

Kelvin as a Variant of the Unit of the Number of Entities

Abstract. This article explains the essence of the electrothermal analogy [1], which served as the basis of the heat charge theory that enabled to take a different view on the physical content of thermodynamic temperature and its unit, kelvin. The article confirms that what is measured is not the absolute value of the temperature, but the temperature difference [2], and kelvin is exactly the unit of temperature difference. A statement is given that the unit kelvin is a particular case of the unit of number of entities, which in thermodynamics is the number of elementary heat charges. It is stated that the heat charge theory, which represents the physical content of thermodynamic temperature and temperature difference in a new way, still remains unnoticed in thermodynamics, though it was published more than half a century ago [3]. The conclusions of this theory lead to dimensions and units of the heat quantities that differ from those that exist in the SI.

1. General Overview of the Heat Charge Theory

1.1. A Brief History of the Origin of the „Heat Charge” Concept

The development of the theory of electromechanical analogies that took place in the first half of the 20th century and their successful application resulted in attempts to include heat quantities into the theory of analogies as well. In this regard we can point out the detailed discussion of the electroheat analogy in the monograph by A.Einstein and L.Infeld [1].

<i>“Heat</i>	<i>Electricity</i>
<i>Two bodies, which at the beginning have different temperature, reach the same temperature in some time after getting in contact.</i>	<i>Two isolated conductors, which at the beginning have different electrical potentials, reach the same potential very shortly after getting in contact.</i>
<i>Equal amounts of heat cause different temperature changes in two bodies, if the heat capacities of the bodies are different.</i>	<i>Equal numbers of electric charges cause different changes of electric potential in two bodies, if the electric capacities of the bodies are different.”</i>

The monograph [1] draws an analogy between such key electric and heat concepts as electric potential and thermodynamic temperature, electric charge (amount of electricity) and amount of heat, electric capacity and heat capacity. On the basis of this analogy I. Lvov [4] suggested to introduce the "**heat charge**" concept as a analog for the "electric charge" concept.

As a matter of fact, the "heat charge" concept, referred to as "thermal charge", first emerged as far back as in 1950's in A. Veinik's General Theory, which was published by its author in the monograph [3]. Unfortunately, A. Veinik's papers were renounced by the USSR Academy of Sciences so vehemently that almost all the copies of his monograph [3] were burned, while the mandatory copies that had to be sent to the libraries were excluded from open access; as a result, "heat charge" was rediscovered anew by other researchers. A. Veinik's General Theory was stigmatized as "pseudo-science", and the stigma still remains.

A. Veinik's works on thermodynamics were translated into English in Israel [5] and in England [6], but we couldn't locate any references to these translations in any literature in English. Later A. Veinik managed to finance a short-run publishing of his new monograph [7]. In that paper instead of the term “thermal charge” he used the term “wärmic charge” (derived from the German word Wärme — heat), which can be literally translated as heat charge.

The validity of introduction of the “heat charge” concept was later confirmed by other scientists' research. For instance, under the influence of the monograph [3] this concept was used in 1990's for systematization of physical quantities [8]. In the 21st century the idea of heat charge was developed anew, independently from A. Veinik, by the author of the article [9], who also reinforced it with additional argumentation. In particular, the author of [9] introduced the “heat particle” concept, which is the counterpart of the “elementary electric charge” in electrodynamics.

A. Veinik stated that the heat charge is included into the so-called “**charge assemblies**”, which are material objects in ordered motion that transfer energy. We consider that the more suitable term for such objects is “**energy carriers**”. For instance, in liquids and gases they are atoms and molecules, while ions and electrons are also energy carriers for electric charge. The conduction electrons that freely move within rigid bodies are also energy carriers. EMR waves are energy carriers as well.

Unfortunately, the heat charge theory is still ignored by physics and metrology, though, as it will be shown in this article, it is exactly this theory that reflects the physical nature of thermodynamic temperature.

1.2. The Two Types of the Heat Charge

If a part of a system or medium is in equilibrium condition, the heat motion of energy carriers in it takes the form of Brownian motion. The kinetic energy of each specific energy carrier is defined by its velocity. In the kinetic theory of gases the equation for kinetic energy of translatory motion of perfect gas molecule W_k is:

$$W_k = m\hat{u}^2/2, \quad (1.1)$$

where m – mass of the molecule; \hat{u} – its root-mean-square velocity. The sum vector of root-mean-square velocity \hat{u} of all the energy carriers in any elementary section in Brownian (disordered) motion is equal to zero.

But equilibrium conditions exist only in theory; they are not observed in nature. In a real non-equilibrium medium or system among the total number of energy carriers there is a certain number of energy carriers in ordered motion, which define the **heat charge** of the system, and which we will indicate by the symbol Θ . The elementary number of energy carriers in ordered motion, which contain heat charge, is also the number of elementary heat charges $d\Theta$.

If a system experiences only disordered motion, it means that the energy carriers in ordered motion were dissipated. We will refer to the heat charge of energy carriers in disordered motion as **heat charge of dissipation**.

Both types of heat charge can transform into each other. For instance, in equilibrium system there is only a heat charge of dissipation, but when the system contacts another system with a different temperature value, the ordered motion of energy carriers through the contact surface begins.

The “**elementary heat charge**” concept should be made more specific. In the electroheat analogy it is being compared to the “elementary electric charge” concept, which in physics stands for an electron or a positron. But such an understanding of elementary electric charge is incorrect from the point of view of mathematics, where the term “elementary” stands for infinitesimal quantity. In reality, electron is not an elementary charge, but rather a charge that cannot be divided into parts without losing its physical content. Nevertheless, the term “elementary charge” has become so ingrained in physical terminology that it seems too late to

correct it. But when using the term “electric charge”, it is necessary to understand that it stands for a single charge.

1.3. The Physical Content of Certain Terms in Thermodynamics

Let us define the physical content of the terms “**quantity of heat**” and “**heat energy**”. A. Veinik [3] pointed out that the quantity, which physicists call “quantity of heat” or simply “heat”, is different from the quantity that Carnot called „heat energy.” The term “quantity of heat” means “*the quantity of energy transmitted to a system by external bodies via heat exchange*” [10, p. 102], without reference to ordered or disordered motion. But heat energy, as understood by Carnot, is a form of energy of objects in ordered motion, similar to kinetic, electrical, and other forms of energy [11]. This means heat energy is merely a part of quantity of heat.

A textbook on physics [12, p. 61] advises to avoid the term “heat energy”, because its content is the same as that of internal energy. But this depends on how one understands heat energy. If heat energy is understood as energy of energy carriers in disordered motion, then the author of [12] is right. But if heat energy is understood as energy of energy carriers in ordered motion, that is, as a process function of heat exchange, one of the forms of energy exchange between an equilibrium system and environment or between different parts of a non-equilibrium system, then the content of heat energy does not coincide with that of the internal energy of the system, which is a state function.

The reasoning by A. Veinik [3] confirms the conclusion that movement of heat charge is manifestation of heat energy exchange between a system and its environment or between different parts of a non-equilibrium system. Thus, movement of heat charge is just a part of total energy exchange. Energy of heat charge movement should be understood as heat energy of energy carriers in ordered motion.

The come back to understanding heat energy as seen by Carnot does not mean coming back to the caloric theory of the 19th century, but rather rethinking that theory in view of transition from thermodynamics of equilibrium processes to thermodynamics of non-equilibrium processes. This is an ordinary example of the philosophical principle of spiral motion. R.Feinman said the following: “*It is often said that Carnot’s arguments were invalid. However, Carnot’s logic is impeccable. What is incorrect is only simplified explanation of those arguments by Clausius, and this is exactly what most people usually learn.*”

1.4. System Potential and Difference of Potentials between a System and Environment

To define a heat exchange between a system and environment that surrounds it, we need to use the equation for **total energy** of an equilibrium thermodynamic system W [10, p. 100]. “*Thermodynamic systems stand for macroscopic objects that can exchange energy both with each other and the environment*”. [10, p. 95]

$$W = Wk + Wp + U \quad . \quad (1.2)$$

where Wk – kinetic energy of the system’s movement as a whole, Wp – potential energy of the system in the external fields of force, and U – internal energy. Variation of total energy dW is the sum of variations of its summands, including variation of internal energy dU . But for a thermodynamic system only two forms of movement are considered: the heat one and the mechanical one.

If we consider a system with arbitrary number of forms of movement, which is equal to i , then the variation of the internal energy of the system dU will be defined by the equation

$$dU = \sum_i (\partial U / \partial q_i) dq_i = \sum_i P_i dq_i \quad , \quad (1.3)$$

where dq_i – variation of coordinate of state of the i -th form of movement. Physical values $P_i = (\partial U/\partial q_i)$ are called **generalized potentials of the system**. System potential belongs to **intensive quantities**, the value of which does not depend on the size of the system, as they are not additive. The intensive quantity in the heat form of movement is the thermodynamic temperature.

The environment that surrounds a system also has a potential for each form of movement. If the potentials of the system and the environment don't coincide for the i -th form of movement, then the **difference of potential** ΔP_i between the system and the environment for this form of movement appears. The difference of potential $\Delta P(t)$ is a vector quantity, since it defines the direction of movement of energy carriers in the heat energy exchange: from the environment to the system or in the opposite direction. It is defined by the **equation of transition process** from one equilibrium state to another.

In the automatic control theory this equation is written as a second order linear differential equation with constant coefficients. This equation connects the step variation of input signal $x(t)$ (influence on the system) with variations of the output signal $y(t)$ (outcome of the influence). In simplified form this equation looks as follows:

$$a_0 y(t) + a_1 (dy/dt) + a_2 (d^2 y/dt^2) = x(t) , \quad (1.4)$$

which can be written as:

$$D \mathbf{q}_{fl} + R d\mathbf{q}_{fl}/dt + I d^2 \mathbf{q}_{fl}/dt^2 = - \Delta \mathbf{P} , \quad (1.5)$$

where $\Delta P(t)$ – the input signal $x(t)$ in the form of **difference of potential** between the system and surrounding environment; $\mathbf{q}_{fl}(t)$ – output signal $y(t)$ in the form of **moving coordinate of state** of the system (the index $_{fl}$ means “flowing”).

The difference of potential is not additive, as it is not an intensive quantity. At the same time, it is not an **extensive quantity**, i.e. a quantity “*which changes in proportion to the system mass*” [12, vol. 2, p. 139], since the difference of potentials doesn't describe the system – it describes its difference from the environment or from other systems.

In the equation (1.5) D , R , and I are constant coefficients (system parameters), which correspond to a_0 , a_1 , and a_2 . The equation of the form (1.5) is used in mechanics [14] in the following form:

$$D \mathbf{x} + R \mathbf{v} + I \mathbf{a} = - \mathbf{F} , \quad (1.6)$$

where \mathbf{F} – the force of influence on the system, which is the pressure difference on the boundary surface between the system and the environment divided by the area of this surface, \mathbf{x} – displacement, $\mathbf{v} = d\mathbf{x}/dt$ – velocity, $\mathbf{a} = d^2 \mathbf{x}/dt^2$ – acceleration, D – system rigidity, R – friction resistance, I – linear inertia.

The equation of the form (1.5) is used in electrodynamics in scalar form

$$(1/C)q + RI + L dI/dt = \Delta U , \quad (1.7)$$

where ΔU – electric difference of potentials, q – electric charge, $I = dq/dt$ – electric current, C – electric capacity, R – ohmic resistance, L – inductance. Though actually q in the equation (1.7) is the moving (flowing) electric charge \mathbf{q}_{fl} , therefore the electric current \mathbf{I} is a vector quantity as well [13]. Further we will show in which form the equation (1.5) is used in the heat transfer theory.

According to the encyclopedic dictionary on physics [14], “*If the system is not isolated, its energy can change either with simultaneous change of the energy of surrounding bodies by the same value, or at the expense of interaction energy of the body with surrounding bodies.*”

This process is called **energy exchange**. Therefore, the variation of total energy of the system dW (if W_k and W_p are not changing) is defined as the variation of the internal energy dU in accordance with the equation (1.3), as well as the variation of energy exchange with environment dW_{ch} according to the equation

$$dW = dU + dW_{ch} = \sum_i P_i dq_i + \sum_i \Delta P_i (dq_{fl})_i , \quad (1.8)$$

where $(dq_{fl})_i$ – the elementary number of energy carriers of the i -th form of movement, which are moving from the system to environment (or back). For the heat form of movement, the difference of potential is the **temperature difference** between the system and the environment ΔT , which in thermodynamics is called **temperature drop**, while $(dq_{fl})_i$ corresponds to the elementary number of heat charges $d\Theta$ in ordered motion.

In a non-equilibrium system the root-mean-square velocity vector of energy carriers in any segment of the system is different from zero – it is directed from a section with a higher potential to a section with a lower potential. For non-equilibrium systems the “**local potential**” concept can be used, which should be understood as the potential of a subsystem of infinitesimal size situated inside a non-equilibrium system. The values of local potential in different points of the non-equilibrium system are different, which is the reason for local difference of potentials and flow of heat charges inside a non-equilibrium system.

Dimensional analysis of the equation (1.5) as applied to heat form of motion led the author of [8] to conclude that it is necessary to update the units of heat quantities.

2. Update of the Units of Heat Quantities

2.1. The Necessity to Modify Fourier's Law

The process of systematization of the heat quantities [8] showed that it is possible only in case of modification of the main law of heat transmission — Fourier's law. This modification was done by A. Veinik [4]. Let us explain its essence.

Fourier's law is used in the paper [4] in its simplified form:

$$\Phi = - \lambda(\partial T/\partial n)S , \quad (2.1)$$

where $\Phi = dQ/dt$ – heat flow; Q – quantity of heat; λ – thermal conductivity; $\partial T/\partial n$ – temperature gradient normal to the isothermal surface; S – section area through which the heat current flows.

When using Fourier's law in this form (2.1), the heat form of movement turns out to be the only form of movement, systematization of which leads to unusual results. If in place of module of difference of potential ΔP_i we use temperature drop ΔT with unit kelvin, and in place of elementary amount of the moving coordinate of state $(dq_{fl})_i$ we use **elementary amount of heat** δQ with unit joule, than the variation of energy exchange dW_{ch} gets the unit J K, which does not exist in physics.

And since the elementary amount of heat δQ also has the unit joule, the conclusion is that temperature drop ΔT loses its unit, or, to be more precise, its unit becomes 1. This situation became clear not long ago [15], which will be explained below.

A. Veinik [4] discovered that the form (2.1) of Fourier's law should be modified — temperature drop should be divided by the unit of thermodynamic temperature T (given that $T \neq 0$). In the paper [4] Fourier's law is written in a modified form:

$$\Phi_a = - a(\partial T/\partial n)S , \quad (2.2)$$

where $\Phi_a = \Phi/T$ is referred to as “thermal current”, while $a = \lambda/T$ is called “thermal conductivity”.

Understandably, such a mathematical operation does not influence practical calculations in the heat transfer theory; that is why formally we can use Fourier's law written as (2.1). This is why the terminology and units of heat quantities in the modern heat transfer theory result from the use of non-modified Fourier's law.

But A. Veinik [4] showed on the numerous examples that the equation (2.1) leads to incorrect understanding of experimental results, while modified Fourier's law written in the form (2.2) leads to natural understanding of a number of phenomena not only in the heat transfer theory, but also in thermodynamics in general.

While classifying physical quantities, the author of [8] arrived at the conclusion that only the modified Fourier's law in the form (2.2) allows to get heat quantities classified similar to mechanical, hydraulical, electrical, and other quantities. But this also leads to changes of heat quantities and their units.

Only the use of the modified Fourier's law in the form (2.2) allows classifying the heat movement similar to other forms of movement. And this can happen only under the condition that the "heat charge" concept is introduced.

2.2. The Introduction of the "Heat Charge" Concept Changes Units of Heat Quantities

While classifying physical quantities in every form of movement the author [8] used a generalized equation of energy exchange between a system and its environment, which follows from the equation (1.8):

$$dW_{ch} = \sum_i \Delta P_i (dq_{fl})_i . \quad (2.3)$$

The generalized equation of energy exchange (2.3) for the heat movement will be the following:

$$\delta Q = \Delta T d\Theta , \quad (2.4)$$

while the equation (1.5) takes the form:

$$D_{tm} \Theta + R_{tm} d\Theta/dt + I_{tm} d^2\Theta/dt^2 = - \Delta T , \quad (2.5)$$

where $D_{tm} = dT/d\Theta$ – thermal rigidity; $R_{tm} = \delta/aS$ – thermal resistance, δ – thickness of heat-conducting layer, $a = \lambda/T$ – thermal transfer coefficient; λ – heat transfer coefficient in the current heat transfer theory, S – section area through which the heat flow flows, I_{tm} – thermal inertia.

But the more suitable equation is the one similar to (1.7) in electrodynamics:

$$(1/C_{tm}) \Theta + R_{tm} \Phi_a + I_{tm} d\Phi_a/dt = \Delta T , \quad (2.6)$$

where $C_{tm} = d\Theta/dT$ – thermal capacity, $\Phi_a = d\Theta/dt$ – flow of heat charges, and $\Phi = \Phi_a T$ is the heat flow in the current heat transfer theory.

All these things required an update of the heat quantity units, as shown in Table 1. The main innovation of Table 1 is the fact that infinitesimal amount of moving heat charge $d\Theta$ is considered as variation of the coordinate of state.

Table 1. Units of Heat Quantities, both Current and Updated

Physical quantity	Symbol or formula	Measurement Unit	
		Updated	In the SI
Current Heat Transfer Theory			
Elementary amount of heat	δQ	-	J
Thermodynamic temperature	T	-	K
Heat capacity	$C = dQ/dT$	-	$J K^{-1}$
Thermal resistance	$R_{tm} = \delta/\lambda S$	-	$W^{-1}K$
Thermal conductivity	$Y_{tm} = \lambda S/\delta$	-	$W K^{-1}$
Heat transfer coefficient	λ	-	$m^{-1} W K^{-1}$
Heat flow	Φ		W
Updated Heat Transfer Theory			
Elementary amount of heat	δQ	J	J
Infinitesimal amount of moving heat charge	$d\Theta$	$J K^{-1}$	-
Temperature drop	ΔT	K	K
Thermal rigidity	$D_{tm} = dT/d\Theta$	$J^{-1} K^2$	-
Thermal capacity	$C_{tm} = d\Theta/dT$	$J K^{-2}$	-
Thermal resistance	$R_{tm} = \delta/aS$	$W^{-1} K^2$	-
Thermal conductivity	$Y_{tm} = aS/\delta$	$W K^{-2}$	-
Thermal inertia	I_{tm}	$W K^{-1}$	-
Thermal conductivity coefficient	$a = \lambda/T$	$m^{-1} W K^{-2}$	-
Heat charges flow	$\Phi_a = d\Theta/dt$	$s^{-1} K$	-

The “thermal capacity” quantity, which reflects the intensity of heat charge variation depending on the variations of the temperature drop, substituted the “heat capacity” quantity. The heat conductivity coefficient λ , which is used in the current heat transfer theory, was included as a factor into the thermal conductivity coefficient a . The thermal flow Φ_a has become the flow of heat charges, unlike the heat flow Φ in the current heat transfer theory, which reflects only the heat exchange rate.

The paper [9] presented new persuasive arguments proving that thermal capacity with the unit $J K^{-2}$ and thermal resistance with the unit that equals to $J^{-1} s K^2$ objectively reflect the essence of physical phenomena. Meanwhile, heat capacity with the unit $J K^{-1}$ and thermal resistance with the unit $W^{-1} K$, which are currently used in the heat transfer theory, do not reflect this essence and lead to “a number of unnecessary additional calculations, formulas, tables, correction factors, and remarks.” The paper [9] contains proofs that calculations of the thermal **efficiency** through using the absolute values of thermodynamic temperature T , lead to physical nonsense, and calculations of thermal **efficiency** should be done only through using the temperature difference ΔT .

2.3. Explanation of the “Thermal Capacity” Concept

Let us understand the variation of heat charge $d\Theta$ in the equation (2.4) as a certain number of energy carriers entering the system in the ordered heat form of motion, without identifying it with the total variation of heat exchange between the system and its environment, i.e. the total of variations of energies of the ordered and the disordered heat movement. This leads us to conclusion that can seem paradoxical at first: the main idea of caloric theory turns out to be correct if we understand caloric not as the total amount of entering heat, but the amount of entering heat energy of ordered heat motion, associated with movement of heat charge. This is

how this situation was understood by Carnot; he did not identify the heat energy with variation of heat exchange.

In accordance with this interpretation, the flow of heat charge should be considered not as the flow of the heat motion energy, but as the flow of the heat motion ordered part. It is exactly heat charge that can be accumulated in a system. This is why *in the heat form of motion the energy capacity of a system should be considered as capacity concerning the heat charge, and not as capacity concerning the total amount of heat.*

This is why **thermal capacity** $C_{tm} = d\Theta/dT$ with the unit $J K^{-2}$, which was listed in Table 1, is different from **heat capacity** $C = \delta Q/dT$ with the unit $J K^{-1}$, that is currently used in thermodynamics. In the same way, the infinitesimal amount of heat charges $d\Theta$ entering the system is less than the elementary amount of heat δQ brought to the system. The heat charge $d\Theta$ that enters the system is a part of the amount of heat δQ .

2.4. Enquality of the Units of Heat Capacity and Thermodynamic Entropy

We have consciously not included the “thermodynamic entropy” into Table 1, in order not to mix this term with the terms “statistical entropy” and “informational entropy,” which have totally different content. We toatally agree with A. Veinik [3] and many other scientists who consider the introduction of entropy into thermodynamics by Clausius as a reason of “disease” that cannot be healed for over a century and a half.

The elementary amount of moving heat charge is defined by the equation $d\Theta = \delta Q/\Delta T$; it cannot be understood as variation of thermodynamic entropia defined by the equation $dS = \delta Q/T$, for one because ΔT and T are two different physical quantities. Thus the amount of heat charge $d\Theta$ and thermodynamic entropia are defined by different quantity equations, and therefore they have different physical content.

A number of articles on metrology (for instance, the review paper [16]) consider the equal dimensions of heat capacity and thermodynamic entropia as one of the drawbacks of the SI. But there is nothing to blame the SI for in this case. The urge of many scientists to look for identity of physical quantities based on identity of ther dimensions or units is totally groundless. The physical content of a quantity is defined only by its quantity equation, and not by the dimension formula. If two physical quantities of different nature have one and the same dimension, the reason should be sought in the incorrect quantity equation of one of these quantities.

3. The Unit of Temperature and the Unit of Temperature Difference

3.1. Metrology Measures Temperature Difference, Not Temperature

In Section 1.4 we showed that difference of potential ΔP and potential of the system P are physical quantities of different content. Accordingly, this also relates to temperature drop ΔT and absolute temperature T . It was already pointed out in papers by Emerson [2, 17, 18] that “*temperature difference is not a quantity of the same nature as thermodynamic temperature, and, possibly, it is of a different type*” and that “*all thermodynamic temperatures are temperature differences, and they should be estimated with a unit of temperature difference.*” In the paper [16, problem 9] attention is drawn to the fact that computer programs, developed to be used in metrology, do not discern between T and ΔT .

Finally, the inclusion of the heat form of movement into the generalized system of physical quantities [8] (see the second half of Table 1) became possible with the use of equation (2.4), in which the temperature difference ΔT is used instead of the thermodynamic temperature T . In modern metrology the difference between temperature and temperatue difference is not yet being taken into account, which will be further discussed below.

3.2. The Current Unit of Thermodynamic Temperature

The decision to make the unit of thermodynamic temperature, kelvin, a conventional base unit in the SI was caused by historical reasons described in the paper [2] — first of all, the presence of measurement equipment and smoothly running measurement techniques.

The unit kelvin was adopted by Resolution 3 of the 13th CGPM [19] (1967-1968) as both the unit of thermodynamic temperature and the unit of temperature difference. The only thing that has changed since then was the list of fixed points on the temperature scale.

But Resolution 1 of the 24th CGPM (2011) on the unit kelvin states the following: “the kelvin will continue to be the unit of thermodynamic temperature, but its magnitude will be set by fixing the numerical value of Boltzmann constant to be equal to exactly $1.380\ 658\ \times 10^{-23}$ when it is expressed in the SI unit $\text{m}^2\ \text{kg}\ \text{s}^{-2}\ \text{K}^{-1}$, which is equal to $\text{J}\ \text{K}^{-1}$ ”. This resolution mentions kelvin only as a unit of thermodynamic temperature. That is, the arguments listen in the papers [2, 17, 18] and the previous understanding of the kelvin unit [19] were not taken into account.

There are several other questions beyond the discussion concerning definition of the kelvin unit. These questions are important both for physicists and for metrologists, while the answers only seem to be clear. The analysis of these questions and answers is given below and leads to important conclusions.

3.3. What Is the Definition of the “Thermodynamic Temperature” Term?

Oddly enough, this physical quantity lacks a generally accepted definition. To put it more exactly, there are many definitions, but all of them are different. It should be for a reason that the leading Russian metrological institute, the All-Russian Scientific Research Institute of Metrology named after D.I. Mendeleev included the following phrase in the introduction on its online portal [21]: “*Temperature is a parameter artificially introduced into the equation of state.*”

The common thing in different definitions is stating the fact that temperature is a physical quantity describing mean kinetic energy of particles of a system W_k , which is in the state of thermodynamic equilibrium.

The original source [21] also provides explanation on the reason why it is the unit kelvin, and not the unit joule, that is used for thermodynamic temperature: “*Since the temperature concept is closely connected to mean kinetic energy of particles, it would be natural to use joule as its unit. However, the energy of heat movement of particles is very small in comparison with joule, its use turns out to be inconvenient. Heat movement is measured in other units, which are derived from joule by means of conversion factor k* ”.

It is also known [22] that L.Boltzmann measured temperature in units of energy, and this corresponds to the value of Boltzmann constant $k = 1$. The constant was introduced not by L.Boltzmann himself, but by M.Planck in 1900, and it was also M. Planck who calculated the value of Boltzmann constant $k = 1,346 \cdot 10^{-16}$ erg/degree.

It follows from this that the use of kelvin as a conventional base unit in the SI is caused by the habit to measure temperature in the units of commonly used temperature scale with commonly used measuring instruments. As a result, the introduction of a separate dimension for temperature Θ in the SI leads to dimensions that are difficult to comprehend, e.g. the dimension $\text{L}^2\text{MT}^{-2}\Theta^{-1}$ for heat capacity.

3.4. What Should Be the Unit of Heat Charge in the SI?

Let us consider the formula for calculation of kinetic energy of translatory motion of a perfect gas molecule. In the kinetic theory of gases there is an equation:

$$W_k = 3kT/2 \quad , \quad (3.1)$$

where k – Boltzman constant, which corresponds to the energy of movement per one degree of freedom of a molecule. If we assume such an understanding as a basis, it then follows from the equation (3.1) that thermodynamic temperature T should be a dimensionless quantity. Indeed,

according to the equation (3.1), thermodynamic temperature T is the ratio of the kinetic energy W_k to the energy of movement of one degree of freedom of the molecule k .

According to the classification of dimensionless quantities given in the paper [23, section 2.1], thermodynamic temperature is a similarity criterion [23, section 2.3]. Then the equation $(3k/2) = W_k/T$ is an off-system unit for thermodynamic temperature [23, section 2.2]. Hence the conclusion is that in the middle of the 20th century a similarity criterion was made a base quantity in the SI, and its unit was called kelvin.

A. Veinik held a similar point of view [3]; he shared the idea that heat charge, as a coordinate of state of the heat movement, is a quantizable quantity. He called the elementary heat charge **thermon** (later, in [7], wärmion) marked it with the symbol τ , and calculated its value by dividing the energy of one mole of gas by the Avogadro number. The value of thermon turned out to be exactly 3 times higher than the value of Boltzmann constant. The conclusion from this is that Boltzmann constant k can be considered as one third of thermon τ , while thermon can be understood as kinetic energy of three degrees of freedom of a molecule. Then the equation (3.1) can be written in the following form

$$W_k = \tau T/2 \quad . \quad (3.2)$$

Since the unit of thermon, as well as that of Boltzmann constant, is J K^{-1} , the thermodynamic temperature T should be understood as the number of thermons in a homogenous system. The kinetic energy of all the molecules in ordered motion should be understood as half the product of kinetic energy of one thermon and the number of thermons in the system. And then the **total heat charge** of the system can be considered as the product of elementary heat charge τ and the number of heat charges in the system.

A similar conclusion was obtained independently of A. Veinik by D. Ermolaev in the paper [9], in which a single heat charge is defined as the kinetic energy of heat movement of one degree of freedom, or, if we use the language of the paper [9], one “heat particle”. A similar point of view is also expressed in the paper [13].

3.5. Dimension and Unit of the Temperature Difference in Updated SI

The number of elementary heat charges in the total heat charge, as well as the number of elementary charges of any nature in total charge can be measured in pieces or quanta [23, section 3.2]. The paper [24] suggests a generalized name ent for the unit of number of entities. Accordingly, in updated SI the dimension of temperature drop (temperature difference) should be the dimension of the number of entities with the symbol N [13, 23].

This proves the lack of necessity to introduce a special “thermodynamic temperature” quantity with its own dimension into the system of quantities ISQ. Kelvin is just another unit of the base quantity “number of entities”, but its numerical value is different from that numerical value of the unit ent.

The base quantity in updated SI as understood in the papers [13, 23] should be energy with dimension E. If the dimension symbols we have suggested — E for energy and N for number of entities are used, the dimension rule for the equations (3.1) and (3.2) in updated SI will be followed if the dimension of thermon τ (and Boltzmann constant k) will be equal to EN^{-1} , which corresponds to the unit J ent^{-1} (J quantum^{-1} or J pcs^{-1}). In the current SI the dimension rule in the equations (3.1) and (3.2) is followed under the condition that the unit of k and τ will be J K^{-1} . Therefore the units of Boltzmann constant and of thermon coincide.

Kelvin, which is equal to one Celsius degree, is a quantum of temperature difference equal to one hundredth of temperature difference between the melting point of ice and the boiling point of water. If they chose to consider kelvin as one fiftieth of this temperature interval, the value of kelvin would be twice bigger.

Truth be told, after the melting point of ice officially got the value 273.15 K, it turned out that the temperature difference between the melting point of ice and the boiling point of water is

slightly less than 100 K. So technically this means one cannot speak of one hundredth of the temperature difference between the melting point of ice and the boiling point of water any more. Such a situation is another proof of the danger of administrative affixment of definitions of units to physical constants, which is persuasively discussed in the paper [25]. The story of affixing the value of kelvin to the temperature of ice melting illustrates this danger.

The understanding of thermodynamic temperature and temperature difference described here leads to the necessity of essential changes of units in the heat form of movement, as it is shown in Table 1. Surely, everything can remain as it is, but this will mean neglecting the long-time disease of the heat transfer theory.

3.6. Temperature According to the Current Temperature Scale

Today there is a special International Temperature Scale ITS-90 for measuring temperature; in fact, it is not a scale, but a calibration standard for measuring equipment. This scale has 6 temperature intervals, from 0.65 K to ∞ ; besides, these intervals are so different from each other that it is convenient to compare them only with the help of logarithmic scale.

The molecular kinetic theory of gases, for the purposes of which the “thermodynamic temperature” concept was introduced, studies macro matter in relatively small range of temperatures, while ultralow and ultrahigh temperatures are estimated with the help of other branches of physics. These branches of physics study not only substance, but also electromagnetic field and other structural levels of matter. Therefore the adjective “thermodynamic” is not relevant for other levels.

Now let us discuss the content of the “temperature” concept on other structural levels of matter.

4. Heat Charge and Level Physics

4.1. Temperature on the Different Structural Levels of Matter

Before discussing the structure levels of matter, we should at least briefly introduce the reader to the “level physics” concept.

Level physics is a relatively new branch of science, which is being intensively developed since the end of the 20th century. However, in the middle of the 20th century A. Veinik [3] already advised to study “*the levels of the general structure of the universe: sub macro world, macro world, micro world, sub micro world, etc.*” He wrote: “*Each elementary motion form is simultaneously inherent to all the levels of the universe. With that, the transition from one level to another (from quantitative characteristics of one system to those of another one) is followed not only by the quantitative, but also by the qualitative changes of motion.*”

Currently level physics slowly turns into a solid edifice. Level physics considers general features of phenomena on different levels of matter structure from the point of view of a single generalized picture. The level approach supplants the linear approach, according to which the data concerning the world around us are gathered and analyzed without consideration of general features that unite them.

The philosophical content of level physics is explained quite fully in the work [26]. A physicist’s view on the level structure of matter is given in the work [27]. A special attention in the work [27] is paid to vortex structure of material objects on any level of structure of matter. The vortex structure of material objects is also taken into account when analyzing the base quantities set in the paper [13]. The hierarchical chart of the structure of matter provided in the work [27] would require explanations the content of which is beyond the scope of an article on metrology. Therefore Fig. 1 shows a simplified chart, which is convenient because of the presence of the temperature axis.

The chart provides qualitative representation of the physical content of structural levels and sublevels of matter. The quantitative proportions are observed in it only partially, according

to the current state of cosmic physics. In this chart E_{fix} stands for binding energy of the components of the system. It is defined by the equation

$$E_{fix} = \sum_i (E_{fix} - E) , \quad (4.1)$$

where E_{fix} — total energy of the i -th component in the unbound state, E — total energy of the bound system.

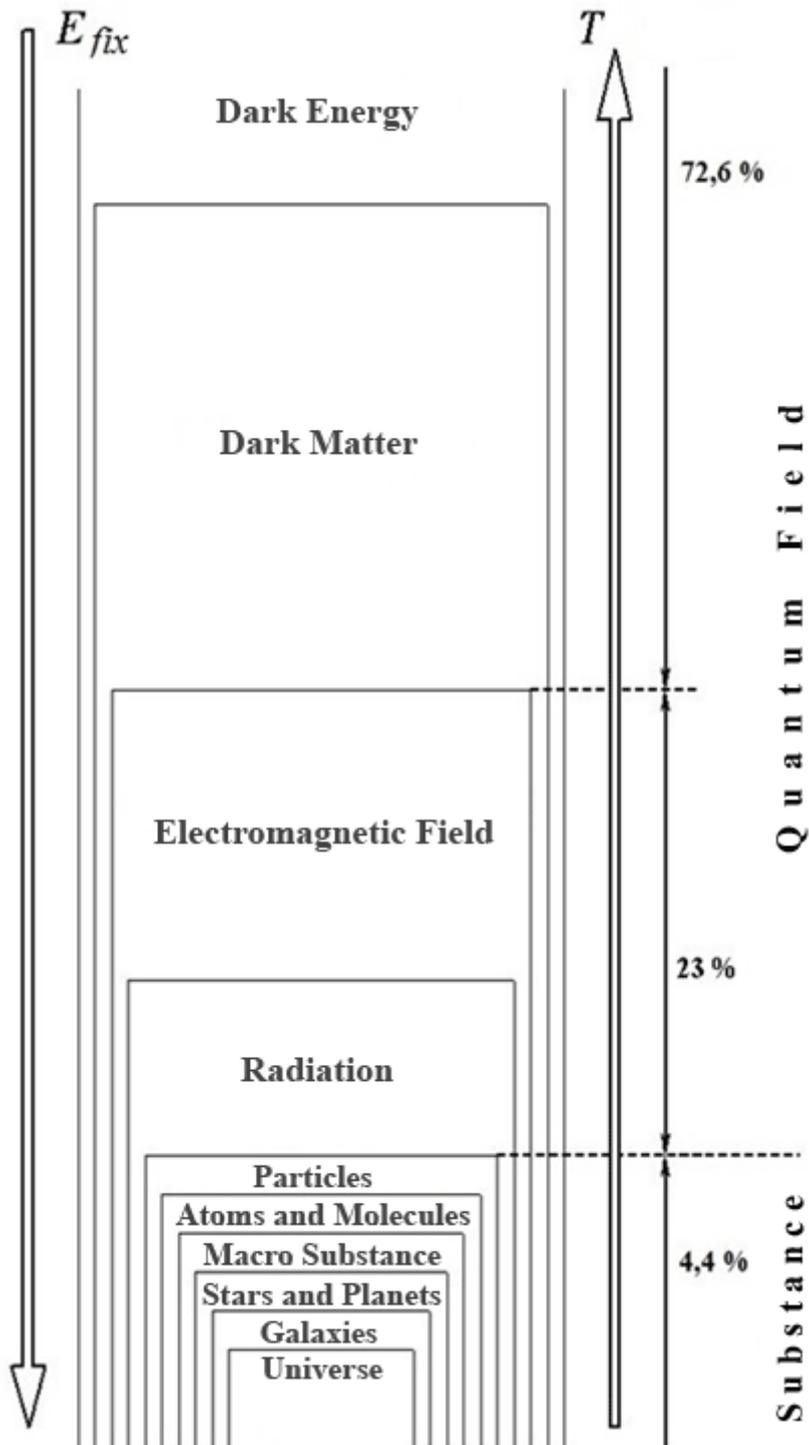


Fig. 1. The Hierarchic Chart of the Level Structure of Matter

According to level physics, the physical content of the components on the different levels of the structure is different. From metrological point of view, each component on any level is a material object, and the number of objects is measured in the units of the number of entities. Therefore the dimension of binding energy E_{fix} is equal to EN^{-1} .

According to the chart, the “**substance**” level within which modern thermodynamics is used, occupies merely a small part of what is called matter. In real numbers the temperature scale ITS-90 considers temperature up to 1234,93 K. But substance fills our Earth and its environment, substance was the first thing that humanity started to study within matter, and the majority of science and research literature is devoted to substance. Modern thermodynamics with its thermodynamic temperature studies merely a small sublevel, “macro substance,” and it is on this level that heat charge is measured in thermons.

On the other levels and sublevels there are energy carriers and elementary charges, which are common only for a considered level. They have their own structure and binding energy. The temperature on other levels cannot be called thermodynamic, since the state of other levels should be studied by other branches of physics. The unit kelvin can be applied to them only conventionally, in order to enable the numerical comparison. But the numerical values of the elementary heat charge change by orders of magnitude when moving from level to level and from sublevel to sublevel. To imagine this better, we can compare such energy carriers as cosmic bodies on the lower sublevel and neutrino on the higher sublevel.

The amount of energy of elementary heat charge on each level is a fundamental physical constant for that level. The higher the level in the chart, the smaller the size of its elementary heat charge, the higher the number of energy carriers, which contain heat charges, and the higher the energy of movement of each elementary heat charge. Therefore, the higher the level, the higher the temperature T , since it is a measure of number of heat charges.

The indications on both axes of the system are conventional, but by nature they are close to logarithmic ones. This means the temperature axis in this chart has neither beginning nor end, to say nothing of temperature equal to 0, and even more so about negative temperature. Besides, what is measured is temperature difference, not the absolute value of temperature, and the temperature difference can indeed be negative. We can speak only of the possibilities of science to measure ultralow and ultrahigh values of temperature.

Let us give examples of understanding temperature on the “Radiation” level.

4.2. Wien’s Displacement Law Confirms the Unit of Boltzmann constant

Wien’s displacement law describes heat radiation, which is a particular case of electromagnetic radiation in a certain wavelength range. Energy carriers are waves themselves, while the single heat charge on this level is the energy of one wave. In this case the number of single charges is also measured in ent (quanta, pieces), except that the unit ent corresponds to one wave.

Wien’s displacement law belongs to dependences of the emissive capacity of a black body from the variation of heat radiation wavelength λ . It sets the connection between the black body temperature T , which is also referred to as **radiational temperature**, and the heat radiation wavelength λ_m , which corresponds to the extreme point (maximum) of this dependence.

Wien’s law is usually written in the following form:

$$T\lambda_m = b, \quad (4.2)$$

where b – Wien constant, which is equal to 0,002899 m K. But the unit of Wien constant b needs to be refined.

As it was shown in the paper [23, section 5.5], the dimension of wavelength is LN^{-1} , and the unit is m ent^{-1} (on the “Radiation” level – m wave^{-1} , since the energy carriers are waves). Therefore, the unit of b is equal to m K ent^{-1} (m K wave^{-1}), that is, the wavelength corresponding to λ_m at a temperature of T in kelvins.

Wien constant can be deciphered as a function of fundamental physical constants

$$b = hc/x_b k , \quad (4.3)$$

where h – Planck constant; c – speed of light in vacuum, k – Boltzmann constant, x_b – a dimensionless physical constant in the form of a numerical factor that equals to 4,965. The analysis of the equation (4.3) shows that if the unit of Planck constant h is J s ent^{-1} (in this case J s wave^{-1} [23, Section 5]), Boltzmann constant k in the equation (4.3) has the unit J K^{-1} , as it was shown in the Section 3.5.

4.3. A New Understanding of Planck's Law of Thermal Radiation

The Planck's law of thermal radiation, which defines emissivity of a black body, contains a dimensionless factor

$$1/[\exp(h\nu/kT) - 1] , \quad (4.4)$$

which defines the physical content of this law (ν – radiation frequency). In this factor let us single out the similarity criterion

$$x_{pl} = h\nu/kT . \quad (4.5)$$

If the denominator (kT) of this criterion is understood as energy carried by waves radiated by the black body in low frequency range, then it should look differently — ($n_w kT$), where n_w is the number of heat radiation waves of the black body. In the same way, the numerator ($h\nu$) of this criterion should be understood as the energy carried by photons radiated by the black body in the high frequency range. This is why in the numerator of the criterion x_{pl} there should be expression ($n_{ph} h\nu$), where n_{ph} is the number of photons radiated by the black body. And the similarity criterion x_{pl} should be written not as in (4.5), but as the following expression

$$x_{pl} = (n_{ph} h\nu)/(n_w kT) . \quad (4.6)$$

In such a form x_{pl} gets the following physical content: it is the ratio of energy of the number of photons n_{ph} emitted by the black body to the energy of a certain number of electromagnetic waves n_w emitted in the thermal range by the same black body. Then the following equation is correct for the similarity criterion [x_{pl}]:

$$[x_{pl}] = (\text{J photon}) (\text{J wave})^{-1} = \text{photon wave}^{-1}.$$

Since the units called “wave” and “photon” are particular cases of the ent unit (quantum, piece), it becomes clear that the similarity criterion x_{pl} includes another similarity criterion (n_{ph}/n_w) as a factor; it is this similarity criterion that defines the physical content of Planck's law. This conclusion is important because when the similarity criterion (n_{ph}/n_w) is absent from the modern form of Planck's radiation law, it is assumed by default that the similarity criterion (n_{ph}/n_w) is equal to 1, though it can be equal to 1 only in a particular case.

If the criterion (n_{ph}/n_w) is used, the sense of impossibility of the “ultraviolet catastrophe” resulting from the Rayleigh–Jeans formula becomes obvious. The total radiation energy of the black body consists of the two summands: the heat radiation energy in the form of energy of electromagnetic waves in the heat range, and the energy of photons radiated by the black body, which are particles, not waves. Though, the velocity of electromagnetic waves in vacuum and the velocity of photons in vacuum are the same, a photon and a wave are two different energy carriers with different physical properties. In particular, there is a big difference between

dissipative absorption of electromagnetic wave energy and dissipative absorption of photon energy in any medium.

In the low frequency range the radiation of a black body consists primarily of electromagnetic waves. The higher the frequency, the higher the percentage of the radiation photons, while the percentage of heat radiation drops till it becomes negligible. As for the total radiation energy, which includes the energy of radiated photons, it grows constantly, both with the rise of frequency and the rise of temperature of the radiating black body.

Let us notice that the curves in the charts of dependence of radiant emittance from wavelength, which reaches maximum at λ_m (according to Wien's law), have to do only with the energy of heat radiation, that is, only one of the summands of the total radiation energy of the black body.

Given that $x_{pl} \ll 1$, that is, on the lower limit of the frequency range of infrared radiation, Planck's formula is transformed into the Rayleigh–Jeans formula, which defines equilibrium density of heat radiation based on statistical representation of distribution of energy into degrees of freedom. Hence, the conclusion that representation of photons radiation energy with the expression (kT) is relevant only on the substance level.

There is one more important consequence. Representation of the similarity criterion x_{pl} in the form (4.6) denies the existence of particle-wave dualism.

As a result, another proof of the importance and necessity of introduction of the number of entities with dimension N and unit ent (quantum, piece, wave, photon, etc.) into the base quantities set [13, 23] is provided.

5. Conclusions

1. It is shown that the heat charge theory, which explains the essence of the units of heat quantities, was developed half a century ago, but unfortunately remains unnoticed (or maybe even ignored) by modern physics and modern metrology.

2. The difference between the concepts of “quantity of heat” and “heat energy” is explained; the latter is represented as shown by Carnot.

3. The physical content of the electrothermal analogy, which allows using generalized equations of transition for the heat movement, is revealed.

4. A modification of Fourier law, which allows applying the generalization and the sistemetization methods for physical quantities of the heat movement, is presented.

5. A table of units of heat quantities corresponding to the modified form of Fourier's law is composed; these units are different from the modern units of heat quantities.

6. It is stated that the unit kelvin should be first of all a unit of temperature difference (temperature drop).

7. It is proven that the unit kelvin is an off-system unit of a similarity criterion, which is thermodynamic temperature.

8. The physical content of the elementary heat charge and its unit is shown.

9. It is explained that the unit kelvin is a particular case of the unit of number of entities with administratively assigned numerical value.

10. An explanation of temperature from the point of view of level physics is given.

11. As an example of the use of the number of entities in quantum optics, an updated form of Planck's law of thermal radiation is provided.

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