THEORETICAL PHYSICS

Field of Study: Physics
Programme name: Physics
Level of Study: Bachelor degree
Year of admission: 2021
Semester, year: : autumn, 2024; spring , 2025
ECTS: 9
Assessment: exam

Learning Outcomes

№	Upon the course completion, students will be able to:
1	Apply knowledge of math, science, and engineering.
2	Design and conduct experiments, analyze and interpret the data.
3	Design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4	Function in multi-disciplinary research teams.
5	Identify, formulate, and solve engineering problems.
6	Demonstrate understanding and awareness of ethical and professional responsibility.
7	Communicate effectively.
8	Understand the impact of engineering solutions in global, economic, environmental, and societal context.
9	Recognise the need for, and be able to engage in life-long learning.
10	Demonstrate the knowledge of contemporary issues materials science and engineering
11	Use techniques, skills and modern engineering tools necessary for engineering practice.

Course Structure

The course "Theoretical Physics" includes 2 Modules comprising lectures and practicals.
Module 1. Atomic Bonding and Material Properties, Crystal Structure, Crystallographic Directions and Planes, Macromolecular Structure, Mechanical Behavior, Fracture, Fatigue, Diffusion.
Introduction. Materials science and application of materials. Classification of materials. Advanced materials. Modern material's needs.

Atomic Structure and Interatomic Bonding
Atomic structure. Electrons in atoms. The Periodic Table. Atomic bonds in solids. Atomic Bonding in Solids. Atomic Structure and Interatomic Bonding.

Laboratory works:
Design of crystal structures.

The Structure of Crystalline Solids

Crystal structures. Fundamental concepts. Unit cells. Metallic crystal structures. Density computations. Crystallographic points, directions, and planes. Linear and planar densities. Close-packed crystal structures. Crystalline and non-crystalline materials.
X-ray diffraction: determination of crystal structures. Bragg's Law. Diffraction techniques. Unit cells. Metallic crystal structures. Density computations. Crystallographic points, directions, and planes. Linear and planar densities.

Imperfections in Solids
Point Defects. Vacancies and self-interstitials. Impurities in solids. Solid Solutions. Specification of composition. Thermodynamics. Equilibrium concentration. Migration. Sources and runoffs. Complexes. Behavior at annealing and cooling. The influence of external pressure on vacancies. Superequilibrium vacancies.
Linear defects - dislocations. Burgers vector. Types and signs of dislocations. The energy and the tension force of dislocations. Interaction of dislocations. Dislocation reactions. The origin and multiplication of dislocations.
Miscellaneous imperfections. Interfacial defects. Bulk or volume defects. Atomic vibrations. Microscopic examination. Grain-size determination.
Point defects: vacancies and self-interstitials. Composition. Equilibrium concentration. The influence of external pressure on vacancy formation. The finding of the concentration of vacancies, the formation and migration energies.
Dislocations. Dislocations in FCC single crystals. Dislocation reactions.

Laboratory works:

Bubble raft. Modelling of Miscellaneous imperfections.

Diffusion
Diffusion mechanisms. Fick's first law. Fick's second law - nonsteady-state diffusion. General method for solving diffusion problems. Factors that influence diffusion. Diffusion in semiconducting materials. Other diffusion paths. Diffusion in metals. Diffusion in semiconductors.

Mechanical Properties of Metals
Tension/compression tests. Shear and torsional tests. Geometric considerations of the stress State. Stress - strain behavior. Hooke's law. The shear modulus. Elastic properties of materials. Plastic deformation.
True stress and strain. Elastic recovery after plastic deformation. Hardness. Property variability and design/safety factors
Mechanical properties of metals. Determination of the mechanical properties of the curves of the stress - strain curves.
Hardness. Plastic deformation. Design. Engineering issues and problems.

Laboratory works:

Mechanical properties of structural materials.

*Strengthening Mechanisms*Dislocations and plastic deformation. Theoretical strength. Slip systems. Slip in single crystals. Plastic deformation of polycrystalline materials. Deformation by twinning.
Mechanisms of strengthening in metals. Strengthening by grain size reduction. Solid-solution strengthening. Strain hardening. Recovery, recrystallization, and grain growth.
Crystallography of plastic deformation.

Interaction between dislocations and point defects. Atmospheres.

Failure

Fundamentals of fracture. Ductile fracture. Brittle fracture. Principles of fracture mechanics. Fracture toughness testing.

Fatigue. Crack initiation and propagation. Factors that affect fatigue life. Creep. Data extrapolation methods. Alloys for high-temperature use.

Laboratory works:

Analysis of the fracture structures.

Module 2. Phase Equilibria, Phase Transformations, Microstructure Control in Metals, Metal Alloys and Processing, Glass and Ceramic Processing, Polymers and Composites, Thermal, Electrical and Magnetic Properties

Phase Diagrams and Phase Transformations

Definitions and Basic Concepts. One-component (or unary) phase diagrams. Binary phase diagrams. Interpretation of phase diagrams. Development of microstructure. Mechanical properties.

Binary eutectic systems. Development of microstructure in eutectic alloys. Equilibrium diagrams having intermediate phases or compounds. Eutectoid and peritectic reactions. Congruent phase transformations. Ternary phase diagrams. The Gibbs phase rule.

The iron–carbon system. Phase diagram. Development of microstructure. The influence of other alloying elements.

The kinetics of phase transformations. Metastable versus equilibrium states. Microstructural and property changes in iron–carbon alloys.

Features of phase diagrams of one-component (or unary) systems.

Reading and interpretation of phase diagrams.

Construction of phase diagrams.

Isothermal transformation diagrams. Design of finish microstructure.

S*tructure and Properties of Ceramics, Polymers and Composites*

Structures and properties of ceramics. Imperfections in ceramics. Diffusion in ionic materials. Ceramic phase diagrams. Mechanical Properties. Types and Applications of Ceramics. Fabrication and Processing of Ceramics.

Polymers. The chemistry. Structure. Polymer crystals. Defects in polymers. Diffusion in polymeric materials. Mechanical behavior of polymers. Fracture of polymers. Mechanisms of deformation and for strengthening of polymers. Crystallization, melting, and glass-transition phenomena in polymers. Polymer types. Advanced polymeric materials. Polymer synthesis and processing.

Particle-reinforced composites. Large-particle composites. Dispersion-strengthened composites. Fiber-reinforced composites. Influence of fiber length. Influence of fiber orientation and concentration. The fiber phase. The matrix phase. Polymer–matrix composites. Metal-matrix composites. Ceramic-matrix composites. Hybrid composites. Structural composites.Structures and properties of ceramics.

Polymers.

Composites.

Electrical Properties

Electrical Conduction. Semiconductivity. Electrical Conduction in Ionic Ceramics and in Polymers. Dielectric behavior. Other electrical characteristics of Materials. Electrical properties in solids.

Thermal Properties

Heat capacity. Thermal conductivity. Thermal stresses.

Magnetic Properties

Diamagnetism and paramagnetism. Ferromagnetism. Antiferromagnetism and ferrimagnetism. The influence of temperature on magnetic behavior. Domains and hysteresis. Magnetic anisotropy. Superconductivity.

Optical Properties

Light interactions with solids. Optical properties of metals. Optical properties of nonmetals. Applications of optical phenomena.

Instructor(-s): Nataliya Pushilina, email: pushilina@tpu.ru

EXPERIMENTAL METHODS IN CONDENSED MATTER RESEARCH

Field of Study: Physics
Programme name: Physics
Level of Study: Bachelor degree
Year of admission: 2021
Semester, year: : autumn, 2024; spring , 2025
ECTS: 8
Assessment: exam

Learning Outcomes

№	Upon the course completion, students will be able to:
1	To estimate correctly tendencies of research development, to set up programs for conducting physical research on a given topic.
2	To set up and solve problems that require creative approach and originality, when conceptual aspects of research are needed to be developed.
3	To make independently a choice of a method / technique for studying the structure and properties of materials in accordance with the settled goals.
4	To have skills in modern methods of analyzing materials structure and properties, and to predict their change under various external influences.
5	To work within research groups that perform interdisciplinary research; to participate in the processing of the results of scientific research at the high level.

Course Structure

The course “Experimental Methods in Condensed Matter Research” includes 4 Sections combining lectures and laboratory sessions.

Section 1. STRUCTURAL METHODS FOR ATTESTATION OF THE SOLIDS
Lecture No.1. Methods for study of elementary particles interactions. Hadron collider. Relationship between solids' structure and their performance characteristics. Experimental methods for the studies of crystals’ phonon and electron spectra. Physical principles of elementary particles detection.
Lecture No.2. Transmission electron microscopy (TEM). Imaging principles. Diffraction patterns/images formation in scanning electron microscope. Bright-field and dark-field images. Samples preparation. Electron diffraction.
Lecture No.3. The principle of pattern obtaining from Electron Backscatter Diffraction (EBSD). Kikuchi lines. EBSD capabilities.
Lecture No.4. X-Ray Diffraction (XRD) principles. X-|Ray generation principle. Bragg law.
Lecture No.5. XRD (X-Ray diffraction) analysis. XRS (X-Ray spectroscopy) analysis. XRF (X-ray fluorescence) analysis. Calculation of coherent scattering regions, micro- and macrostresses.
Lecture No.6. Secondary ion mass-spectrometry (SIMS), Auger spectrometry. Desorption methods of analysis. Thermal desorption, electron-stimulated desorption (ESD),

photodesorption, ion beam desorption. Modern mass-spectrometers.
Lecture No.7. Ultrasonic inspection. Basic laws of ultrasonic waves propagation in the crystal. Effect of the crystal lattice defects on the speed of sound. Methods for signal detection and processing.
Lecture No.8. Synchrotron radiation. Theory of synchrotron radiation. Synchrotron spectroscopy. Study of the structure using SR. Technical applications of SR. Experimental methods for condensed matter studies using neutron beams.

Laboratory classes:
1. Studying of the operation of vacuum systems.
2. Studying of the physical vapor deposition.
3. Studying of the basics of glow discharge optical emission spectroscopy.
4. Studying of the depth distribution of elements.

Section 2. METHODS FOR SOLIDS' SURFACE INVESTIGATION
Lecture No.9. Scanning probe microscopy (SPM). Imaging principle. Scanning tunneling microscopy (STM) - measurements in direct-current and constant-altitude modes. Contact, non-contact and semi-contact modes of atomic-force microscope (AFM) operation. Lennard-Jones potential. Advantages and disadvantages of STM and AFM. Limitation of methods application.
Lecture No.10. Scanning electron microscopy (SEM). Imaging principle in SEM. Advantages and disadvantages of the SEM. Fractographic analysis.
Lecture No.11. Operation principle, magnification and resolution of an optical microscope. Optical profilometry. Metallographic studies. Determination of the orientation in crystals. Attestation of the grain structure.

Laboratory classes:
1. Estimation of the size of coherent scattering regions by diffraction peak broadening.
2. X-ray analysis of microstresses and sizes of coherent scattering regions in polycrystalline materials.

Section 3. MECHANICAL CHARACTERISTICS OF SOLIDS
Lecture No.12. Types of deformation in solids. Elastic and plastic deformation. Types of static and dinamic loading. Extension, compression, three- and four-point bending, reverse bending, impact viscosity, creep of materials. Tension testing machines. Determination of material's impact viscosity. Cold-shortness threshold. Sources of errors in strength tests.
Lecture No.13. Friction wear. Determination of frictional coefficient. Methods for evaluating the wear-resistance of materials.
Lecture No.14. The stress-strain curve. Elastic constants, yield stress point and ultimate stress point, ductility of materials. Brittle and ductile fracture of solids. Fractography.
Lecture No.15. Analysis of materials hardness. Methods hardness measuring. Brinell, Rockwell and Vickers hardness. Measurement of microhardness. Physics of microhardness. Structural and kinetic features of materials shaping under indentation. Installation for micromechanical studies by the method of indentation. Calculations of hardness according to the results of the microhardness test.
Lecture No.16. Nanoindenting. The principle of the device. Effect of substrate's hardness on thin films' mechanical characteristics, that are determined by the method of

nanoindentation. Determination of indentation parameters by the Oliver-Pharr method. Method for true hardness determination.

Laboratory classes:
1. Hardness testing.
2. Tensile testing.

Section 4. PHYSICAL PROPERTIES OF CONDENSED MATTER

Lecture No.17. Determination of the phase-transition temperature of a substance in a condensed state. Thermo-gravimetric analysis and differential scanning calorimetry. Coefficient of volumetric and linear thermal expansion. Optical-mechanical, capacitive, induction, interference, X-ray and radio-resonance dilatometers. Methods for determining the characteristics of the porous structure of materials. Mercury porometry. Reference porometry. Instruments for measuring micropores, nanopores. Methods and instruments for density determination.

Lecture No.18. Electrical properties of metals, semiconductors and dielectrics. Methods for measuring electrical resistance. Magnetic characteristics of materials, and methods for their studying. Scheme and operating principle of the vibration magnetometer. Barkhausen noise.

Instructor(-s)

Kudiiarov Viktor Nikolaevich, kudiyarov@tpu.ru

ANNOTATION

METALS AND SEMICONDUCTOR MATERIALS PHYSICS TECHNOLOGIES AND PROCESSES

Field of Study: Physics
Programme name: Physics
Level of Study: Bachelor degree
Year of admission: 2021
Semester, year: : autumn, 2024;
ECTS: 6
Assessment: exam

Learning Outcomes

№	Upon the course completion, students will be able to:
1	To choose methods for production of construction materials with required microstructure, phase composition, physical and mechanical properties in accordance to the goals set.
2	To perform theoretical and experimental research in metal science and metal heat treatment, as well as in the field of semiconductor electronics, using specific knowledge of physics and other disciplines within the courses taken.
3	To apply in practice the obtained professional knowledge on existing methods for the formation of nanocrystal structure in surface layers and volume of metals and alloys, as well as on methods for thin films and nanostructure coating.
4	To work in research groups to perform interdisciplinary research.
5	To process the scientific research results with high accuracy.

Course Structure

The course “Metals and semiconductor materials physics technologies and processes” includes 3 Modules combining lectures and laboratory sessions.

Module 1. Methods for production of bulk mono- and polycrystal materials

Lectures

Lecture 1. Metals, semiconductors, dielectrics. Electronic structure. Band diagram. Physical, chemical, mechanical and technical properties. Applications.
Lecture 2. Crystal growth methods. Gaseous-phase (vapor) crystallization in the presence of pressure gradient. Melt crystallization in the presence of temperature gradient. Melt crystallization in the presence of concentration gradient at the crystal/solution interface.
Lecture 3. Steel casting. Iron-carbon diagram. Phases and structural components in ironcarbon steels.
Lecture 4. Iron-carbon phase diagram. Phases and structural components of iron-carbon steels. Thermal and chemical heat treatment of metals.
Lecture 5. Alloying of metals and semiconductors. The main methods of alloying.

Practicals
Practics 1. Studying the main uses for metals and semiconductors.
Practics 2. Comparison the basic methods of growing crystals. **Practics 3.** Learning basic techniques of steel casting.
Practics 4. Studying the main phase states of iron with carbon.
Practics 5. Learning the difference in basic methods of metals alloying.

Laboratory session and work
Laboratory work 1: Metallographic studies.

Module 2. Processes and methods for the formation of nanostructured states in structural materials

Lectures

Lecture 1. Defects of the crystal lattice. Severe plastic deformation.
Equal Channel Angular Extrusion. The High Pressure Torsion. Multi-axial forging.
Lecture 2. Nanostructuring of surface layers of metals and semiconductors.
Methods and equipment for high-energy impact.
Lecture 3. Ultrasonic shock treatment. Regularities of changes in surface morphology and microstructure of surface layers of structural materials.
Lecture 4. Mechanical properties of nanostructured materials.
Mechanisms of deformation and destruction.
Lecture 5. Surface treatment with electron and ion beams. Patterns of change in the microstructure of the surface layers.

Practicals

Practics 1. Studying the basic types of defects.
Practics 2. Learning the difference in methods for high-energy impact.
Practics 3. Learning the methods of ultrasonic shock treatment.
Practics 4. Learning the mechanical properties of nanostructured materials and mechanisms of deformation and destruction.
Practics 5. Learning the main patterns of change in the microstructure of the surface layers of materials after treatment by electron and ion beams.

Laboratory sessions and works Laboratory work 1: Hardness testing.

Module 3. Thin films and coatings

Lectures
Lecture 1. Physical methods of thin film depositing. Thermal evaporation. Vacuum-arc deposition.
Lecture 2. Magnetron sputtering. Electrolytic deposition.
Lecture 3. Chemical methods for thin films deposition. Types of CVD processes. Advantages and disadvantages. Areas of use.
Lecture 4. Epitaxial growth of semiconductors. Epitaxy from the gas phase. Liquid phase epitaxy. Molecular beam epitaxy.

Lecture 5. Growth mechanisms for films and coatings. Effect of deposition parameters on the structure and functional properties of thin films. Stresses in thin films.
Lecture 6. Deformation and destruction of thin films during thermal loading and under mechanical loading.

Practicals

Practics 1. Examination the differences in physical methods of thin film depositing.
Practics 2. Examination the differences in methods of magnetron sputtering and electrolytic deposition.
Practics 3. Examination the differences in methods of chemical thin films deposition.
Practics 4. Studying the main methods of epitaxial growth of semiconductors.
Practics 5. Studying the main growth mechanisms for films and coatings.
Practics 6. Studying the deformation and destruction of thin films during thermal loading and under mechanical loading.

Laboratory sessions and works Laboratory work 1: Tensile testing.
Laboratory work 2: Elemental analysis.

Instructor(-s) Egor Borisovich Kashkarov, ebk@tpu.ru

STUDENT ACADEMIC RESEARCH

Field of Study: Physics
Programme name: Physics
Level of Study: Bachelor degree
Year of admission: 2021
Semester, year: : autumn, 2024; spring , 2025
ECTS: 4
Assessment: differential score

Learning Outcomes

№	Learning Outcomes
1	Upon the course completion, students will be able to: (a) identify the most promising research areas in the professional field, modify modern methods and develop new methods in accordance with the objectives of the research. (b) search for and process new information, work with software packages, simulate physical phenomena, work in interdisciplinary fields of scientific research.

Course Structure

The discipline «Student Academic Research» includes 3 modules.

Module 1. Preparation for Student Academic Research

In accordance with a penchant to perform a particular type of research work, students choose the direction of research from the directions proposed by the divisions, research institutes and other research organizations. An interview with the head of the student academic research is conducted. The head of the student academic research conducts briefing on the implementation of research work and presentation of the research results. For individual students with limited health, it is possible to develop an individual education plan with respect to individual characteristics.

Module 2. Carrying-out of Student Academic Research

At this module students perform the research work, collect and process information, recording the workbook and write sections of the report. The scientific supervisors is responsible person for whole work of students. The students can refer to the scientific advisors for all issues.
Student academic research can be organized on the problem group’s basis that develop the common theme. Problem groups are independent organizational units that consist of 3-5 people. The participants in the problem group either collectively solve one problem or distribute the particular aspects of the problem among themselves. The problem group can

consist of students of different courses.
Another form of student academic research is the individual work of students with the supervisor The scientific supervisor can lead one or more student academic research.

Module 3. Preparation the report and presentation
At this module the student's report is checked and public defense of results is carried out. The public defense in the form of the oral presentation are one of the key elements for training a young specialist.

Instructor(-s) Roman S. Laptev

SAFETY TRAINING

Field of Study: Physics
Programme name: Physics
Level of Study: Bachelor degree
Year of admission: 2021
Semester, year: : autumn, 2024;
ECTS: 3
Assessment: graded pass/fail test

Learning Outcomes

№	Upon the course completion, students will be able to:
1	Eliminate hazardous and harmful factors based on their analysis in everyday life and professional performance
2	Develop an action plan for the protection of personnel and population based on the regulations of behavior in emergency situations and military conflicts, provide the first aid and emergency response
3	Forecast prospective consequences of professional activity impact on the environment, know the basic methods of environmental protection

Course Structure

Section 1. Theoretical, legal, standard and and organizational regulations to ensure life safety, the first aid and emergency response

Purpose and content of the Safety Training course, its comprehensive nature. The main objectives of the course.
Human habitat. The concept of danger. The axiom of potential danger. Dangerous and harmful factors: classification. Criteria of safety and comfort. The concept, classification and characterization of types of risk. Quantitative indicators. The concept of acceptable risk. Issues of life safety, the first aid and emergency response in laws and by-laws.
Injuries and occupational diseases, methods of analysis. Accidents. First aid. Employers' responsibility.
Labor legislation. By-laws on labor protection. Regulatory and technical documentation. Instructions on labor protection. System of labor safety standards (SSBT).
Labor safety management. Labor safety management system. Occupational safety training, types of instruction.

Lecture topics:
1. Theoretical fundamentals of life safety, the first aid and emergency response.

Topics of practical classes:
1. Identification of dangerous and harmful factors.
2. Investigation of an accident.

Titles of laboratory works:
1. Provision of first aid.

Section 2: Industrial Sanitation

Harmful substances. Industrial microclimate, lighting. Acoustic and mechanical vibrations. Ionizing radiation.

Sources, the effect on the human body, the main characteristics, classification, rationing, measures to reduce, means of protection: collective and individual. Calculation of parameters.

Electromagnetic fields (EMF) and radiation. Laser radiation. Effects of infrared radiation, UV radiation. Norming of EMF and radiations. Protection from EMF.

Ensuring safety when working with computers.

Lecture topics:

2. Industrial microclimate, lighting.

Topics of practical classes:

1. Calculation of the required air exchange.
2. Calculation of artificial lighting.

Titles of laboratory works:

1. Study of microclimate of production premises.
2. Study of noise in industrial premises.
3. Study of vibration and methods of protection against it.
4. Study of the efficiency and quality of artificial lighting.

Section 3: Occupational Health andltq Safety

Fire-explosion hazard. Physical and chemical basis of combustion. Causes of fires, classification. Hazardous factors. Indicators of fire and explosion hazard. Classification of buildings and premises. Main preventive measures. Fire resistance. Evacuation routes. Methods and means of extinguishing. Primary means of fire extinguishing. Means of fire automation and signaling.

Electrical safety. Action of electric current. Influence of factors. Classification of premises on the shock hazard. Static electricity. Measures to improve safety. Technical means of protection.

Requirements for safe operation of pressure vessels and systems. Registration and technical inspection. Safety of automated and robotic production.

Lecture Topics:

1. Fire and explosion hazards.
2. Electrical safety.

Topics of practical classes:

3. Calculation of lightning protection zones of buildings and structures.

Titles of laboratory works:

4. Investigation of human body resistance.
5. Electrical safety in residential and office premises.
6. Fire safety.

Section 4. Safety in peacetime and wartime emergencies

Classification and general characteristics of emergencies (ES) of wartime and peacetime. Sustainability of production facilities in emergencies and military conflicts. Organization and methodology of research into the stability of functioning, methods and means of increasing the stability of enterprises. Protection of production personnel.

Assessment of the situation. Determining the parameters of the detriment location. Techniques and methods of rescue operations. Protection and evacuation of the population. Use of protective structures, personal protection devices and medical equipment.

Elimination of the consequences of the emergency. Stages of rescue and other emergency works. Organization of decontamination works. Development of the plan of repair and recovery works.

Regional peculiarities of emergencies. The most characteristic natural disasters in the Tomsk region. Potentially dangerous technogenic objects of the Tomsk region.

Topics of practical exercises:

1. Estimation of the detriment locations in an emergency.
2. Assessment of radiation situation.

Section 5: Environmental Safety

Sources of pollution, dangerous and harmful factors of the environment. Types of industry negative impact on the biosphere, industrial emissions, solid and liquid waste, energy pollution, accidents and disasters.

Classification, basics of application of ecobio protective equipment. Definition of maximum permissible emission.

Apparatuses and systems of emission purification. Calculation, design of systems and apparatuses. Dispersion of emissions in the atmosphere.

Rational water use, devices for liquid waste treatment. Calculation of liquid waste outlets. Wastewater treatment.

Discharge, utilization, disposal of solid and liquid industrial waste. Radioactive waste. Secondary resources. Low-waste technologies and production.

Topics of practical classes:

1. Calculation of pollutant dispersion in atmospheric air.

Instructor(-s): Alexandr Sechin, email: seanal@tpu.ru