



World Scientific News

An International Scientific Journal

WSN 94(2) (2018) 313-320

EISSN 2392-2192

SHORT COMMUNICATION

Physical meaning temperature of gas and separate molecule

B. G. Golovkin

Public Institute of Natural and Human Sciences,
Chelyuskintsev Street, 10. Pokrovsk. Sverdlovsk region, 623795, Russia

E-mail address: gbg1940@mail.ru

ABSTRACT

Starting from the equation of state of the Clapeyron gas, it is shown that the temperature of a monatomic molecule τ of radius r and mass m moving with velocity v is equal to $\tau = \frac{l}{kr} \cdot \frac{mv^2}{2} = \frac{l}{kr} E$, where: l are the length of a molecule without collisions, k – the Boltzmann constant, E – the kinetic energy of the molecule. The physical meaning of the temperature of a molecule should be understood as the kinetic energy that it has in the path without collisions l . The dimension of temperature coincides with the size of energy, but quantitatively the energy differs by the presence of a dimensionless factor l/r , characterizing the motion of a molecule in fractions of its radius. Based on the temperatures of the individual molecules and their relative amounts contained in the gas, a formula is proposed for the overall gas temperature, for any, even nonequilibrium, distribution. The physical meaning of the gas temperature is determined by the product of the mean kinetic energy, the average mean free path of its molecules, and their size.

Keywords: temperature of a molecule, distribution of molecules by temperature, gas cell, mean free path

1. INTRODUCTION

It is generally accepted that the inverse of the derivative of the entropy of a body by its energy is called *the absolute temperature* or simply the temperature T :

$$\frac{dT}{dE} = \frac{1}{T} \quad (1)$$

The main disadvantage of such a formal definition is that (like entropy) the temperature should be a purely statistical quantity, meaning only for macroscopic bodies. This definition of temperature is not essential, it does not reveal the physical meaning of temperature, but plays a role only as a tool for constructing theories of statistical physics, which gave the parameter "temperature" the meaning of the characteristic of the distribution of the statistical ensemble over possible states. In fact, she just used it as such a characteristic. This application created the illusion that temperature alone is the characteristic of the distribution of the statistical ensemble over possible states. This misleading brought enormous damage to physics and, above all, physics itself. In fact, the concept of temperature, as characteristics of an individual particle, of several particles and even of a large number of particles, if their velocity distribution does not correspond to a stationary distribution, formally, ceased to make sense. As a result, this has caused difficulties in theories where the concept of temperature is required. It was necessary to adapt and reconstruct these theories in such a way that the temperature either was involved in some indirect way, when instead of it the kinetic energy or velocities of the particles are used.

The concept of temperature is the primary one that arose on the basis of experience, long before the emergence of the concept of entropy, as a thermodynamic function of the state of a statistical ensemble, and the emergence of statistical physics itself. However, in practice, indirect measurement of the temperature as a quantity characterizing the direction of heat exchange is often used, so that the amount of heat (as energy transferred by heat exchange) is transferred from a body with a higher temperature to a body with a lower temperature. But the essential definition is also used: "*Temperature is a quantity characterizing the average kinetic energy of the translational motion of molecules of an ideal gas*". It is easy to see that from this point of view the concept of the temperature of a molecule has a completely definite meaning: for one molecule, its average kinetic energy is equal to the kinetic energy of this molecule. The fact that when using the definition of the concept of temperature (1), the temperature of a single particle or even groups of particles is devoid of physical meaning, is a failure of the probabilistic approach in statistical physics.

It was noted in [1,2] that thermal radiation plays an important role in the interaction between gas molecules, the curve of frequency dependence on the temperature of which has a domed shape, as well as the Maxwell distribution curve. The relaxation of this distribution from the resulting fluctuations can be provided by photons of this radiation, whose velocity far exceeds the velocity of the gas molecules. Based on this, it was concluded that during the free path of the i -molecule ϑ_i , it will have its own temperature τ_i :

$$\tau_i = \frac{0,289776829}{\lambda_i^{max}} \text{ K}, \quad (2)$$

where: $0.289776829 \text{ cm}\cdot\text{K}$ is the Wien constant (K is the Kelvin degree), λ_i^{\max} – the wavelength of the maximum intensity in the spectrum of the corresponding gas cell. Since the temperature of a particular molecule in the gas composition is considered, in addition to the thermal radiation surrounding the molecule, it must be determined by the interactions of a given molecule with other gas molecules.

Since the temperature of a particular molecule in the gas composition is considered, in addition to the thermal radiation surrounding the molecule, it must be determined by the interactions of a given molecule with other gas molecules. Such a volume is the gas cell in which the test molecule is located, and other molecules of the surrounding gas environment, which collide with the given gas molecule, act as the walls of a given volume.

The concept of temperature is often associated with the kinetic energy of particles, and sometimes even the temperature is measured not in degrees, but in energy units. Formula (2) formally allows us to determine the temperature of the molecule, and most importantly, to show that each molecule can have and has its temperature, but the physical meaning of this temperature remains unclear. The intrinsic definition of the temperature is qualitative, and its extrapolation to the temperature of one molecule is not formally made. The purpose of this paper is to reveal the physical meaning of the concept of the temperature of gas and separate molecule.

2. GAS CELL

In contrast to [1,2], under a gas cell we mean a cylinder with an area πr^2 (r is the radius of the molecule) at the base and a height l equal to the mean free path of the molecule being analyzed. This value is not equal to the mean free path of the molecules of the gas under investigation, but is inherent only in the particular molecule chosen and over a specific time interval ϑ . Accordingly, the free path ϑ of this molecule is equal to

$$\vartheta = \frac{l}{v}, \quad (3)$$

where: v is the velocity of the molecule moving in the direction of the counter molecule, with which the nearest collision will occur. The volume W of a gas cell will be determined, respectively, by formula

$$W = \pi r^2 l. \quad (4)$$

If the gas is strongly rarefied and the value of l is relatively large, then during the time other molecules can enter the cell, which will either cross it, or move along the same trajectory as the molecule being analyzed. To determine the temperature of the molecule under analysis by formula (2), it is necessary that there be no other molecules in the time interval $\Delta\vartheta \leq \vartheta$ in the gas cell in which the molecule being analyzed. If they are present, (for example, molecules that intersect the cell at an angle to the generatrix of the corresponding cylinder or following it at some distance), then the temperature of the gas cell itself, in which there are already several molecules, will be fixed. The entire space of the gaseous medium consists of a mosaic of various gas cells, in each of which there is a corresponding molecule or more than one, but not colliding with each other within a time ϑ . The real existence of gas

cells is confirmed by the possibility of creating laser traps [3], where only a few molecules fall, which, in principle, does not exclude the penitization of just one molecule. In such traps there is a fundamental possibility of measuring the temperature by formula (2) of a single molecule trapped in a laser trap.

3. DERIVATION OF THE BASIC FORMULAS

For definiteness, we shall assume that the gas consists of monatomic molecules of radius r and mass m . The equation of state of such a gas is described by the Clapeyron formula

$$PV = nRT, \quad (5)$$

where: P – the gas pressure, n – the number of moles of gas in the volume V , T – the temperature, $R = 8,3144 \cdot 10^7$ erg /mole·K. For one mole of gas from formula (5) we have:

$$PV = RT = N \frac{R}{N} T = NkT, \quad (6)$$

where: $N = 6,02 \cdot 10^{23}$ – the Avogadro number, $k = 1,38 \cdot 10^{-16}$ erg /mole·K. Let us denote the fraction of the pressure per molecule that is among other molecules, when it strikes the end wall of the gas cell through

$$P_1 = \frac{P}{N}. \quad (7)$$

Dividing equation (6) by N , we obtain

$$P_1 V = kT \quad (8)$$

If in the last equation we choose the gas volume equal to the volume of the gas cell $V = W$, in which there is only one gas molecule, then the gas temperature in this cell will obviously be equal to the temperature of this molecule $T = \tau$, and equality (6) can now be written in the form

$$P_1 W = k\tau. \quad (9)$$

Equation (9) allows us to give a formal definition of the temperature of an individual molecule. The wall of the gas cell in question is a molecule from the surrounding gaseous medium, with which the molecule under analysis is located inside this gas cell. The mechanism of interaction of colliding molecules lies in the fact that the molecules must first extinguish their velocities to zero and only then the exchange of velocities with the corresponding dissipation coefficient will occur in the next stage of the interaction. Therefore, the change in the velocity of the colliding molecules is

$$\Delta v = v, \quad (10)$$

and the impact force, respectively:

$$F = \frac{m\Delta v}{\Delta t} = \frac{mv}{\Delta t}, \quad (11)$$

where: Δt – the time of collision of a molecule with another molecule, which is counted from the moment of their contact to the point of their collision in a plane normal to the trajectory of the motion of the colliding molecules, coinciding with the end plane of the cylinder of the gas cell:

$$\Delta t = \frac{2r}{v}. \quad (12)$$

Substituting (12) into (11), we obtain:

$$F = \frac{mv^2}{2r}, \quad (13)$$

then:

$$P_1 = \frac{F}{S} = \frac{F}{\pi r^2}, \quad (14)$$

where: S – the area of the end plane of the gas cell. Substituting (13) into (14), we obtain:

$$P_1 = \frac{mv^2}{2\pi r^3}. \quad (15)$$

Substituting expressions (4) and (15) into formula (9), finally for the temperature of the molecule we obtain:

$$\tau = \frac{l}{kr} \cdot \frac{mv^2}{2} \quad (16)$$

or

$$\tau = \frac{l}{kr} E, \quad (17)$$

where: $E = mv^2/2$ – kinetic energy of the molecule. Thus, as expected, the temperature of the molecule is directly proportional to its kinetic energy. But it still differs from it still by the dependence on the mean free path and the size of the molecule. The presence of this dependence makes the temperature of the molecule, unlike energy, a nonadditive function. Formula (16) additionally indicates the dependence of the temperature of the molecule on its mass and velocity.

If we take into account equality (3), then formula (16) can be rewritten as:

$$\tau = \frac{\vartheta}{kr} \cdot \frac{mv^3}{2} = \frac{\vartheta}{kr} Q, \quad (18)$$

where: $Q = mv^3/2$ – kuberger molecule.

4. THE DISCUSSION OF THE RESULTS

It follows from (15-17): the physical meaning of the temperature of a molecule can be understood as the kinetic energy that it carries in the path of its free path l , or as a kuberger, which it possesses during the time of free travel ϑ . The dimension of temperature coincides with the dimension of energy, but quantitatively differs by the presence of a dimensionless factor l/r , characterizing the motion of the molecule in fractions of its radius. The Boltzmann constant in formulas (15-17) serves only to transfer energy units to degrees Kelvin. In the particular case, when $l = r$ the temperature of the molecule is exactly equal to the energy of the molecule.

As can be seen from formulas (15-17) for $l, \vartheta = 0$, and $r \neq 0$, the temperature of the molecules τ of such a gas is zero. The overall gas temperature T , obviously, should be determined as the average value from the temperatures of the molecules and their quantities having the same τ_i , which should depend on the corresponding distribution. In the general case, for any distributions, including nonequilibrium distributions, we can write:

$$T = \frac{\sum_i^A \alpha_i \tau_i}{B}, \quad (19)$$

where: A – the number of varieties of molecules that differ in speed (in increments h);

$$B = \sum_i^A n_i \quad (20)$$

– total number of molecules in the volume of gas under study; n_i – the number of molecules of gas of the i -kind, that is, having almost the same speed $V_i \pm \delta$;

$$\alpha_i = \frac{n_i}{B} \quad (21)$$

– the statistical weight of the number of i -molecules. Substituting (21) into (19), we obtain a formula for determining the total gas temperature for any distribution, starting from the temperatures that make up the molecules:

$$T = \sum_i^A \frac{n_i \tau_i}{B^2} = \sum_i^A \frac{n_i \tau_i}{(\sum_i^A n_i)^2}. \quad (22)$$

Formula (22) can be written more simply if, in formula (16), instead of l and v for a particular molecule, choose their mean values \bar{l} and \bar{v} for different gas molecules (with the same values of m and r), substituting them into formula (16), then the temperature of such a gas is determined by the formula:

$$T = \bar{\tau} = \frac{m}{2kr} \bar{v}^2 = \frac{\bar{l}}{kr} \bar{E}, \quad (23)$$

where: \bar{E} – the average kinetic energy of the gas molecules. The temperature of a mixture of various gases, respectively, is determined by the formula:

$$T = \bar{\tau} = \frac{\bar{m}}{2kr} \bar{v}^2 = \frac{\bar{l}}{kr} \bar{E}, \quad (24)$$

where: \bar{m} and \bar{r} – the average values of the mass and radius of the molecules of gases entering the gas mixture. Thus, the gas temperature is proportional to the average mean free path and the average kinetic energy of its molecules (corresponding to their mass and average velocity) and inversely proportional to the dimensions of its molecules. It is important to note that the gas cell plays the role of a thermostat. The molecule in the cell is in equilibrium with the photon gas of the cell, and its temperature, in the absence of other molecules, is equal to the temperature τ of this photon gas. But it is also in equilibrium with the walls of the gas cell, the temperature of which is equal to the temperature of the surrounding medium T . This equilibrium lies in the fact that within the time of free travel ϑ , it does not collide with the walls of the cell, which consist of chaotically moving other molecules. Despite the equilibrium between the molecule and the environment, the temperature of the molecule, as a rule, is not equal to the total temperature of the gas $\tau \neq T$.

The equilibrium of the temperature of the contents of the gas cell (molecule and photons) with the ambient temperature indicates that the entire gas medium is a discrete at any instant of time a set of corresponding gas cells having different temperatures whose distribution formula, according to their temperatures τ at the general temperature of the medium T , is proposed above. After a short interval of time, the mosaic of the gas cells changes, but the temperature distribution of the molecules remains, if we ignore the small evolution of the gas, the same.

Formally, the velocity of the molecule in formula (16) is indifferent to the frame of reference with respect to which it is defined: it can be an observer, a counter molecule, a physical vacuum or even an Absolute space. Accordingly, if a monochromatic beam of molecules moves with velocity V relative to the same frame of reference as the individual beam molecules, then the velocity V does not play any role in determining the temperature of the beam, since the beam temperature itself is determined by formulas (22–24), to which the velocity beam is not included. However, it is possible that these formulas can be modified taking into account the choice of the frame of reference so that the beam velocity will enter explicitly into the formula for its temperature. The dependence of the temperature of the molecular beam on its velocity will take place if its molecules interact with the medium in which they move - this can be air or other material medium, physical vacuum, etc. In a monochromatic beam of molecules, the molecules themselves still have some distribution both in their velocities and in the direction. If, however, such a beam is made in which the velocities of all molecules will be exactly the same in magnitude and in direction, the beam will be isolated from the influence of the surrounding medium, so that collisions of the beam molecules with other molecules will not occur at all, and this means that the mean free path the beam molecules will be infinite, then the temperature of each beam molecule in

accordance with formula (16) should become infinite. But, most likely, the beam molecules will interact with the medium in which they move (including the vacuum). As a result of the dissipation of their energy, the velocities of molecules and the beam will decrease, but the mean free path will remain the same, which means that the temperature of the molecular beam must formally remain infinite. At the same time, if the velocity of the molecule becomes zero, and, consequently, the mean free path is also zero, formula (16) implies that the temperature of the molecule at rest also becomes zero.

5. CONCLUSIONS

1. The widespread opinion arising from the probabilistic approach, based on the interdependence of entropy on temperature, that the concept of temperature can only make sense with respect to a large number of particles, is erroneous.
2. The derivation of the formula for the temperature of the molecule shows that the concept of temperature is applicable to an individual molecule.
3. The physical meaning of the temperature of a molecule lies in the fact that it is determined by the product of its kinetic energy by the mean free path of a molecule, and also depends on its mass and size, which is different from the simple kinetic energy.

The physical meaning of the gas temperature is determined by the product of the mean kinetic energy and the average mean free path of its molecules, and also depends on their mass and dimensions.

References

- [1] Golovkin B.G. *Engineering physics* 11 (2016) 22-24.
- [2] Golovkin B.G. *East European Scientific Journal* 4 (3) (2015) 103-105.
- [3] Cohen-Tannoudji C.N. *Successes of physical sciences* 3 (1999) 292-304.