COURSE SYLLABUS

1. Data about the program

1.1 Higher education institution	Babeş-Bolyai University
1.2 Faculty	Faculty of Physics
1.3 Doctoral school	Physics
1.4 Field of study	Physics
1.5 Study cycle	Doctorate
1.6 Study program / Qualification	Doctoral training / PhD in Physics

2. Course data

2.1 Name of discipline	Advanced methods in the study of the condensed state						
2.2 Teacher responsible for lectures	Prof. dr. Romulus Tetean, Prof. dr. Viorel Pop, Prof. dr. Iosif Deac, CSII dr. Diana Benea, Prof. dr. Ioan Grosu						
2.3 Teacher responsible for seminars	Prof. dr. Romulus Tetean, Prof. dr. Viorel Pop, Prof. dr. Iosif Deac, CSII dr. Diana Benea, Prof. dr. Ioan Grosu						
2.4 Year of study	1	2.5 Semester	1	2.6. Type of evaluation	Ex	2.7 Course framework	DS

3. Estimated total time of teaching activities (hours per semester)

3.1 Hours per week	3	Out of which: 3.2 Lectures	2	3.3 Seminars / Laboratory classes	1
3.4 Total hours in the curriculum	36	Out of which: 3.5 Lectures	24	3.6 Seminars / Laboratory classes	12
Allocation of study time:					
Study supported by textbooks, other course materials, recommended bibliography and personal student notes					36
Additional learning activities in the library, on specialized online platforms and in the field					36
Preparation of seminars / laboratory classes, topics, papers, portfolios and essays					50
Tutoring					12
Examinations					10
Other activities: -					–

3.7 Individual study (total hours)	144
3.8 Total hours per semester	180
3.9 Number of credits	10

4. Preconditions (where applicable)

4.1 Curriculum	•
4.2 Competences	•

5. Conditions (where applicable)

5.1 Conducting lectures	• Adequate room, blackboard, video projector, computer, dedicated software
5.2 Conducting seminars / laboratory classes	• Adequate room, blackboard, video projector, internet access, dedicated software

6. Specific competences acquired

Professional competences	• The use of advanced knowledge of physics, mathematics and chemistry of solids for studies in condensed state physics and materials science. Ability to analyze and synthesize physical data, the ability to model complex phenomena. • Capitalization of the physical foundations, methods and tools of solid-state physics and materials science for specific production, expertise and monitoring activities. Acquiring a multi- and interdisciplinary way of thinking. • Planning and conducting experiments to assess uncertainty and interpretation of results. Use of laboratory equipment for basic research, equipment and industrial laboratories for conducting research experiments. Planning and implementation of independent experiments or experimental investigations and evaluation of results. • Communicating complex scientific ideas, conclusions or results of a scientific experiment. The ability to obtain and argue scientific results, the ability to produce scientific papers and to liaise with the editorial board of scientific journals in the field. Identify and properly use the main laws and physical principles in a given context.
Transversal competences	• Performing professional tasks efficiently and responsibly in compliance with the legislation and deontology specific to the field under qualified assistance. Responsible execution of professional duties regarding decision-making based on self-assessment. • Effective work in multidisciplinary teams on various hierarchical levels. Identifying roles and responsibilities in a team and applying effective relationship and work techniques within the team, based on dialogue, positive attitude, mutual respect, diversity and multiculturalism as well as a continuous improvement of the activity. • Efficient use of information sources and assisted communication and training resources, both in Romanian and in a language of international circulation. Identifying opportunities for continuous training and efficient use of learning resources and techniques for their own development and adaptation to the requirements of the labor market.

7. Course objectives (based on the acquired competencies grid)

7.1 The general objective of the course	• Acquiring theoretical and experimental notions on the use of advanced methods in the study of the condensed state
7.2 Specific objectives	Acquiring the notions related to: - Determining the crystal structure of different classes of materials, both massive and nanostructured. - Determination of thermal properties of materials. - Determining the magnetic structures, the respective magnetic moments, determining the local magnetic properties included in samples with phase mixture. - Analysis of surface defects. - Knowledge of the specific properties of surfaces and their role in practical applications. - Studying the effect of intense magnetic fields on electrical conductivity; magnetoresistance measurement - Determination of Fermi surface (by de Haas van Alphen effect) and electronic structure (XPS and ARPES), - Measurement of magnetic susceptibility in alternating current for determining the dynamic magnetic properties, of the phase transformations, using the nonlinear components of the complex susceptibility. - Writing in the second quantification of a series of operators and groups of

	operators. - Using the method of the equation of motion to determine the energy spectrum, in the case of multi-particle systems with interactions. - Determination of properties of many particle systems, in Hartree and Hartree-Fock approximations. - Choosing the type of measurements taking into account the specificity and sensitivity of the method. - Processing and interpretation of experimental results. - Valorization of data obtained through publications. - Analysis of possible technological applications. - Determination of electrical / magnetic properties of solids starting from their crystalline structure. - Determination of spectroscopic properties of solids starting from their crystalline structure - Establishing correlations between theoretical calculations and experimental data. - Knowledge and use of research laboratory equipment for conducting experiments in the field of magnetic nanomaterials.

8. Content

8.1 Lectures	Teaching methods	Comments
Determination of the crystal structure with the help of X-rays: X-ray diffraction. X-ray sources. High angle diffraction. Crystalline and non-crystalline materials, respectively. Particular aspects of small dimensional systems.	Presentation, discussion, case studies, exercises	3 h
X-ray absorption spectroscopy. XANES, EXAFS. EXAFS signal extraction. Electron diffraction. Neutron diffraction		2h
Magnetic nanostructures: specific magnetic properties of magnetic systems with dimensions comparable to the characteristic lengths in magnetism (domain wall, exchange length, etc.)		3 h
Production, characterizing and applications of magnetic nanostructures.		2h
AC magnetic susceptibility and the magnetic properties of solids. The principles of the method. Implementation. Calibration. Characterization of the magnetic order of solids by ac susceptibility measurements. Frequency and magnetic field dependence of the ac susceptibility. Non- linear ac susceptibility. Ac susceptibility study of superconducting materials.		2h
Experimental techniques and principles of structure-related phenomena. Experimental study of the Fermi surface in metals. Electrons in high magnetic fields. Quantum oscillation and the topology of Fermi surface. De Haas-van Alphen Effect. Photoemission spectroscopy. X-ray photoelectron spectroscopy (XPS). Angle Resolved Photo Emission Spectroscopy (ARPES).		2h

Transport phenomena in high magnetic fields (Focus on colossal magnetoresistance). Magnetoresistance. Introductory remarks. Ordinary MR, AMR, Giant MR, Tunel MR, CMR. Colossal Magnetoresistance. Mixed valence manganites. Phase diagrams. Electrons' interaction. Double exchange interaction. Jahn-Teller distortion. Polarons. Charge/orbital ordering. Phase separation. Examples. Cryostats for magneto-transport measurements.		1h
Introduction.Density functional theory. Principles. Kohn-Sham equations. Local density approximation. Electronic structure of solids. One electron model. Multiple scattering theory (Korringa-Kohn-Rostocker). Green functions. Calculation of observables.		2h
Ab initio methods for description of the magnetic/spectroscopic properties of solids: magnetic Compton scattering, positron annihilation, X ray magnetic dichroism, XPS spectroscopy, Heisenberg model for exchange coupling.		2h
Second quantization, fermions and bosons. Operators in the second quantization, biparticle interaction.		3h
Representatives. The method of the equation of motion. Hartree and Hartree-Fock approximations		2h
8.2 Seminars / laboratory classes	Teaching methods	Comments
Case studies prepared with the doctoral students, based on their individual doctoral research topics	Presentation, modelling, discussion, debate, exercises	
Particular aspects of X-ray diffraction in small dimensional systems.		2 h
New magnetic behaviors at the nanometer level		2h
Interpretation of electronic structures in solids; Interpretation of the results of complex susceptibility measurements		2h
Band structure self-consistent calculations for selected systems. Density of states. Dispersion relation and Bloch spectral functions. Calculation of the valence-band photoemission spectra. Calculation of the exchange-coupling parameters for several magnetic materials. Stability of spin structures.		3h
Operators in the second quantization, biparticle interaction.		3h

Bibliography:

1. C. Kittel, Introduction to Solid State Physics (7ed., Wiley, 1996)
2. N. W. Ashcroft, N. D. Mermin, *Solid State Physics*, Saunders, 1976
3. U. Mizutani, Introduction to the Electron Theory of Metals,Cambridge University Press 2001.
4. E.Burzo, "Fizica Fenomenelor Magnetice" vol. 1-3, Editura Academiei Române 198-1987, 1255 pag.
5. H. Alloul, Introduction to the Physics of Electrons in Solids, Springer-Verlag Berlin Heidelberg 2

6. Z. L. Wang (editor), Characteriyation of Nanophase Materials, Ed. Wiley-VCH, Weinheim, New York, Chichester, Brisbane, Singapore, Toronto, 2000
7. F.J.Himpsel, J.E.Ortega, G.J.Mankey, R.F.Willis, Magnetic nanostructures, Advances in Phys, Vol.47, Nr. 4, 511-597, 1998
8. Z.I.Wang, Elastic and Inelastic Scattering in Electron Diffraction and Imaging, Plenum Pub.Co, New York, 1995
9. Handbook of Magnetism and Advanced magnetic materials, Willey : volume 1: Fundamentals and Theory; volume 2: Micromagnetism; volume 3: Novel Techniques for Characterizing and Preparing Samples; volume 4: Novel Materials; volume 5: Spintronics and Magnetoelectronics.
10. Blundel S., Magnetism in condens matter, Oxford University Press, New York 2001.
11. Coey J.M.D., Magnetism and Magnetic Materials, Cambridge University Press, New York 2010.
12. J. M. D. Coey, M. Viret, and S. von Molnar, Mixed-valence manganites, Adv. Phys. 48, 167 (1999)
13. E. Dagotto, Nanoscale Phase Separation and Colossal Magnetoresistance, Springer, 2003
14. D. C. Tsui, de Haas—van Alphen Effect and Electronic Band Structure of Nickel, Phys. Rev. **164**, 669 – Published 10 December 1967
15. Andrea Damascelli, Probing the Electronic Structure of Complex Systems by ARPES, Physica Scripta. Vol. T109, 61–74, 2004
16. F. Gömöry, Characterization of High-Temperature Superconductors by AC Susceptibility Measurements, Superconductor Science and Technology 10(8):523 · January 1999.
17. A.H. Morrish, The Physical Principles of Magnetism, John Wiley & Sons (New York, 1965).
    SPRKKR manual – H. Ebert , LMU Munich 2017 (http://ebert.cup.uni-muenchen.de)
18. Structura electronica de benzi cu aplicatii in solide, D. Benea 2014 (lucrari de laborator).
19. P. Strange, Relativistic Quantum Mechanics (Cambridge University Press, 1998).
20. H. Ebert, J. Minar, and D. Kodderitzsch, Rep. Prog. Phys. 74, 096501 (2011).
21. A. I. Liechtenstein,M. I. Katsnelson, V. P. Antropov, and V. A. Gubanov, J.Magn.Magn. Materials 67, 65 (1987).
22. Introduction to photoemission spectroscopy, M. Singh, Univ. Wuerzburg, https://www.cond-mat.de/events/correl14/manuscripts/sing.pdf
23. D. Pines, P. Nozieres, “The Theory of Quantum Liquids”, vol.I, Benjamin, New York, (1966)
24. I.Tifrea, I.Grosu, M.Crisan, “Metode cuantice pentru studiul sistemelor cu multe particule. Aplicatii la sisteme fermionice si bosonice”, Presa Universitara Clujeana, (2005)
25. I.Grosu, I.Tifrea, “Teoria materiei condensate. Probleme”, Casa Cartii de Stiinta, Cluj, (2006)

9. Aligning the contents of the discipline with the expectations of the epistemic community representatives, professional associations and standard employers operating in the program field

- The content of the discipline is in accordance with what is studied in other university centers in the country and abroad. In order to adapt to the requirements imposed by the labor market, the content of the discipline was harmonized with the requirements imposed by the specifics of research institutes, the economy and the labor market.

10. Examination

Activity type	10.1 Evaluation criteria	10.2 Evaluation methods	10.3 Weight in the final grade
10.4 Lectures	Assessment of knowledge	Written exam	40 %
	Assessment of knowledge	Ongoing tests	20 %
10.5 Seminars / laboratory classes	Activity during seminars	Discussions, answers to questions	20 %
	Assessment of knowledge	Written exam	20 %
10.6 Minimum performance standard			
• Choosing an experimental method for a certain kind of characterization.			

Date of issue

Signature of the teacher responsible for lectures	Signature of the teacher responsible for seminars
Prof. dr. Romulus Tetean	Prof. dr. Romulus Tetean

Signature of the teacher responsible for lectures	Signature of the teacher responsible for lectures
Prof. dr. Viorel Pop	Prof. dr. Viorel Pop

Signature of the teacher responsible for lectures	Signature of the teacher responsible for lectures
Prof. dr. Iosif Deac	Prof. dr. Iosif Deac

Signature of the teacher responsible for lectures	Signature of the teacher responsible for seminars
CS II dr. Diana Benea	CS II dr. Diana Benea

Signature of the teacher responsible for lectures	Signature of the teacher responsible for seminars
Prof. dr. Ioan Grosu	Prof. dr. Ioan Grosu

Date of approval by the doctoral school council	Signature of the doctoral school director
08.10.2021	