SYLLABUS 2018/2019

Level of study	Master's Course

Course title in Ukraine	**Термодинаміка та статистична фізика**		
Course title in English	**Thermodynamics and Statistical Physics**		
Course code		ECTS credits	5
Lecturer(s)	Prof. dr hab. Ryszard J. Radwański sfradwan@up.krakow.pl Dr Renata Bujakiewicz-Korońska, rbk@up.krakow.pl		

Course objectives (learning outcomes)	This course aims to get students acquainted with knowledge of laws, issues and concepts of statistical physics in description of systems with enormous number of particles. . The course concentrates on description of thermodynamical properties revealing correlations between macroscopic parameters and atomic-scale parameters. The lecture is completed with the use of derived theoretical formulas to real crystalline solids.

Knowledge	Knowledge of the algebra and mathematical analysis.
Skills	Ability to differentiate, integrate, solve ordinary and partial differential equations. Ability to calculate basic characteristics of the matter.
Courses completed	Mathematical analysis and higher algebra. Basic course of thermodynamics.

Learning effects:

	Learning effects of the course	Relation of the learning effects to the specialization
Knowledge	**W01** A student gets knowledge on construction of matter containing enormous number of particles. **W02** A student knows **Classical Thermodynamics and Fundamentals of Statistical Mechanics** **W03** A student knows description of **Classical gases** and knows the Maxwell model for the velocity distribution. **W04 A student knows the Boltzmann distribution - the effect of temperature on population of higher energy states** **W05**. A student knows the existence of discrete energy states in solids associated with transition-metal atoms (Ce^{3+}, Er^{3+},Eu) and their influence on the thermodynamical properties of solids **W06** A student knows description of **Quantum Gases -** the Fermi-Dirac distribution for electrons in metals and the Bose-Einstein distribution. **W07**: A student knows energy states of the quantum harmonic oscylator and its applicability in the Debye-Einstein model of solids. **W08**: A student knows laws of black-body radiation in connection to the Planck quantum hypothesis. **W09** A student knows description of **Phase Transitions** **W10** A student knows description of **magnetic systems** in statistical physics formalism.	W01 – W09

Skills	Learning effects of the course	Relation of the learning effects to the specialization
	U01: A student can use of the ideal-gas equation for practical calculations. **U02**: A student can derive the ideal-gas equation from the statistical mechanics. **U03**: A student understands thermodynamic laws and microscopic definition of temperature. **U04** A student applies thermodynamic laws, thermodynamics functions and relations in description of physical systems. **U05** A student constructs Microcanonical Ensemble, Canonical Ensemble and can calculate populations of different energy states using the Boltzmann-Maxwell distribution (2-level system). **U06**: can discuss the Maxwell distribution of velocities of particles in the ideal gas and in real gases. **U07** A student can derive the discrete quantum low-energy energy states for paramagnetic ions (Ce^{3+}, Pr^{3+}, Er^{3+}, Eu^{3+}, ..). **U08** A student can discuss the effect of discrete energy states on low- and room-temperature properties ($CeMg_3$, $ErNi_5$) revealing relations between microscopic atomic-scale statistical properties and macroscopic electronic and magnetic properties. **U09**: A student can describe the quantum harmonic oscylator and its energy states and can use in practice the formalism of the Einstein and Debye Model of vibrations in a Solid. **U10**: A student can describe the black-body radiation and the Planck hypothesis of the quantum radiation. **U11** A student applies the Fermi-Dirac Distribution in description of the electron gas in metals. **U12** A student can discuss the discrete energy states for paramagnetic ions used in lasers and in optoelectronics. **U13** A student can study properties of systems with phase transitions, starting from water.	U01 – U07 U01 – U07

Social skills	Learning effects of the course	Relation of the learning effects to the specialization
	K01. A student has the creativity and the ability to conceptual thinking. **K02** A student is able to present and justify the personal point of view. **K03** A student is able to use the required knowledge and skills for the communication with the scientific community. **K04** A student is aimed to expand personal knowledge and skills. **K05** A student has the physical scientific erudition.	K01 – K06

Course organization:

Form of classes	Lecture (W)	Group-exercises					
		A (large group)	K (small group)	L (Lab)	S (Seminar)	P (Project)	E (Exam)
Contact hours	30		30				1
Semester	3						
Language	English						

Teaching methods:

The course consists of open for discussion and questions lectures and classes.
In-class exercises are designed to probe knowledge with emphasis on how well students have understood the underlying topics of the course.

Assessment methods:

	E – learning	Didactic games	Classes in schools	Field classes	Laboratory tasks	Individual project	Group project	Discussion participation	Student's presentation	Written assignment (essay)	Oral exam	Written exam	Other
W01-W02								x	x		x		
W03-W04								x	x		x		
W05-W06								x	x		x		
W07-W08								x	x		x		
W09								x	x		x		
W10								x	x		x		
U01-U03						x	x	x	x		x		
U04-U05						x	x	x	x		x		
U06-U08						x	x	x	x		x		
U09-U11						x	x	x	x		x		
U12								x	x		x		
U13								x	x		x		
K01							x	x	x		x		
K02							x	x	x		x		
K03							x	x	x		x		
K04							x	x	x		x		
K05							x	x			x		

Assessment criteria:

Grades	The grading scale will be as follows: 90 – 100 % - **A** including **A**- **excellent** (eq. in Ukraine:відмінно (very good)) 82–89 % : **B** including **B** – **very good** (eq. in Ukraine: добре (good)) 74–81 %: **C** including **C** - **good** (eq. in Ukraine: добре (good)) 64–73 %: **D** including **D** – **satisfactory** (eq. in Ukraine: задовільно (satisfactory)) 60–63 %: **E** including **E** – **acceptable** (eq. in Ukraine: задовільно (satisfactory)) < 59 %: **F** **failded** (eq. in Ukraine: незадовільно (unsatisfactory))
Criteria	**A.** A student knows all terms and concepts mentioned in W1-W10, U1- U13 and K1-K5. A student can work without any assistances, his/her knowledge's are creative and easily applied to decision of specific problem. **B**. A student knows all terms and concepts mentioned in W1-W10, U1- U13 and K1-K5, yet needs a little help when decision of specific problem. **C.** A student knows all terms and concepts mentioned in W1-W10, U1- U13 and K1-K5, however needs a help when decision of specific problem. **D.** A student knows the most of terms and concepts mentioned in W1-W10, U1-U13 and K1-K5 and has difficulty in decision of specific problem. **E.** A student knows only several terms and concepts mentioned in W1-W10, and can solve only a simple problem. **F**. A student does not know most of terms and concepts mentioned in W1-W13, U1-U13 and K1-K5, he/she did not reach the satisfactory level of knowledge this course.

Course content (topics list):

Topics	1. Fundamentals of Statistical Physics: Concepts of the statistical physics - Statistical Physics as consistent mathematical theory for the description of great-number particle systems and of phenomenological thermodynamic laws. 2. The ideal-gas equation and its use. Mean quadratic velocity of particles and pressure of the ideal gas from statistical mechanics. Microscopic definition of temperature as the kinetic energy. 3. Microcanonical ensemble and calculated examples with the use of combinatorical methods calculations of the most probable distribution. Microstates and the macrostate. 4. Equilibrium state. Statistical probability of macrostates. Entropy (Boltzmann definition). Real gases. Equipartition energy. 5. Mathematical methods of statistical physics - Stirling's formula, Lagrange multipliers; Boltzmann distribution. Maxwell distribution of velocities of particles in the ideal gas. 6. Canonical ensemble and its applications: Boltzmann distribution and calculated examples on occupancy over discrete energy states at different temperatures; 2-level system. 7. Calculations of population of energy states of multi-electron atom (Ce^{3+}, Pr^{3+}) in different temperatures - exemplary use of the Boltzmann distribution. 8. Gas of electrons in metals (Na, Cu). Calculations of different characteristics of the electron gas for different metals (density, the Fermi energy). Quantum statistics. Fermi-Dirac distribution. 9. Classical and Quantum harmonic oscylator and its allowed energy states. Experimental temperature dependence of the specific heat c(T) of solids. The Einstein and Debye model of c(T) as associated with Vibrations in a Solid. Bose-Einstein Distribution and Bose-Einstein condensation. 10. The black-body radiation - History of the black-body radiation. The Planck distribution and quantum effects in the high-energy region. 11. Stefan-Boltzmann law and Wien law. Temperature of Sun.

	12. Visible light and the relict radiation. The expansion of the Universe and the Big Bang theory. 13. Laser and optoelectronic materials: rare-earth ions with atomic-like states; two Hund's rules; ground term and multiplet. Effect of the relativistic spin-orbit coupling. Magnetism: spin susceptibility, relations between microscopic statistical properties and macroscopic electronic and magnetic properties ($CeMg_3$, $ErNi_5$,..). 14. Phase Transitions: Water and its characteristics, phase diagram of water, anomalous properties of water; calculations of the heat and the entropy during liquidization and evaporation. van der Waals equation; Phase Equilibrium; Maxwell Construction; Grand Canonical Ensemble, Chemical Potential; Landau Theory for second-order phase transition (magnetic transition). 15. Summary - Statistical physics provides very consistent theoretical explanations for observed thermodynamical properties; Spontaneous symmetry breaking as realization of the Third thermodynamic law in Nature. Removal of the degeneracy and formation of a singlet state by interactions in crystals as the general rule. 16. Preparation to exam - free discussion on given problems. Finishing Reports.

Literature:

Compulsory reading	1. A. K. Wróblewski, J. A. Zakrzewski, Wstęp do fizyki, vol.1, ch VII, PWN 1984 2. David Tong: Lectures on Statistical Physics (pdf in the Internet) http://www.damtp.cam.ac.uk/user/tong/statphys.html 3 D. Halliday, R. Resnick, Podstawy fizyki, vol.2 chapter 21, PWN 2003 4. P. K. Das, Magnetic properties of $CeMg_3$ - Phys. Rev. B 83 (2011) 134416; (in the internet: arXiv:10115414). 5. R. J. Radwański, et al., Physica B 319 (2002) 78. (in English) 6. R. J. Radwański, Acta Physica 3 (2007) 1 (in English).
Recommended reading	1. K. Huang, Introduction to Statistical Physics 2. L. D. Landau, J. M. Lifshitz: Statistical Physics

Estimation of the total working time of students:

Contact hours	Lectures	60
	Classes in small group	
	Other (consultation, meetings)	10
Students' work hours (without the lecturer)	Reading books and preparation for the lectures	10
	Preparation to the seminar	10
	Preparation of an individual presentation	10
	Preparation to the exam	25
Total works' hours		125
ECTS credits 1 ECTS = 25 h		5