluate the accuracy and reliability of the results obtained.
LO 7. Be able to conduct practical research and find a solution of incorrect tasks.
LO 12. Solve individual engineering problems and/or tasks that arise in at least one subject area: sociology, economy, ecology, and medicine.
LO 14. Demonstrate the ability to self-learn and continue professional development.
LO 15. Be able to organize your own activities and get results within a limited time frame.
LO 16. Demonstrate skills of interaction with other people, ability to work in a team.

Student workload

The total volume of the course is 180 hours (6 ECTS credits): lectures – 56 hours, laboratory classes – 32 hours, self-study – 92 hours.

Course prerequisites

"Physics. Part 1": "Mathematical Analysis. Part 1"; "Physics. Part 2": "Analytical Geometry"; "Mathematical Analysis. Part 2"

Features of the course, teaching and learning methods, and technologies

All physical laws and phenomena are demonstrated visually or with the help of videos or animations. Along with the theory, a real-life example is immediately provided, and attention is focused on the correct choice of the mathematical model when solving the corresponding problems.

Program of the course

Topics of the lectures

Topic 1. Introduction
Subject of physics. Key stages in the history of physics. Physics as a culture of modeling. Interconnection of physics and IT: Artificial Intelligence, Computer Vision, Machine Learning. Physics in computer modeling. Basic physical models. Measurement and its significance in science. Elements of the theory of dimensions of physical quantities.
Topic 2. Elements of particle kinematics.
Trajectory, path, displacement. Velocity and acceleration in the general case of curvilinear motion. Principle of independence of motions. Basic motions: rectilinear motion and motion in a circle. Equations and kinematic characteristics of basic motions.
Topic 3. Dynamics of a material point.

Mass, force, momentum, and their units. Concept of state in classical mechanics. Basic task of dynamics. Newton's first law. Concept of an inertial reference frame. Newton's second law as an equation of motion. Force as a derivative of momentum. Newton's third law. Interconnection and physical meaning of Newton's laws. Forces in mechanics.

Topic 4. Rigid body in mechanics and laws of its motion.

Motion of a rigid body as a superposition of translational and rotational motions. Translational motion. Center of mass. Theorem of the motion of the center of mass. Rotational motion. System of the center of mass. Moment of force. Angular momentum. Basic equation of the dynamics of a rigid body (equation of moments). Equation of the dynamics of rotational motion of a rigid body about a fixed axis. Moment of force about an axis. Lever arm of a force. Moment of inertia of a rigid body about an axis. Steiner's theorem. G-sensor, gyro sensor.

Topic 5. Conservation laws in classical mechanics.

Isolated system as a physical model. Internal and external forces. Law of conservation of momentum and examples of its manifestations in nature and technology. Law of conservation of angular momentum and examples of its manifestations in nature and technology. Work and power in mechanics. Energy. Kinetic energy. Work, power, and kinetic energy in rotational motion of a body. Energy of a rolling body. Physical (force) field. Conservative and non-conservative fields. Potential energy of a particle. Law of conservation of energy in classical mechanics and examples of its manifestations in nature and technology.

Topic 6. Elements of mechanics of continuous media.

Reactive motion. Meshchersky's equation. Screw motion. Operating principle of a quadcopter. Mechanical properties of liquids and gases. Ideal and viscous fluid. Equilibrium and motion equations of an ideal fluid. Hydrostatics of incompressible fluid. Stationary flow of fluid. Bernoulli's equation. Hydrodynamics of viscous fluid. Coefficient of viscosity. Flow in a pipe. Poiseuille's formula. Law of similarity. Stokes' formula. Hydrodynamic instability. Turbulence

Topic 7. Fundamentals of the molecular-kinetic theory of gases.

Matter as a macroscopic system. Molecular-kinetic and thermodynamic methods of studying macroscopic systems. Thermodynamic parameters of macroscopic systems. Equilibrium states. Position of the molecular-kinetic theory. Temperature and its molecular-kinetic meaning. Temperature scales. Model of an ideal gas. Classical principle of detailed equilibrium. Derivation of the main equation of the molecular-kinetic theory for an ideal classical gas and its comparison with the experimental Mendeleev-Clapeyron equation. Average kinetic energy of a particle. Boltzmann's constant.

Topic 8. Fundamentals of thermodynamics.

Thermodynamic method of research, its generality and limitations. Equilibrium states and thermodynamic processes, their representation on thermodynamic diagrams. Equation of state in classical thermodynamics. Equation of state of an ideal gas. Internal energy and other thermodynamic functions. First law of thermodynamics. Work in thermodynamics. Amount of heat and its calculation. Specific heat of monoatomic and polyatomic gases. Number of degrees of freedom. Law of uniform energy distribution by degrees of freedom.

Topic 9. Fundamentals of thermodynamics.

Application of the first law of thermodynamics to isoprocesses and adiabatic process of an ideal gas. Second law of thermodynamics. Reversible and irreversible processes. Circular process (cycle). Heat engines. Carnot's theorem. Maximum efficiency of an ideal heat engine. Entropy. Definition of entropy of a macroscopic system through the statistical weight of its macrostate. Principle of increasing entropy. Third law of thermodynamics - Nernst's theorem and its conclusions.

Topic 10. Electrostatics in Vacuum

Subject of the study of electricity and magnetism. Electric charge. Electric field. Discreteness of electric charge. Law of charge conservation. Coulomb's Law.Electric field intensity - its force characteristic. Principle of superposition. Calculation of electrostatic fields using the superposition method. Work of electrostatic field forces when moving charges. Electric potential – the energetic characteristic of the electrostatic field. Relationship between electric potential and electrostatic field intensity.

Topic 11. Conductors and Dielectrics in an Electrostatic Field

Ideal conductor. Free electric charges. Conductor in an electric field. Phenomenon of electrostatic induction. Distribution of charges in conductors located in an electrostatic field. Surface charge density. Conditions at the "conductor-vacuum" boundary. Electrostatic shielding. Dielectrics. Polarization of dielectrics in an electric field. Electric dipole. Dipole in an external electric field. Dielectric susceptibility and permittivity. Electric capacitance. Capacitors. Electric capacitance of capacitors of various geometric shapes. Capacitor systems. Energy of the interaction of electric charges. Energy of a charged capacitor.

Topic 12. Direct Electric Current

Electric current, its characteristics, and conditions for existence. Electric current strength. Current density vector. Difference in electric potentials, electric voltage. Direct electric current in a solid conductor (resistor). Electrical resistance of conductors. Ohm's and Joule-Lenz's laws for a homogeneous section of a circuit in integral and differential forms. Systems of resistors.

Topic 13. Direct Electric Current

Temperature dependence of conductor resistance. Current source. External forces. Electromotive force. Electromotive force of a galvanic element. Ohm's law for a section of a circuit with a current source and for the simplest closed electric circuit. Kirchhoff's rules. Multiple voltage sources. Semiconductors.

Topic 14. Magnetostatics in Vacuum

Magnetic field. Circuit with current in a magnetic field. Magnetic moment of a circuit with electric current. Magnetic induction vector - the force characteristic of the magnetic field. Magnetic field lines. Vortex nature of the magnetic field. Constant magnetic field. Biot-Savart-Laplace law. Principle of superposition of magnetic fields. Magnetic field of the simplest systems: a straight conductor with current, a circular current. Ampere's law.

Topic 15. Magnetostatics in Vacuum

"Potential energy" of a current loop in an external magnetic field. Magnetic flux. Ostrogradsky-Gauss theorem for magnetic induction. Motion of charged particles in a magnetic field. Lorentz force. Motion of a charged particle in electric and magnetic fields. Practical applications of the laws of motion of charged particles in electric and magnetic fields: in accelerators, MHD generators, mass spectrometers, electron-beam devices. Hall effect.

Topic 16. Magnetic Field in Substance

Magnetic field in a substance. Magnetic field of a moving charge. Molecular currents. Magnetic moments of atoms. Magnetization. Magnetic susceptibility and permeability. Magnetic field intensity. Conditions at the boundary between two media. Types of magnets: diamagnets, paramagnets, ferromagnets. Stoletov's experiment. Basic equations of magnetostatics in a substance. Application of magnetostatic laws in technology. Phenomenon of electromagnetic induction. Faraday's experiments. Lenz's law. Eddy currents, skin effect.

Topic 17. Harmonic Mechanical Oscillations

Concept of oscillatory processes. Unified approach to oscillations of different physical nature. Concept of linear and nonlinear oscillations. Classification of oscillations. Natural free oscillations of a one-dimensional oscillator - harmonic oscillations. Characteristics of harmonic oscillations: displacement from the equilibrium position, amplitude, period, linear and angular frequencies, phase, initial phase. Necessary and sufficient conditions for the existence of harmonic oscillations. Differential equation of harmonic oscillations. Examples of harmonic oscillators of various physical natures.

Topic 18. Addition of Harmonic Mechanical Oscillations

Addition of harmonic oscillations in one direction. Graphical representation of harmonic oscillations using a rotating vector. Vector diagrams. Beats. Addition of perpendicular oscillations. Lissajous figures. Practical applications of the addition of oscillations.

Topic 19. Damped and Forced Oscillations

Natural damped mechanical oscillations and their differential equation. Logarithmic decrement of damping, quality factor, relaxation time. Simplest circuit where natural damped electromagnetic oscillations occur. Forced mechanical oscillations of an oscillator under the action of a harmonic force. Establishment process of oscillations. Amplitude and phase of forced oscillations. Resonance. Forced oscillations in electrical circuits. Impedance.

Topic 20. Wave Processes

Waves and the conditions for their emergence and existence. Main types of waves by their physical nature. General characteristics of wave processes. Wave front, wave surface: plane, spherical, and cylindrical waves. Phase velocity, wavelength, wave number, and wave vector. Relationship between phase velocity and wave vector. Plane wave and its equation. Principle of wave superposition and its limits of applicability. Coherence. Relationship between wave path difference and phase difference. Interference of sinusoidal waves. Standing waves. Nodes and antinodes. Mechanism of mechanical wave formation. Elastic waves in solids, gases, and liquids.

Topic 20. Acoustics

Physical characteristics of sound. Sound phenomena. Speed of sound. Classification of sounds and their characteristics. Characteristics of auditory perception. Ultrasound, infrasound.

Topic 21. Geometric Optics

Development of ideas about the nature of light. Geometric, scalar wave, electromagnetic, and quantum models of light, their main principles. Laws of propagation, reflection, and refraction of light. Refraction of light on a spherical surface. Thin lenses. Optical systems of lenses. Magnifying glass, eyepiece, telescope, microscope. Image defects and aberrations of optical systems. Photometry. Energy and luminous units, their relationship. Main laws of photometry.

Topic 22. Interference and Diffraction of Light

Interference of monochromatic waves. Calculation of the interference pattern from two sources. Interference of light in thin films, bands of equal thickness, and equal inclination. Newton's rings. Optical coatings. Quasi-monochromatic waves. General formulation of the diffraction problem. Huygens-Fresnel principle. Fresnel and Fraunhofer diffraction. Diffraction grating as a spectral device and its characteristics (resolving power, dispersion).

Topic 23. Propagation of Light in Matter

Main phenomena observed when light propagates in matter and their general mechanism. Light scattering and its manifestations in nature. Phenomenon of light dispersion. Concept of the mechanism of light dispersion. Light absorption. Bouguer-Lambert law. Relationship between dispersion and absorption. Spectral analysis, its scientific and practical applications. Light polarization. Polarization of light upon reflection and refraction, Brewster's law. Double refraction in uniaxial crystals and its explanation. Malus's law.

Topic 24. Color Spaces

Electromagnetic wave scale. Optical spectroscopy. Light sources. Light receivers. Eye as an optical system. Color models CMYK, RGB, Lab, HSB. Typical tasks and examples of computer vision applications.

Topic 25. Fundamentals of Relativistic Mechanics

Relativistic kinematics. The problem of space and time. Postulates of the special theory of relativity. Relativity of simultaneity. Interval. Lorentz transformations. Consequences of Lorentz transformations: length contraction of moving scales, time dilation of moving clocks. Velocity addition law. Invariants of Lorentz transformations.

Topic 26. Elements of Quantum Optics

Thermal equilibrium radiation of a black body, its laws: Kirchhoff's, Stefan-Boltzmann, Wien's. Quantum hypothesis and Planck's formula. Planck constant. Photons. Energy, momentum, and mass of photons. Wave-particle duality of light. Optical pyrometry. External photoelectric effect. Hertz's, Stoletov's, and other experiments establishing the regularities of the external photoelectric effect. Einstein's theory of the photoelectric effect. Multiphoton photoelectric effect. Practical applications of the photoelectric effect.

Topic 27. Fundamentals of Non-relativistic Quantum Mechanics

De Broglie hypothesis. Experimental confirmation of the wave properties of matter particles. Electron diffraction (Davisson and Germer experiments and others). Heisenberg's uncertainty principle. Heisenberg's uncertainty relations.

Topic 28. Quantum Mechanics and Wave-Particle Duality of Matter

Setting the state of microparticles: classical and quantum. Wave function, boundary conditions. Probability in quantum theory. Physical meaning of the wave function. Principle of state superposition. Operators of physical quantities. Spectrum of the operator and its degeneracy. Causality principle in quantum mechanics. Time-dependent Schrödinger equation. Stationary states. Schrödinger equation for stationary states.

Topic 29. Atom

Difficulties of classical physics in explaining the structure and stability of the atom. Rutherford's atomic model. Excitation and ionization potentials of atoms. Line spectra of hydrogen-like atoms. Spectral series in the emission spectrum of the hydrogen atom. Discreteness of atomic energy levels. Key concepts of Bohr's theory. Stationary quantum states. Bohr's frequency rule. Difficulties of Bohr's theory. Hydrogen-like atoms.

Topic 30. Crystals

Structure of crystals. Nature of chemical bonds in solids. Band structure of the energy spectrum of electrons. Energy bands in crystals. Charge carriers in metals. Superconductivity.

Topic 31. Atomic Nucleus

Characteristics of nuclei: charge, size, and mass. Composition of the nucleus according to Ivanenko and Heisenberg. Nucleons. Mass and charge numbers. Angular momentum of the nucleus and its magnetic moment. Interaction of nucleons in the nucleus and the concept of the properties and nature of nuclear forces. Exchange interaction. Mass defect. Mass defect and binding energy of nuclei. Dependence of specific binding energy on mass number and nuclear stability. Phenomenological models of the nucleus: gas, drop, and shell models. Nuclear reactions.

Topic 31. Modern Physical Picture of the World
Brief historical overview of the main physical pictures of the world. Concept of the most important problems of modern physics and astrophysics. Development of modern physics. Progress of physical science as the basis for technological development.

Topics of the workshops

Practical classes within the discipline are not provided

Topics of the laboratory classes

Topic 1: Kinematics of Translational and Rotational Motion
Topic 2: Dynamics of Translational and Rotational Motion
Topic 3: Conservation Laws in Classical Mechanics
Topic 4: Fundamentals of the Molecular Kinetic Theory of Gases
Topic 5: Fundamentals of Thermodynamics
Topic 6: Electrostatics in Vacuum
Topic 7: Steady Electric Current
Topic 8: Magnetostatics in Vacuum
Topic 9: Harmonic Oscillations
Topic 10: Damped and Forced Oscillations
Topic 11: Wave Processes
Topic 12: Interference of Light
Topic 13: Diffraction of Light. Electromagnetic Waves in Matter
Topic 14: Quantum Mechanics
Topic 15: Atom
Topic 16: Atomic Nucleus

Self-study

Preparation for laboratory sessions involves reviewing lecture materials and completing research projects on topics such as mechanics, thermodynamics, electromagnetism, oscillations and waves, and optics.

Non-formal education

Within the framework of informal education, according to the corresponding Regulation (http://surl.li/pxssv), educational components or their individual topics may be credited in the event of independent completion of professional courses/training, obtaining civic education, online education, professional internships, etc. Specifically, individual topics of this component may be credited upon the successful completion of the following courses:

- **Topic 1. "Mechanics: Motion, Forces, Energy, and Gravitation"** https://www.coursera.org/learn/machine-learning?specialization=machine-learning-introduction
- **Topic 2.Introduction to Thermodynamics** https://www.coursera.org/learn/thermodynamics-intro

Course materials and recommended reading

Basic literature

1. Кононова К. Ю. Машинне навчання. – Харків: ХНУ ім. В. Н. Каразіна, 2020. – 301 с.
1. Фізика. Лабораторний практикум : навч. посіб. : / Т. М. Шелест, О. М. Андреєв, Т. І. Храмова та ін. – Дніпро : Середняк Т. К., 2023. – 304 с. https://repository.kpi.kharkov.ua/handle/KhPI-Press/69100
2. Гапоченко С. Д. Механіка. Навчально-методичний посібник для самостійної роботи з дисципліни «Фізика» / Гапоченко С. Д. Харків : ТОВ «В СПРАВІ», 2021. – 116 с. http://repository.kpi.kharkov.ua/handle/KhPI–Press/53032
3. Гапоченко С. Д. Механічні коливання і хвилі [Електронний ресурс] : опорний конспект лекцій з дисципліни “Фізика” : для студентів техн. спец. / С. Д. Гапоченко ; Нац. техн. ун-т “Харків. політехн. ін-т”. – Електрон. текст. дані. – Харків, 2021. – 49 с. : іл. – Представлено у вигляді презентації. –

https://repository.kpi.kharkov.ua/handle/KhPI-Press/56830
4. Фізика. Навчально-методичний посібник для дистанційного навчання / Н. Б. Фатьянова, Т. М. Шелест, І. В. Галущак, Ю. В. Меньшов – Харків :НТУ «ХПІ», 2021. – 164 с.
http://repository.kpi.kharkov.ua/handle/KhPI–Press/49895

Additional literature

5. Методичні вказівки до самостійної роботи за темою «Механіка. Частина 1. Кінематика» з курсу «Фізика» для студентів усіх спеціальностей / уклад.: Храмова Т. І., Кривоніс С. С., Шелест Т. М. – Харків: НТУ «ХПІ», 2020. – 36 с. http://repository.kpi.kharkov.ua/handle/KhPI-Press/49380.
6. Методичні вказівки до самостійної роботи за темою «Механіка. Частина 2. Динаміка» з курсу «Фізика» для студентів технічних спеціальностей / уклад.: Храмова Т. І., Кривоніс С. С., Шелест Т. М. – Харків : НТУ «ХПІ», 2021. – 48 с.
http://repository.kpi.kharkov.ua/handle/KhPI–Press/53080.
7. Методичні вказівки до самостійної роботи за темою “Механічні коливання та хвилі” з курсу “Фізика” : для студентів техн. спец. / уклад.: Т. І. Храмова, С. С. Кривоніс, Т. М. Шелест ; Нац. техн. ун-т “Харків. політехн. ін-т”. – Харків : Друкарня Мадрид, 2022. – 60 с.
https://repository.kpi.kharkov.ua/handle/KhPI-Press/55943
8. Водоріз О. С. Оптика, атомна і ядерна фізика [Електронний ресурс] : навч. посібник / О. С. Водоріз, О. А. Любченко, Т. В. Тавріна ; Нац. техн. ун-т “Харків. політехн. ін-т”. – Електрон. текст. дані. – Харків, 2021. – 159 с.
http://repository.kpi.kharkov.ua/handle/KhPI–Press/54012
9. Водоріз О. С. Оптика, атомна і ядерна фізика: посібник з розв’язання задач [Електронний ресурс] : навч.-метод. посібник / О. С. Водоріз, О. А. Любченко, Т. В. Тавріна ; Нац. техн. ун-т “Харків. політехн. ін-т”. – Електрон. текст. дані. – Харків, 2021. – 172 с.
http://repository.kpi.kharkov.ua/handle/KhPI–Press/54001

Internet resources

10. https://www.motionmountain.net/

Assessment and grading

Criteria for assessment of student performance, and the final score structure

Description of the final score structure, course requirements, and necessary steps to earn points, especially paying attention to self-study and individual assignments.

Grading scale

Total points	National	ECTS
90–100	Excellent	A
82–89	Good	B
75–81	Good	C
64–74	Satisfactory	D
60–63	Satisfactory	E
35–59	Unsatisfactory (requires additional learning)	FX
1–34	Unsatisfactory (requires repetition of the course)	F

Norms of academic integrity and course policy

The student must adhere to the Code of Ethics of Academic Relations and Integrity of NTU «KhPI»: to demonstrate discipline, good manners, kindness, honesty, and responsibility. Conflict situations should be openly discussed in academic groups with a lecturer, and if it is impossible to resolve the conflict, they should be brought to the attention of the Institute's management.
Regulatory and legal documents related to the implementation of the principles of academic integrity at NTU «KhPI» are available on the website: http://blogs.kpi.kharkov.ua/v2/nv/akademichna-dobrochesnist/

Approval

Approved by	Date, signature 29.08.2024		Head of the Department Olena LYUBCHENKO
	Date, signature 29.08.2024		Guarantor of the Educational Program Olena AKHIIEZER