Ministry of Education and Science of Ukraine

V. N. Karazin Kharkiv National University

Educational and Scientific Institute

of Computer Physics and Energetics

APPROVE

Deputy Chairman of the admissions

Committee acting rector of V.N. Karazin

Kharkiv National University

_____ Oleksandr HOLOVKO

“___”_____2024

PROGRAM

entrance exam

"Thermodynamics and molecular physics"

specialty: 105 "Applied physics and nanomaterials"

(educational level "Master")

based on NRK6

Kharkiv 2024

Part 1.

Molecular physics and principles of statistical physics

The subject of molecular physics. Masses of atoms and molecules. Amount of substance. Aggregate state of matter The ideal gas model. Ideal gas laws. Barometric formula.

Random events and quantities. Probability. Gauss distribution. Macroscopic and microscopic state of the system. Postulate of equal probability of microstates. Ergodic hypothesis.

Maxwell's distribution. Distribution of molecules by velocities. Derivation of the Maxwell distribution. Characteristic speeds of molecules. The frequency of collisions of molecules against the wall. The number of molecules in in different sections of the Maxwell distribution. Experimental verification of the Maxwell distribution.

Fluctuations. Relative magnitude of fluctuations.

Statistical weight. Entropy. Boltzmann formula for entropy. Nernst's theorem.

The concept of ensembles. Gibbs ensemble, ergodic hypothesis, Gibbs, Fermi-Dirac, Bose-Einstein, Maxwell-Boltzmann distributions. The principle of detailed balance.

Kinematic characteristics of molecular motion. Cross section. Mean free path. Experimental determination of the cross section of collisions. The frequency of collisions.

Pressure and temperature. The basic equation of the kinetic theory of gases. Pressure measurement. Thermometers. International practical temperature scale. Absolute zero temperatures.

Boltzmann distribution. Justification of the Boltzmann distribution. A mixture of gases in a vessel. The relationship between the Maxwell and Boltzmann distributions. Planetary atmospheres. Experimental testing the Boltzmann distribution.

Distribution of energy by degrees of freedom and Brownian motion. Theorem on equal distribution of kinetic energy by degrees of freedom. Brownian motion and its description. Rotary Brownian motion. Experimental determination of the Boltzmann constant.

Gases with intermolecular interaction and liquids. Forces of intermolecular interaction. Ionic interaction. Covalent bond. Van der Waals forces. The structure of liquids.

Part 2.

Thermodynamics

The first principle of thermodynamics. Work. Warmth. Internal energy. Physical content the first principle. State functions and their complete differentials. Equilibrium and non-equilibrium processes. Reversible and irreversible processes.

Heat capacity. Heat capacity at constant volume. Heat capacity at constant pressure for ideal gas. Robert Mayer's equation.

Processes in ideal gases. Isobaric process. Isochoric process. Isothermal process. Adiabatic process. Polytropic process. Polytrope equation.

The second principle of thermodynamics. Cyclic processes. Cycle operation. The efficiency coefficient. Efficiency coefficient of the Carnot cycle. Carnot's theorem. The second principle thermodynamics in the formulations of Kelvin and Clausius. Equivalence of Kelvin's formulations and Clausius. Refrigeration machine.

Absolute thermodynamic temperature scale. The concept of negative absolute temperature Carnot's second theorem. Clausius inequality. Entropy as a state function. Statistical nature of the second principle of thermodynamics. Entropy change in irreversible processes. Gibb`s paradox. Examples of calculations of entropy and its changes.

Real gases. Deviation of the properties of real gases from the properties of ideal gases. Van der Waals equation, Physical meaning of the constants included in the Van der Waals equation. Van der Waals isotherms. Metastable states. Comparison of conclusions from the van der Waals with experimental data. Internal energy of Van der Waals gas.

The Joule-Thomson effect. Differential and integral effects of Joule - Thomson.

Joule-Thomson effect for van der Waals gas. Liquefaction of gases. Properties of matter at low temperatures.

Phase transitions

Transition from a gaseous state to a liquid state. Experimental isotherms. Critical condition. The region of two-phase states. Saturated couple. The rule of leverage. Phase transitions of the first kind. The Clapeyron-Clausius equation. Crystallization and melting. Sublimation. Phase diagrams.

Polymorphism. Phase transitions of the second kind and their examples.

Part 3

Liquids and surface phenomena, crystals

Free surface energy. Surface tension. The condition of equilibrium at the boundary of two liquids and at the boundary, the liquid is a solid. Pressure under a curved surface. Capillary phenomena.

Evaporation and boiling of liquids. The essence of dynamic equilibrium at the vapor boundary is a liquid. Pressure of saturated vapor near the curved liquid surface. Overheated liquid. Bubble cameras. Supercooled steam. Wilson's camera.

Liquid solutions, their quantitative characteristics. Solubility. Heat of dissolution. Ideal solutions Raoult's law. Henry's Law. Dependence of solubility on temperature. Examples the simplest state diagrams of binary mixtures.

Osmotic pressure. The mechanism of its occurrence. Patterns of osmotic pressure. Manifestation of osmotic pressure.

Basic qualitative information about alloys, solid solutions.

Transport processes

Types of transport processes (thermal conductivity, diffusion, viscosity). Transfer processes in gases and coefficients characterizing the transport processes in them.

Physical phenomena in rarefied gases. Definition of vacuum. Heat transfer, diffusion and friction at small pressures. The main distinguishing features of transport phenomena in solids and liquids in comparison with transport phenomena in gases.

Knowledge assessment criteria

1. The examination ticket will have 35 questions, including:
- 10 questions for 8 points each;
- 10 questions for 6 points each;
- 15 questions for 4 points.

The performance of each ticket task is evaluated by a point according to the table:

N	Points	Evaluation of answers to theoretical questions	Evaluation of the problem solution
1	0	It was found that the student showed academic dishonesty	
2	1-40	Only definitions of terms are provided, which are included in the wording of the question	A short condition is recorded, given diagram or drawing for the problem, written down basic laws on this topic
3	41-99	Only general information is	In addition to item 2, the method is

		provided	specified problem solving
4	100-120	A vague answer is given	In addition to item 3, if the correct choice is made solution method is admittedly coarse errors
5	121-160	The answer is given with minor mistakes	In addition to item 3, with the correct choice the solution method has not been completed
6	161-180	It is correct in general answer with violations of logic presentation of material or without appropriate illustrations or design answers make it difficult to understand the text	The problem has been brought to the correct final point, but formula and the solution is stopped there
7	181-200	Full flawless answer	The correct final formula is obtained, its analysis and dimensionality verification are carried out, numerical value is defined correctly.

2. The general assessment of the professional entrance test on a scale from 100 to 200 points are calculated according to the formula:

Score = (P1 + P2 + P3 + ... + P35),

where P1, P2, P3,… are points for the answers to individual tasks of the examination ticket.

Recommended Books
Basic

1. David Tong. Lectures on Statistical Mechanics. – University of Cambridge, 2012.
2. David Tong. Lectures on Kinetic Theory. – University of Cambridge, 2012.
3. Kardar M. Statistical Physics of Particles. – Cambridge University Press, 2007.
4. Буляндра О.Ф. Технічна термодинаміка: Підручн. для студентів енерг. спец. вищ.
навч. закладів. – К.: Техніка, 2001.
5. M. Abramowitz and I.A. Stegun. Handbook of Mathematical functions: With Formulas, Graphs, and Mathematical Tables, Dover Publications, New York, 1965.
6. W.H. Press, S.A. Teukolsky, W.T. Vetterling, B.P. Flannery. Numerical Recipes. The Art
of Scientific Computing, Cambridge University Press, 2007.

7. E.A. Bender. An introduction to mathematical modelling. Dover Publications, New York,
2000.
8. M. Cross and A.O. Moscardini. Learning the art of mathematical modelling, Ellis Horwood
Ltd., Chichester, 1985.
9. J. France and J.H.M. Thornley. Mathematical models in agriculture. Quantitative Methods
for the Plant, Animal and Ecological Sciences, Cromwell Press, Trowbridge, 2007.
10. P. Turchin. Complex Population Dynamics: A Theoretical/Empirical Synthesis, Princeton University Press, Oxfordshire, 2003.

Information resources on the Internet, video lectures

1. Mehran Kardar. The author's page on the MIT (Massachusetts Institute of Technology) website, which contains video lectures from the courses "Statistical Theory of Particles" and "Statistical Theory fields":
http://www.mit.edu/~kardar/teaching/index.html.
2. David Tong. Author's page on the University of Cambridge website, containing abstracts lectures from the courses "Statistical Physics" and "Kinetic Theory":
http://www.damtp.cam.ac.uk/user/tong/teaching.html.

The program of the entrance exam in the discipline "Thermodynamics and molecular physics" for educational and qualification level "Master" was developed on the basis of current programs in the disciplines "Molecular physics", "Thermodynamics and statistical physics" and "Thermodynamics of energy systems" for the educational and qualification level "Bachelor

Head of the professional certification
commission of SEI CPhE Kostiantyn NEMCHENKO

Approved at the meeting of the admissions committee,
protocol No. __ dated April ___, 2024

Responsible secretary of
the admissions committee Serhii YELTSOV