

TERMODINAMIKANING AYRIM ELEMENTLARI

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НЕКОТОРЫЕ ЭЛЕМЕНТЫ ТЕРМОДИНАМИКИ

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SOME ELEMENTS OF THERMODYNAMICS

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Annotatsiya. Maqolada fizikaning bo'limlaridan biri bo'lgan Termodinamikaning elementlari so'z boradi. Termodinamika oliy ta'lim muassasasi o'quv dasturining predmeti, termodinamikani o'qitish metodikasi fizika o'qituvchisining kasbiy tayyorgarligining asosi, termodinamikani fan sifatida o'qitish metodikasining mazmuni va vazifalari, termodinamika o'qitish metodikasi fanini o'rganish metodikasi kabi qator masalalarida fikr yuritiladi.

Tayanch so'zlar: termodinamika, issiqlik hodisalari, ma'ruza, laboratoriya ishlari, mashg'ulot, o'qitish, fizika metodikasi, metodlar, samaradorlik, baholash, dars.

Аннотация. В статье рассматриваются элементы термодинамики, которая является одним из разделов физики. Термодинамика – предмет учебной программы высшего учебного заведения, методика преподавания термодинамики – основа профессиональной подготовки учителя физики, содержание и задачи методики преподавания термодинамики как науки, методика обучения ведется наука термодинамика.

Ключевые слова: термодинамика, тепловые явления, лекция, лабораторная работа, обучение, преподавание, методика физики, методы, эффективность, оценка, урок.

Abstract. *The article deals with the elements of thermodynamics, which is one of the branches of physics. Thermodynamics is the subject of the curriculum of the higher educational institution, the method of teaching thermodynamics is the basis of the professional training of a physics teacher, the content and tasks of the method of teaching thermodynamics as a science, and the method of learning the science of thermodynamics. is conducted.*

Key words: *thermodynamics, thermal phenomena, lecture, laboratory work, training, teaching, physics methodology, methods, efficiency, assessment, lesson.*

Thermodynamics studies systems consisting of a very large number of particles. Describing such systems using the methods of classical mechanics is not only not possible, but is actually meaningless. Features of the thermodynamic description arise due to the fact that the behavior of large ensembles of particles obeys statistical laws and cannot be reduced to the analysis of the deterministic evolution of dynamic systems. However, historically, thermodynamics developed without relying on the ideas of statistical theory, and the main provisions of thermodynamics can be formulated on the basis of a limited number of postulates, which are generalizations of experimental facts. The number of these postulates varies among different authors in accordance with how the axiomatics of thermodynamics are constructed, but it is traditionally believed that four principles of thermodynamics can be distinguished.

Basic concepts of thermodynamics.

Thermodynamic systems. Thermodynamics is the study of physical systems consisting of a large number of particles and being in a state of thermodynamic equilibrium or close to it. Such systems are called thermodynamic systems. This concept is generally quite difficult to define strictly, so a descriptive definition is used, in which a thermodynamic system is a macroscopic system that is somehow

(for example, using a real or imaginary shell) isolated from the environment and is capable of interacting with it. A shell that does not allow heat exchange between the system and the environment is called adiabatic, and a system enclosed in such a shell is called thermally insulated or adiabatically insulated.

Thermodynamic parameters. Thermodynamics does not consider the structural features of bodies at the molecular level. Equilibrium states of thermodynamic systems can be described using a small number of macroscopic parameters, such as temperature, pressure, density, concentrations of components, etc., which can be measured by macroscopic instruments. The state described in this way is called the macroscopic state, and the laws of thermodynamics allow us to establish the relationship between the macroscopic parameters. If a parameter has the same value, independent of the size of any selected part of the equilibrium system, then it is called non-additive or intensive, but if the value of the parameter is proportional to the size of the part of the system, then it is called additive or extensive [1]. Pressure and temperature are non-additive parameters, and internal energy and entropy are additive parameters.

Macroscopic parameters can be divided into internal, characterizing the state of the system as such, and external, describing the interaction of the system with the environment and force fields affecting the system, however, this division is quite arbitrary. So, if a gas is enclosed in a vessel with moving walls and its volume is determined by the position of the walls, then the volume is an external parameter, and the gas pressure depends on the speed of thermal movement of the molecules and is an internal parameter. On the contrary, if external pressure is specified, then it can be considered an external parameter, and the volume of gas - an internal parameter. It is postulated that in a state of thermodynamic equilibrium, each internal parameter can be expressed in terms of external parameters and the temperature of the system. Such a functional connection is called the generalized equation of state of the system [2].

Thermodynamic processes. When external parameters change or when energy is transferred into a system, complex processes can arise in it at the

macroscopic and molecular level, as a result of which the system transitions to a different state. Equilibrium thermodynamics does not deal with the description of these transition processes, but considers the state established after the relaxation of nonequilibria. In thermodynamics, idealized processes are widely used in which a system passes from one state of thermodynamic equilibrium to another, which continuously follow each other. Such processes are called quasi-static or quasi-equilibrium processes. A special role in the methods of thermodynamics is played by cyclic processes in which the system returns to its original state, doing work during the process and exchanging energy with the environment.

First law of thermodynamics. The first law of thermodynamics expresses the universal law of conservation of energy in relation to problems of thermodynamics and excludes the possibility of creating a perpetual motion machine of the first kind, that is, a device capable of doing work without corresponding expenditure of energy. The internal energy of a thermodynamic system can be changed in two ways, by performing work on it or through heat exchange with the environment. The first law of thermodynamics states that the heat received by the system goes to increase the internal energy of the system and to perform work by this system. The basis of thermodynamics is made up of two laws, or principles, of thermodynamics¹.

To do this, you need to apply some external forces to the system and move the points of their application. However, as experience shows, the internal energy of a thermodynamic system can change in some other, “invisible” way, when external forces do not do work on it. This method is called heat transfer, and the above statement represents the first law, or principle, of thermodynamics. So, the first principle, which is a generalization of a huge number of experimental facts, states that there is, in addition to work, another way to change the internal energy of a system. It does not reveal the mechanism of this change, but only indicates its possibility. From the point of view of this principle, there are two reasons for changes in the energy of the system: the performance of work (when there are macro-movements of the points of application of forces) and everything else

(when there are no such movements), called heat transfer, and both of these reasons can act simultaneously. Quantitatively, the first law of thermodynamics can be written as follows:

$$\Delta U = A' + Q, \quad (1)$$

Where ΔU - change in internal energy U of the system, A' - work of external forces on the system, and Q - amount of heat received by the system. The quantity of heat, as follows from (1), is understood as a measure of the change in the internal energy of a system without performing work on it (or it).

If instead of A' we introduce the work of the system (against external forces) $A = -A'$, then we get another form of writing the first beginning

$$Q = \Delta U + A, \quad (2)$$

that is, the heat transferred to the system goes to increase its internal energy and perform work on it. The unit of heat, as follows from (1) or (2), is the joule in the SI system. Comment. It should be borne in mind that the above formulation of the first law of thermodynamics (and it is generally accepted) assumes the invariance of the mechanical energy E_{mex} of the system. In the general case, heat and work of external forces can partially or completely go towards increasing the mechanical energy of the system, so the term ΔE_{mex} must be added to the left side of equation (1):

$$\Delta U + \Delta E_{\text{mex}} = A' + Q. \quad (1')$$

This same term will obviously appear in the equation (2):

$$Q = \Delta U + A + \Delta E_{\text{mex}}. \quad (2')$$

The definition will change accordingly Q : In the general case, the amount of heat should be understood as a measure of change in the internal energy of a system without performing work on it (or it) while its mechanical energy is

constant. This can be illustrated using the following simple examples. The brake shoe is pressed against the rotating disk, and the disk stops. Obviously, the rubbing parts will heat up and their internal energy will increase. If the disc brake system is isolated, then both work and heat are zero. The increase in internal energy here occurs only due to a decrease in the mechanical (kinetic) energy of the system in strict accordance, for example, with (1'), but not with (1). Similarly, heating of the atmosphere during the movement of a parachutist occurs due to a decrease in the potential gravitational energy of the parachutist-Earth system. In the future, we will assume that the mechanical energy of the system remains constant and use formulas (1) and (2).

THERMODYNAMICS OF AN IDEAL GAS What results will result from applying the first law of thermodynamics to the simplest ideal gas system?

Gas work.

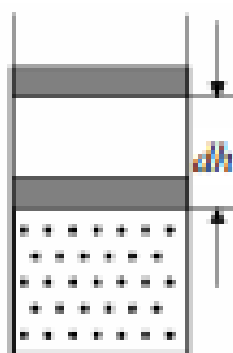


Fig.1.

We will consider only quasi-static, or equilibrium, processes, i.e., processes for which at any time the state of the gas can be considered equilibrium. This means that the process must proceed slowly enough (in the limit infinitely slow) so that all thermodynamic parameters have time to take their equilibrium values. In other words, the time to establish equilibrium must be much less than the time during which the gas parameters change noticeably. Let us first consider the gas located in the cylinder under the piston (Fig. 1). Let the piston (slowly) make a small displacement dh , so that the gas pressure remains practically unchanged. The work of the gas dA corresponding to this movement is equal to the product of the

force acting on the piston (it is constant) and its displacement (which we will consider positive if it leads to an increase in the volume of gas, and negative otherwise):

$$dA = Fdh = pSdh = pdV, \quad (3)$$

where S is the area of the piston, and dV is a small change (positive or negative) in the volume of gas.

In the more general case of a gas bounded by a shell of arbitrary shape, its

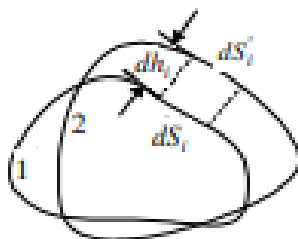


Fig.2

work is also determined by formula (3). Really, let 1 and 2 be two close positions of the shell (Fig. 2). Let us divide it into small sections of area dS_i , each of which makes small movements, moving into section i dS'_i .

If positions 1 and 2 are close enough, then, obviously, shown in Fig. 2 with a dotted line, is an approximately oblique cylinder of height dh_i . Since the gas pressure forces at each point are perpendicular to the surface of the shell, the work done by it to move the i -th section of it, the total work of the gas is determined by the summation of dA_i over the entire surface:

$$dA = dA = p dS dh = p dV,$$

where dV is the change in volume occupied by the gas. Let us note once again that this work corresponds to small displacements of the shell, at which the gas pressure does not change significantly. If there are significant changes in the

position and shape of the shell, it is necessary to divide the entire process into a sequence of close states, calculate using formula (3') the work for the transition between each pair of neighboring states and add the results:

$$A = \sum dA = \sum p dV \quad (4)$$

Formulas (3) and (4) allow for a very clear graphical interpretation. If we depict an arbitrary (quasi-static) process on the $p - V$ diagram (Fig. 3; curve 1-2)

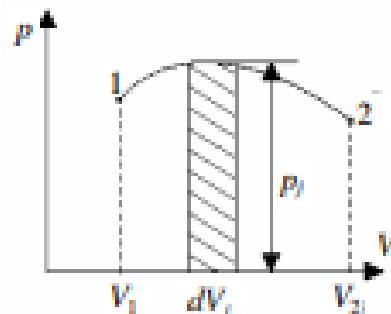


Fig.3.

and divide the change in volume into small sections dV_j , then the work of the gas on each of them in accordance with (3) turns out to be numerically equal to the area of the corresponding curved trapezoid (the j -th trapezoid is shaded in Fig. 3). The total work in the process 1 - 2 will be equal, obviously, to the area under the curve 1 - 2, taken with a plus sign if the volume increases and with a minus sign if it decreases.

Internal energy of an ideal gas. Number of degrees of freedom. The internal energy of an ideal gas, whose particles interact only through elastic collisions, obviously consists of the energies of each molecule separately and for one mole can be represented as

$$U_{\mu} = NaE, \quad (5)$$

where E is the average energy per molecule. If the gas is monatomic, then

all the energy is kinetic and according to the basic MKT equation, so

$$U_{\mu} = 2/3 RT \quad (6)$$

If the gas is polyatomic, then expression (6) includes only part of its energy associated with the movement of the centers of mass of the molecules, and does not take into account the energy of motion of the atoms relative to the center of mass of the molecule.

For example, a free material point (monatomic molecule) has three degrees of freedom, two unbound points have $i = 6$, etc. Two rigidly bound material points (diatomic rigid molecule) have five degrees of freedom: of the six coordinates, only five are independent, so how six coordinates of points must satisfy one connection equation, expressing the invariance of the distances between them.

It can be calculated differently: three coordinates determine the position of the center of mass of the molecule (translational degrees of freedom) and two (rotational degrees) fix the position of its atoms relative to the center of mass. These are the angles of rotation α and ϕ of the axis of the molecule relative to the horizontal xy and vertical xz planes (Fig. 4).

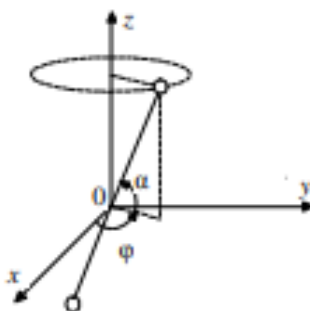


Fig.4.

For a triatomic rigid molecule, if its atoms are not located on the same straight line (Fig. 5), in addition to the three coordinates of its center of mass, it is necessary to set three more rotation angles: two of them determine the position of any axis rigidly connected to it (for example, AA), and the third characterizes the rotation around this axis. For such a molecule $i = 6$ (three translational and three

rotational powers).

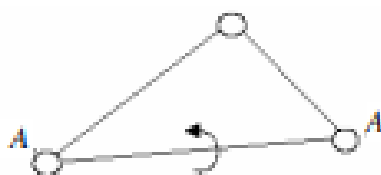


Fig.5.

In the general case of an n-atomic rigid molecule (as well as an absolutely solid body), the number of degrees of freedom is also six, because specifying the positions of any three of its atoms (not lying on the same straight line) uniquely determines the position of all the others.

Boltzmann's law of equipartition. In statistical physics, the following theorem (Boltzmann) is proven: if a system of molecules is in a state of thermodynamic (thermal) equilibrium at temperature T, then for each degree of freedom of the molecule there is the same kinetic energy

$$w = kT/2.$$

First of all, we note that the basic MKT equation we obtained earlier (for a monatomic ideal gas) is in complete agreement with Boltzmann's theorem: the average energy of its molecule $w = 3kT/2$ can be considered uniformly distributed over its three degrees of freedom, so that for each there is just $kT/2$. The proof of this theorem in the general case, based on the use of a mechanical model of n-atomic molecules colliding according to the laws of elastic impact, is very cumbersome, but its meaning is quite clear. As an illustration, consider a gas consisting of diatomic rigid molecules ("dumbbells").

Thus, the mechanism of energy transfer between different degrees of freedom "works" in both directions. The theorem states that it will lead to complete equalization of average energies across all powers.

So, the more degrees of freedom a molecule has, the more energy, on average, it stores when in thermal equilibrium with other particles. Are there other

“containers” of energy in the molecule? It turns out that there is, but not kinetic, but potential.

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