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Research Article

TEACHING MOLECULAR PHYSICS WITH PROBLEM SOLVING

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ABSTRACT

This article provides with some of the tasks and goals of molecular physics as a subject and shows several examples of problems solved in molecular physics, and methods for solving them. Here are some ways to solve each problem in several ways.

KEYWORDS

Pedagogical work, molecular physics, problems, system of continuous education, educational process, educational activity, set of requirements.

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INTRODUCTION

Molecular physics is a branch of physics that studies the structure and properties of matter based on the so-called molecular-kinetic concepts. The molecular-kinetic theory aims to interpret those properties of bodies that are directly observed in experience as the total result of the action of molecules. At the same time, she uses the statistical method, being interested not in the movement of individual molecules, but only in such average values that characterize the movement of a huge collection of particles. Hence its other name - statistical physics.

MATERIALS AND METHODS

In contrast to the molecular-kinetic theory, thermodynamics studies the macroscopic properties of bodies and natural phenomena without being interested in their macroscopic picture. In this section, the goal was to reveal to students the methods of scientific knowledge of physical phenomena in the framework of studying the foundations of thermodynamics and molecular physics.

When presenting transport phenomena, surface phenomena, phase transitions and some issues of gas dynamics, this section reflects the works of the authors published in the press.

The second law of thermodynamics is presented in two parts - separately for reversible and irreversible processes. The Boltzmann distribution is taken as the basis for the formation of molecular-kinetic representations under the conditions of applicability of classical statistics. This distribution is used to describe interacting particles.

Combining the methods of statistical physics and thermodynamics makes it possible to study both the structure of matter and the processes occurring in gases, liquids and solids.

The selected topics in teaching this subject cover all the basic laws of molecular physics and thermodynamics. They set out the scientific foundations of the course, which are necessary for understanding and explaining physical phenomena and laws, their use in science and technology.

Without knowledge of the basic laws and phenomena related to the course, one cannot begin to study applied and special courses. To this end, the molecular physics course has chosen topics that will help improve the educational process in the future and will be useful in studying other courses in physics.

To do this, students must have the following skills in the course "Molecular Physics":

- Using the laws of an ideal gas and the equation of state of an ideal gas, they must be able to determine the parameters of a particular state of the gas;
- Calculate the number or proportion of moving molecules in a certain speed interval;
- Calculate in various processes the change in the internal energy of the gas, the work done by the gas, the amount of heat received or given away, corresponding to the heat capacities of gases;
- Know the cause of the occurrence of transport phenomena in gases and liquids, know the meaning of the transport coefficients, calculate the mean free path and the value of the transport coefficients;
- Master the basic laws of thermodynamics, the principle of operation of cyclic machines and the

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conditions for obtaining maximum useful work in them;

- Know the cause of the difference between the states of ideal and real gases. Based on the acquired knowledge, determine the parameters of the state of a real gas;
- Know the causes of the surface tension force on the surface of the liquid and the appearance of the capillary phenomenon.

Before studying ready-made solutions to problems in molecular physics, you need to know the theory, so for you I have prepared a brief theory in the section "molecular physics", and examples of solutions in which problems are solved in detail.

Problem 1. Atmospheric pressure at the peak of the tower (height 7134 m) $p_1 = 3{,}8{\cdot}10^4$ Па. Determine air density ρ_1 at the top at temperature $t_1 = -10\ ^\circ\mathrm{C}$, if under normal conditions $(t_0 = 0\ ^\circ\mathrm{C}, p_0 = 10^5\ \text{Па})$, air density $\rho_0 = 1{,}29\ \text{кг/м}^3$.

Solution :

The equation of state for an ideal gas (Clapeyron-Mendeleev equation) can be written in the following form:

$\rho = \dfrac{pM}{RT}$, where $\rho = m/V$ — air density, p — pressure, M — molar mass, T — absolute gas temperature. Given that $\rho_0 = \dfrac{p_0 M}{RT_0}$, $\rho_1 = \dfrac{p_1 M}{RT_1}$, where $T_0 = t_0 + 273^\circ C$, $T_1 = t_1 + 273\ ^\circ\mathrm{C}$, we get the answer: $\rho_1 = \rho_0 \dfrac{p_1 T_0}{p_0 T_1} = 0,51\ \text{кг/м}^3$.

Problem 2. Find the ratio k of the maximum density of an ideal gas to its minimum density, which are achieved in the cyclic process shown in the figure.

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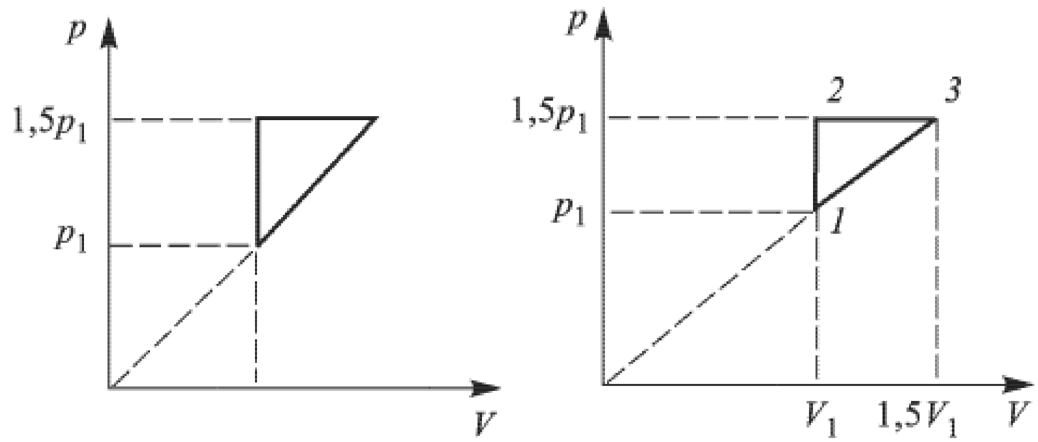


Solution:

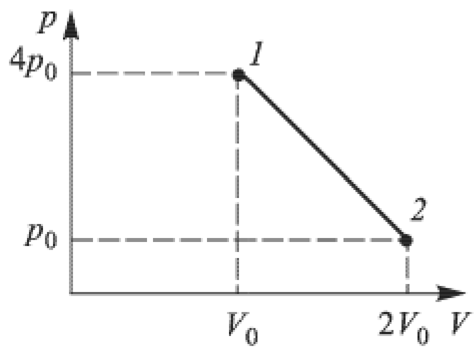
The gas density values at points 1, 2 and 3 (see figure) are equal to:

$$\rho_1 = \frac{p_1 M}{RT_1}, \quad \rho_2 = \frac{p_2 M}{RT_2}, \quad \rho_3 = \frac{p_2 M}{RT_3},$$

where M —molargasmass, T_1, T_2 and T_3 — gas temperature at these points. Since the volume of gas at points 1 and 2 is the same, $p_1/T_1 = p_2/T_2$. Hence, $\rho_2 = \rho_1$ т.e. those. in section 1–2, the gas density does not change. In section 2 - 3, passing at constant pressure $V_1/T_2 = V_3/T_3$, whence it follows that, $T_3 = 1,5T_2$. So $\rho_3 = \frac{1}{1,5}\rho_1$. Thus, the maximum gas density is reached at points 1 and 2, and the minimum at point 3.

Answer: $k = \frac{\rho_1}{\rho_3} = 1,5$.

Problem 3. With an ideal monatomic gas, process 1 - 2 is carried out, shown in the figure. How many times will the average kinetic energy of a gas molecule change in this case?



Solution:

Since the average kinetic energy of a monatomic gas molecule

$$\overline{E_{\kappa}} = \frac{3}{2}kT,$$

the desired energy ratio is equal to the ratio of the absolute temperatures of the gas in states 2 and 1, i.e $\alpha = T_2/T_1$.Writing the Clapeyron-Mendeleev equation for these states, we have:

$$V_0 \cdot 4p_0 = \nu RT_1, \quad 2V_0 \cdot p_0 = \nu RT_2,$$

where ν — moles of gas, R — universal gas constant. From here it is clear that $T_2/T_1 = 1/2$. Hence, $\alpha = \frac{1}{2}$, those. the average kinetic energy of a gas molecule in process 1-2 will decrease by a factor of 2.

Problem 4. A horizontal gas cylinder is divided into three chambers by two fixed pistons. The gas temperature in all chambers is the same and equal to T_1. Gas pressure in the first chamber p_1, volume V_1, in the second p_2, V_2, in the third respectively p_3, V_3. What will be the pressure p, in the chambers after releasing the pistons, allow them to move freely, and make the gas temperature equal to T_2?

Solution:

Let us write the equations of state for gas portions in the chambers:

$$p_1V_1 = \nu_1 RT_1, \quad p_2V_2 = \nu_2 RT_1, \quad p_3V_3 = \nu_3 RT_1.$$

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From here we find the amount of gas in each chamber

$$\nu_1 = \frac{p_1 V_1}{R T_1}, \quad \nu_2 = \frac{p_2 V_2}{R T_1}, \quad \nu_1 = \frac{p_3 V_3}{R T_1}.$$

When the pistons are released, the pressure in all chambers will become the same and the equation of state of the gas will take the form:

$$p(V_1 + V_2 + V_3) = (\nu_1 + \nu_2 + \nu_3) R T_2.$$

Substituting here the above found quantities of gas, we get the answer:

$$p = \frac{(p_1 V_1 + p_2 V_2 + p_3 V_3) T_2}{(V_1 + V_2 + V_3) T_1}.$$

Problem 5. A bottle containing $m_1 = 1$ кг nitrogen, when tested for strength exploded at a temperature $t_1 = 327°\mathrm{C}$. What mass m_2 of hydrogen could be stored in such a cylinder at a temperature $t_2 = 27°\mathrm{C}$, having a fivefold margin of safety? Molar mass of nitrogen $M_1 = 28$ г/моль, Molar mass of hydrogen $M_2 = 2$ г/моль.

Solution:

From the equation of state of nitrogen it follows that the pressure at which the balloon exploded $p_1 = \frac{m_1}{M_1}\frac{RT_1}{V}$, where V - baloon volume. According to the condition, hydrogen can be stored at a pressure $p_2 = p_1/5$. Considering,

$p_2 = \frac{m_2}{M_2}\frac{RT_2}{V}$, . We get the answer: $m_2 = \frac{m_1}{5}\frac{M_2}{M_1}\frac{t_1 + 273\,°\mathrm{C}}{t_2 + 273\,°\mathrm{C}} \approx 28\text{г}.$

CONCLUSION

Therefore, for students to develop the ability to solve physical problems is the "Methodology for solving problems", which is compiled in such a way that it can be used for independent work. All material is divided into several stages. The analysis of the tasks is carried out according to a single scheme, and each chapter can be worked out independently of the others.

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