**SOUTH-WEST UNIVERSITY „NEOFIT RILSKI“**
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# INFORMATION PACKAGE

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|---|---|
| SCIENTIFIC FIELD: | **4. NATURAL SCIENCES, MATHEMATICS AND INFORMATICS** |
| PROFESSIONAL FIELD: | **4.1 PHYSICS SCIENCES** |
| DOCTORAL DEGREE PROGRAMME: | **CONDENSED MATTER PHYSICS AND WAVE PROCESSES** |
| EDUCATIONAL AND QUALIFICATION DEGREE: | **DOCTOR** |
| NATIONAL QUALIFICATIONS FRAMEWORK LEVEL: | **8** |
| PROFESSIONAL QUALIFICATION: | **A RESEARCHER** |
| DURATION: | **3 / three / or 4 /four/ YEARS** |
| FORM OF TRAINING: | **FULL-TIME / INDEPENDENT / PART-TIME** |
| THE PLAN WAS INTRODUCED BY: | **2023 YEAR** |

# QUALIFICATION CHARACTERIZATION

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|---|---|
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| PROFESSIONAL FIELD: | **4.1 PHYSICS SCIENCES** |
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The doctoral program in “*Condensed Matter Physics and Wave Processes*” from the professional field 4.1. *Physical Sciences* provides the opportunity to obtain the third educational and scientific degree of higher education – *Doctor* (PhD).

This doctoral program offers opportunities for conducting scientific research, teaching, and managerial-organizational activities in the field of physical sciences.

## I. Competencies and Requirements

A graduate of the doctoral program in “*Condensed Matter Physics and Wave Processes*” is expected to:

- Possess comprehensive knowledge in the fields of condensed matter physics, wave process physics, methods for analyzing material media using electromagnetic waves, as well as a solid understanding of the operating principles and applications of modern scientific instruments used in the respective scientific field;
- Be able to use and interpret original scientific works;
- Have a high level of foreign language proficiency;
- Be proficient in computer technologies and tools;

- Be familiar with the latest achievements in condensed matter physics and wave process physics and their applications in other fields such as materials science, chemistry, engineering, and others;
- Have experimental experience in solving problems of practical importance;
- Be able to apply theoretical knowledge, as well as interdisciplinary and cause-effect relationships, in conducting in-depth scientific analysis and in solving specific theoretical and practical problems.

## II. Qualification and Career Opportunities

With the knowledge and skills acquired during the doctoral studies, the holder of the educational and scientific degree *“Doctor”* in the specialty *“Condensed Matter Physics and Wave Processes”* can pursue a career in institutions with relevant areas of activity, including:

- As a researcher in scientific institutes and laboratories conducting fundamental and applied research in the fields of condensed matter physics and wave process physics;
- As a lecturer at universities and colleges in the corresponding scientific field and specialty;
- As a specialist in scientific and applied laboratories, production facilities, and companies where analytical thinking, innovation, and a scientific approach to solving complex practical problems are required, including organizational, managerial, and marketing activities;
- As a consultant or associate in consulting agencies and companies dealing with the trade of scientific equipment and laboratory instrumentation.

Graduates of the doctoral program can also participate in various forms of continuing education, such as postdoctoral programs, to further develop their professional qualifications and experience in the scientific field.

# CURRICULUM STRUCTURE

## OF THE DOCTORAL PROGRAM „CONDENSED MATTER PHYSICS AND WAVE PROCESSES”

| № | ACTIVITIES | Form of preparation and implementation | | | Form of recognition |
|---|---|---|---|---|---|
| | | Credits ECTS | HORARIUM | Lectures, seminars laboratory exercises, independent preparation, consultations, participation, other | exam, ongoing assessment, interview, certificate, report, protocol, certification, other |
| | | | | | |
| **I.** | **EDUCATIONAL ACTIVITY** | | | | |
| 1. | Project preparation and management | 3.0 | 90 | 45 L, 45 i.w. | I/ Exam |
| 2. | English language | 4.0 | 120 | 60 S, 60 i.w. | I/ Exam |
| 3. | Elective course 1 | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II/ Exam |
| 4. | Elective course 2 | 8.0 | 240 | 45 L, 15 S, 180 i.w. | III/ Exam |
| 5. | Compulsory course in the thematic area of the dissertation | 12.0 | 360 | 30 L, 330 i.w. | III/ Exam |
| | **TOTAL:** | **35.0** | **1050** | | |
| **II.** | **SCIENTIFIC–RESEARCH ACTIVITY** | | | | |
| 1. | Dissertation Project Discussion – First Stage. | 11.0 | 330 | Individual work | Discussion |
| 2. | Presentation of Research Concept and Methodology. | 12.0 | 360 | Individual work | Report and Discussion |
| 3. | Preparation for the Specialty Examination. | 10.0 | 300 | working with literature for outlining, consultations | Consultations and Interview |
| 4. | Development and Presentation of a Scientific Thesis. | 12.0 | 360 | Individual Work with Scientific Literature | Report |
| 5. | Dissertation Project Discussion – Second Stage. | 10.0 | 300 | Individual work | Discussion |
| 6. | Preparation and Publication of an Article, Study, and/or Scientific Report. Participation in Research Projects. | 14.0 | 420 | Independent Scientific Research Activity | Article / Report |
| 7. | Interim Discussion of the Research Results on the Dissertation Work | 8.0 | 240 | Scientific Seminar Presentation | Discussion |
| 8. | Preparation and Publication of Articles, Studies, and/or Scientific Reports. | 20.0 | 600 | Scientific Research Activity | Articles / Reports |
| 9. | Presentation and Discussion of the Dissertation. | 10.0 | 300 | Presentation at a Scientific Seminar | Defense |
| 10. | Completion of the Dissertation | 10.0 | 300 | Individual work | Defense |
| 11. | Preparation for Defense | 5.0 | 150 | Individual work | Defense |
| 12. | Dissertation Defense | 15.0 | 450 | Public Defense | Defense |
| | **TOTAL:** | **137.0** | **4110** | | |
| **III.** | **PEDAGOGICAL ACTIVITY** | | | | |

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|---|---|---|---|---|---|
| 1. | Conducting Seminar and Laboratory Sessions or Out-of-Class Student Activities | 6.0 | 180 | Conducting Educational Classes | Discussion |
| | **TOTAL:** | **6.0** | **180** | | |
| **IV.** | **OTHERS** | | | | |
| 1. | For example: *Participation in department meetings; involvement in the work of departmental, faculty, and university committees; and other academic activities.* | 2.0 | 60 | Participation | Protocol, Approval by Department Head |
| | **TOTAL:** | **2.0** | **60** | | |
| | **TOTAL (for the entire duration of the education):** | **180** | **5400** | | |
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| | **ELECTIVE COURSES** | | | | |
| 1. | Nonlinear Optics | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |
| 2. | Interaction of Charged Particles with Matter | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |
| 3. | Modern Instrumental Methods | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |
| 4. | Vibrational Spectroscopy | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |
| 5. | Methods for Processing Experimental Data | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |
| 6. | Digital Signal Processing | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |
| 7. | Fundamentals of Mathematical Modeling | 8.0 | 240 | 45 L, 15 S, 180 i.w. | II-III/ Exam |

* The courses “English Language” and “Project Preparation and Management” are included in the curriculum of all doctoral students at South-West University “Neofit Rilski” as compulsory subjects, in accordance with a decision of the Academic Council.

# DESCRIPTIONS OF THE COURSES

## COMPULSORY COURSES

### PROJECT PREPARATION AND MANAGEMENT

**Annotation**:

The course in the discipline "Project Preparation and Management" introduces doctoral students to the main aspects of project development, which are the basis for the organization and management of projects when applying for European Union programs. The goal of the course "Project Preparation and Management" is for doctoral students to gain in-depth knowledge of the effective development of projects, the management process in their creation and implementation, as well as the preparation of a project budget.

In order to ensure quality training for doctoral students and achieve the set goals, teaching in the discipline "Project Preparation and Management" flexibly combines different methods and forms of training: lectures on key topics, case studies and independent work. The forms of control are also consistent with the nature of the discipline - conducting control checks in the form of discussing case studies during classroom sessions and preparing a project proposal.

Course content:

The set of thematic areas allows doctoral students to acquire knowledge about the main categories and concepts in preparing a project, its implementation and control. By studying them, they become familiar with and form a certain level of practical ideas for applying forms, techniques and methodologies in building a project proposal, as well as knowledge about their areas of application. Including basic analysis tools such as SWOT, STEP and PEST.

Teaching and assessment:

Training in the course is carried out in the form of lectures. It ends with the presentation and defense of a project proposal. The priority in the training is the practical and independent work of doctoral students. Knowledge, skills and competence are assessed during classroom work, with the results achieved from the assigned tasks being of great importance. The development of a project proposal builds responsibility for the tasks set in doctoral students, self-discipline, systematicity in preliminary preparation, builds habits for optimizing time, develops logical thinking, skills for selecting and analyzing information acquired from various information sources.

Current control is carried out by checking the acquired knowledge by solving cases on the taught material.

The assessment criteria include: quality and depth of the written work; ability to present and successfully defend the formulated conclusions and proposed solutions; demonstration of knowledge, skills and competence; use of a creative approach in solving cases; ability to work independently in extracurricular activities.

### ENGLISH LANGUAGE

**Annotation:**

According to Decision No. 21 of 04.09.2013 of the Academic Council, the English language course is mandatory for all doctoral students in the first year of their studies, who are studying in various doctoral programs in all faculties of the South-West University "Neofit Rilski".

The course is intensive and involves training within 6 hours per day. It is held (usually every year in the first month after the end of the summer semester) and its duration may vary depending on the formation of groups by language proficiency levels. The level of proficiency is determined by a preliminary entrance test, on the basis of which the participants are divided into levels - beginners, intermediate and advanced, corresponding to levels A1, A2 - B1 and B2 - C1 of the Common European Framework of Reference for Languages.

The English course for doctoral students necessarily contains the following modules: practical grammar, vocabulary, written exercises, reading and listening comprehension and conversation. Depending on the specific needs of students from different faculties and specialties, specialized vocabulary for the field is also introduced, as well as exercises in specialized and general translation. For the purposes of training, approved teaching aids from the field of university didactics are used, as well as materials developed by the teachers to meet the specialized needs of doctoral students.

Content of the course:

The course contributes to the development of speaking and listening skills, as well as the acquisition of basic principles of constructing an academic text in English, as well as the skills of preparing presentations, autobiographies, abstracts and articles in English. The main directions and activities are carried out through training in integrative modules, which are set out in the main methodological guide, mainly the teaching systems Headway (Oxford), Straightforward (Macmillan), General English Course (Elementary level) and Academic English (Elementary level). Following the teaching system, doctoral students become familiar with and deepen their knowledge of grammar, vocabulary, functional language.

Teaching and assessment technology:

The training in the subject "English Language" is carried out in the form of seminars and is conducted in the traditionally established manner with the use of multimedia products and interactive materials.

The final exams for each level are tailored to the goals and expected results of the training and are based on the achievements of the doctoral students in practically applying the knowledge and skills acquired during the course. All exams consist of a written and oral part, each of which has a weight of 50% in forming the final grade.

Beginners: The written part of the exam is a lexical and grammatical test, a reading comprehension text and questions to it, as well as an essay with a volume of 150 words, which is on topics from the daily life of the doctoral students, as well as their academic experience and achievements.

The oral part of the exam is conducted in the form of an interview, in which the examiners ask questions related to the topics covered in the textbook used during the course. Doctoral students also have a few minutes to tell their biography with a focus on education, scientific interests and achievements.

Intermediate: The written part of the exam is a lexical and grammatical test, a reading comprehension text and questions to it, as well as an essay or autobiography/abstract for an article with a volume of 200 - 220 words, or a short summary of a short article, which are on topics from the professional everyday life of the doctoral students and their academic experience and achievements.

The oral part of the exam is conducted in the form of an interview, in which the examiners ask questions related to the topics covered in the textbook used during the course and questions that relate to the specific scientific field in which the doctoral students are trained. A mandatory part of the oral part of the exam is a presentation of the doctoral students with a focus on education, scientific interests and achievements.

Advanced: The written part of the exam consists of 2 parts:

- a commentary on given statistical data or facts related to a certain social or scientific problem or a summary of a short article;
- an academic essay with a scientific problem with a volume of 250 - 300 words.

The oral part of the exam is conducted in the form of an interview, in which the examiners ask questions related to the topics affecting the scientific interests and future dissertation work of the doctoral students.

## COMPULSORY COURSE IN THE THEMATIC AREA OF THE DISSERTATION

### WAVEGUIDE NONLINEAR OPTICS

**Annotation:**

The course covers fundamental phenomena in the physics of wave processes, related to the wave nature of light.

In the first part, the electromagnetic theory of light is presented based on Maxwell's equations. The main properties of plane electromagnetic waves propagating in an isotropic medium are described. Topics related to the polarization and energy of electromagnetic waves are addressed. The basic laws of reflection and refraction of light at the boundary between two media are derived. The wave equation describing the propagation of a laser pulse (a pulse with finite aperture and temporal duration) in a bulk isotropic medium is examined.

The second part of the course is dedicated to the propagation of light in optical waveguide structures. The formation of waveguide modes, typical for each waveguide, is described, and their main properties are shown. The influence of group velocity dispersion on the propagation of optical pulses and their dispersive broadening is analyzed.

The third part focuses on nonlinear optical effects and their impact on optical pulse propagation. Kerr nonlinearity is examined, along with the resulting self-phase modulation and changes in the pulse spectrum, such as chirping. The nonlinear Schrödinger equation, which describes pulse propagation in nonlinear waveguide media, is derived. The soliton regime of optical pulse propagation is discussed. Attention is also given to nonlinear parametric processes and stimulated processes at the vibrational and acoustic frequencies of the medium.

The final part is devoted to the use of optical waveguides as a transmission medium in modern communication systems. Their parameters and transmission characteristics are considered.

### MAGNETIC MATERIALS AND METHODS OF CHARACTERIZATION

**Annotation:**

The program includes material on the fundamental experimental facts, key quantitative relationships between physical quantities, and widely accepted models used to explain the main phenomena in the field of magnetism.

The practical sessions are aimed at familiarizing PhD students with the basic experimental methods in magnetism, and in particular, with techniques for studying the fundamental magnetic properties of materials.

The objective of the course is for PhD students to acquire knowledge of the fundamental concepts in the field of magnetism and magnetic materials, as well as the methods used to investigate them. The results of acquiring this knowledge become evident in the subsequent stages of the educational process.

## PLASMONICS

**Annotation:**

Plasmonics (or nanoplasmonics) is a relatively young but vibrant field of science and core branch of nanophotonics. It studies the physical phenomena arising from the interaction of light with metallic or heavily doped structures. The focus of this program is on the study of electronic oscillations in metallic nanostructures and nanoparticles. A plasmon is a quasiparticle that describes the collective oscillations of free electrons under the influence of the electric field created by the positive ions forming the material. The interactions of plasmons with an external electromagnetic field will be examined and how this leads to the appearance of plasmon-polariton waves. The emphasis will be on how, unlike conventional electromagnetic waves, plasmon-polariton waves exhibit a strong spatial localization of optical frequencies, which potentially enables the development of optoelectronic devices and sensors. When these oscillations propagate along a metal surface, the phenomenon is known as surface plasmon resonance, or localized surface plasmon resonance in the case of a nanoparticle. Special attention will be paid to how surface plasmons have the unique capacity to confine light at the nanoscale. Moreover, surface plasmons are highly sensitive to the environment and to the properties of the materials on which they propagate. PhD students will gain knowledge about how surface plasmon resonances can be controlled by adjusting the size, shape, periodicity, and nature of the materials involved and how technological advancements now allow the fabrication of new systems through precise control of all these parameters. The course explores the application of optical methods in condensed matter physics and covers the fundamentals of light interaction with electron oscillations in matter, as well as methods for describing the plasmonic properties of individual metal nanoparticles and nanoparticle arrays.

# ELECTIVE COURSES

## NONLINEAR OPTICS

**Annotation:**

The course addresses the fundamental issues related to the propagation of electromagnetic waves in bulk and waveguide media, as well as the main nonlinear processes that arise during such propagation.

In studying the interaction of electromagnetic waves with matter, both linear and nonlinear polarization are taken into account. Based on Maxwell’s equations, the fundamental equations of nonlinear optics are derived, including those describing the propagation of optical beams with finite aperture and ultrashort pulses.

The course also presents the basic optical materials, their properties, characteristics, and methods for their investigation. The specific features of nonlinear crystals for various spectral regions—ultraviolet, visible, and near-infrared—are described in detail. The key nonlinear processes responsible for frequency conversion of laser radiation are covered, including second harmonic generation, three- and four-wave parametric mixing. The conditions and methods for achieving phase matching are also discussed.

Special attention is given to the interaction of laser radiation with condensed matter and its scattering on the acoustic and vibrational oscillations of the medium, which leads to Mandelstam–Brillouin and Raman light scattering. The course also addresses self-action effects of laser radiation, such as self-focusing.

In addition, the course examines nonlinear processes arising from the propagation of laser radiation in optical waveguides.

Waveguides are unique in their ability to maintain high energy densities over long distances—up to several kilometers—leading to extremely efficient nonlinear interactions. Planar and cylindrical waveguide structures are considered, beginning with ray-optics-based analysis, followed by wave theory. The modal composition of the guided light is described.

The course explores the specific features of various nonlinear processes and additional opportunities for achieving phase matching through the propagation of light in different waveguide modes. Particular attention is given to the phenomenon of self-phase modulation and its application in laser pulse compression. The course concludes with a description of optical soliton propagation in the region of negative group velocity dispersion in silica optical fibers.

## INTERACTION OF CHARGED PARTICLES WITH MATTER

**Annotation:**

The course is closely related to the preceding courses in physics and mathematics, as well as to the specialized courses within the doctoral training program.

The content is selected in accordance with the allocated number of academic hours, and within a reasonable balance between theoretical and applied material, priority is given to the applied aspects of the topics covered. From a methodological perspective, the material is divided into sections following a logical sequence—from the physical foundations of atomic and quantum mechanical theory, through the atomic nucleus and its radioactive decay, to the interaction of charged particles with matter, and more. The course also includes sections related to the applications of nuclear physics methods in various scientific and practical fields. The objective of the course is to provide fundamental knowledge about the interactions of charged particles with matter, the main modern methods of nuclear spectroscopy, experimental setup, techniques, and initial data processing in nuclear physics experiments, as well as to develop practical skills for their application.

The course aims to foster a way of thinking that perceives natural phenomena as interconnected and interdependent processes within a hierarchical structure. The results of mastering the course content and fully developing the related skills will manifest later in the doctoral students’ academic training and future professional practice.

## MODERN INSTRUMENTAL METHODS

**Annotation:**

The course covers the fundamental stages of analysis using instrumental methods. It includes: absolute and relative methods, calibration, and basic metrological characteristics of instrumental methods; principles of atomic spectral, electrochemical, and radiochemical methods for analysis. The second part covers basic methods of molecular spectroscopy — ultraviolet and visible, luminescent, infrared, and Raman spectroscopy. It also addresses magnetic-chemical methods for analysis — mass spectrometry, nuclear magnetic resonance, and electron paramagnetic resonance, as well as chromatographic methods for separation and determination.

Course objective: The course aims to familiarize students with the basic principles of the most commonly used instrumental methods for analyzing the elemental composition of various objects. The physical basis, advantages, and limitations of the discussed analytical methods are examined. The goal is for students to acquire the knowledge necessary to select an appropriate analytical method to solve a given analytical problem. Special attention is given to the specifics of trace element analysis.

## VIBRATIONAL SPECTROSCOPY

**Annotation:**

The curriculum for the course Vibrational Spectroscopy includes lectures covering some of the fundamental instrumental methods of molecular spectroscopy used to characterize organic and inorganic compounds. The main characteristic bands of different classes of organic compounds are examined, enabling the use of the studied methods for their characterization in solving specific tasks and problems. The aim of the course is for doctoral students to acquire systematic knowledge and skills for identifying and characterizing the studied compounds through molecular spectroscopy methods (UV, IR, Raman) and for the correct interpretation of the obtained results.

## METHODS FOR PROCESSING EXPERIMENTAL DATA

**Annotation:**

I. Processing of Deterministic Experimental Data

Classical interpolation problem. Lagrange interpolation formula. Interpolation error. Formula and estimation of the error.

Divided differences. Newton's interpolation formula with divided differences.

Least squares approximations. Method of least squares.

Numerical differentiation.

II. Processing of Probabilistic and Statistical Experimental Data

Basic concepts from probability theory. Classical probability. Conditional probability. Independent events.

Probability of the sum of events. Law of total probability. Bayes' theorem.

Discrete and continuous random variables. Numerical characteristics of random variables. Some common distributions.

Introduction to mathematical statistics. Samples. Empirical distribution function. Statistical series. Histogram.

Basic numerical characteristics in mathematical statistics.

Point estimates. Methods for obtaining estimates. Method of moments. Maximum likelihood method.

Hypothesis testing. Criteria.

Smoothing of empirical data. Correlation and regression.

## DIGITAL SIGNAL PROCESSING

**Annotation:**

Digital signals.
Digital systems.
Continuous frequency transforms. Fourier transform. Z-transform.
Z-transforms of elementary functions.
Properties of the Z-transform and Fourier transform.
Discrete Fourier transform. Fourier transform of periodic signals.
Fast Fourier transform.
Circular convolution. Discrete cosine transform.
Ideal low-pass filter. Window functions.
Digital filters with finite impulse response (FIR).

Digital filters with infinite impulse response (IIR).
Digital processing of analog signals via Fourier transform. Sampling theorem.
Analog-to-digital converter. Digital-to-analog converter.
Multirate digital signal processing.
Two-band quadrature mirror filters.
Multiscale approximation of bandpass filters.
Fast Fourier transform as bandpass filters (Filter banks).
Modulated transforms with overlap.
Statistics of stochastic processes.
Stationary processes.
Linear time-invariant systems with stochastic inputs. Power spectral density. Noise.

## FUNDAMENTALS OF MATHEMATICAL MODELING

**Annotation:**

The course “Fundamentals of Mathematical Modeling” involves the study of the basic concepts and methods of mathematical modeling, as well as their application to the description of important physical processes and phenomena.

When investigating complex objects and phenomena, it is not possible to account for all factors. Some of these factors turn out to be more important, while others can be neglected. In this process, the model of the studied object plays an important role. This is a mentally representable or materially realizable system capable of depicting or reproducing the object under study, whose examination provides new information about it.

Mathematical models are formulated using equations, which are solved analytically or numerically with the help of algorithms and computer programs. The course will cover examples and include assignments for independent solving, including the use of software packages such as Matlab.

Studying this course requires basic knowledge of mathematical analysis, numerical methods, and differential equations.