ON THE TEMPERATURE AND NATURE OF HEAT TRANSFERS IN RADIATIVE HEAT TRANSFER

Milyute E.
Milyuvene V.
Milyus A.
IRG „LITAVEM-3", Vilnius
https://doi.org/10.5281/zenodo.20448097

Abstract

This paper examines the nature of temperature and heat transfer during radiative heat exchange and proposes an alternative interpretation of thermal phenomena. The authors review the historical development of theories of heat, from caloric theory to wave and molecular-kinetic approaches, and argue for reconsideration of several fundamental concepts related to temperature and heat. Based on the proposed model of matter as a self-contained rotating spherical vortex ("atom-vortex"), the paper suggests that temperature is determined by the rotational state of matter and that heat transfer is associated with photons interpreted as carriers of heat and mass transfer. A relationship between emitted heat, temperature, and rotational motion is proposed, and radiative heat transfer is interpreted within this framework. The authors conclude that the presented results motivate a revision of conventional views in thermodynamics and heat-transfer theory.

Keywords: temperature; heat; heat transfer; radiative heat exchange; thermal radiation; photon; caloric theory; molecular-kinetic theory; atom-vortex model; thermodynamics; electromagnetic radiation; heat–mass transfer

In modern physics, there is still no unified understanding either of the nature of temperature T or of the nature of heat Q [1–3]. A correct understanding of the nature of heat is of fundamental importance, since the correct understanding of a large branch of physics depends on it. The material theory of heat that existed until the middle of the 19th century viewed heat as the motion of a certain substance in the form of "imperceptible particles" — corpuscles much finer than air and moving rapidly through space, whose propagation was considered identical to the rectilinear propagation of light [4]. Based on this theory, measuring instruments were developed that made it possible to begin quantitative (calorimetric) studies of thermal phenomena (**J. Black**, 1762). This theory was later discarded and replaced by wave and molecular-kinetic theories of the nature of heat.

The foundations of the science of temperature were laid by the work of **M. V. Lomonosov** [5] two and a half centuries ago. Nevertheless, these ideas have still not been considered by mainstream science, accepted officially, or developed further.

In the present work, from the standpoint of the model proposed by the authors - according to which the fundamental form of existence of a liquid homogeneous substance is a self-contained rotating spherical vortex [6–7] - several basic concepts concerning the nature of temperature and heat are reconsidered.

For several centuries, there was a struggle between two hypotheses concerning the nature of heat: the **material** and the **kinetic** theories. The material theory of heat regarded heat as a form of motion of "imperceptible particles" — the motion of corpuscles of a certain substance.

This theory was developed by **F. Bacon** (1561–1626), **P. Gassendi** (1592–1655), **R. Descartes** (1596–1650), **R. Boyle** (1627–1691), **R. Hooke** (1635–1703), **E. Mariotte** (1620–1684), **J. Locke** (1632–1704), **I. Newton** (1643–1727), **N. Lémery** (1645–1715), **C. Wolff** (1679–1765), **H. Boerhaave** (1668–1738), **G. Hamberger** (1697–1755), **P. Musschenbroek** (1692–1761), and **L. Euler** (1707–1783).

Quantitative studies of caloric (heat substance) were carried out by **G. W. Krafft** (1701–1754), **G. W. Richmann** (1711–1753), **J. Black** (1728–1799), **I. Wilcke** (1732–1796), **L. de Morveau** (1737–1816), **A. Lavoisier** (1743–1793), **C. L. Berthollet** (1748–1822), **P. S. Laplace** (1749–1827), **A. F. de Fourcroy** (1755–1809), **J. B. J. Fourier** (1768–1830), **P. L. Dulong** (1785–1838), **A. Petit** (1791–1820), **N. L. S. Carnot** (1796–1832), and **B. P. E. Clapeyron** (1799–1864).

Their work led to the establishment, by the 1770s, of the basic calorimetric concepts: the unit for measuring the quantity of heat (the calorie introduced by **Wilcke**), heat capacity, specific heat capacity, and the heat of fusion and vaporization. The English chemist **Joseph Black** was the first, in 1754–1755, to clearly distinguish between the concepts of **quantity of heat and temperature**, defining temperature as an indicator of the degree of heating measured by a thermometer. To relate these concepts, he introduced the concept of **specific heat capacity** (1760): the amount of heat required to raise the temperature of a unit mass of a substance by one degree. Heat capacity differed from one substance to another. It turned out to be a characteristic property of matter rather than of heat itself. Black discovered not only that the melting point of ice remains constant, but also that thermometer readings stay unchanged at one and the same temperature despite the input of heat, until all the ice has melted. From this, he arrived at the concept of **latent heat of fusion.** Using the calorimeter he invented in 1762, Black carried out, during 1759–1763, the first measurements of the heat capacities of substances and of the latent heat of fusion of ice and the evaporation of water.

In 1787, the French chemists **Claude Louis Berthollet** (1748–1822), **L. Guyton de Morveau** (1737–1816), **A. Lavoisier**, and **A. Fourcroy** proposed a special name for the unit of measurement of the quantity of heat -**calorique** ("caloric," or heat substance).

Only almost one hundred years later (in 1852) was the unit of quantity of heat legalized and later given the name **calorie**. However, the state of physical experimentation at that time did not make it possible to determine what kind of substance it actually was.

The period from the end of the 18th century to the beginning of the 19th century was enriched by other important discoveries, whose true significance, according to the authors, has still not been fully appreciated. It was during this period that the doctrine of "**radiant heat**" began to take shape. The term "radiant heat" and the first observations of heat rays belong to the Swedish chemist **C. W. Scheele** (1742–1786), who, in his *Chemical Treatise on Air and Fire* (1777), along with reporting the discovery of oxygen, also discussed heat rays. He introduced the concept of **thermal radiation** ("radiant heat") and investigated thermal radiation. Scheele pointed out that air is not heated by heat rays and that a glass mirror does not reflect heat rays. In doing so, he confirmed an earlier observation by **Lambert** that glass blocks heat rays. The beginning and middle of the 19th century were also marked by other landmark discoveries in physics which, if correctly interpreted, could have directed the development of physics in a completely different direction.

The beginning and middle of the 19th century were also marked by the appearance of other landmark discoveries in physics which, if interpreted correctly, could have redirected the development of physics along an entirely different path.

First, important manifestations of the interrelation of thermal phenomena with other phenomena were discovered - primarily their relationship with light. The connection between light and heat had long been noted. These questions were studied by **G. B. della Porta** (1582–1666), **P. del Buono** (1625–1659), **E. Mariotte** (1620–1684), **J. G. Schultze** (1687–1744), and **P. Bouguer** (1698–1758). In 1777, **J. Lambert** (1728–1777) conducted experiments on the propagation of heat along a rod and demonstrated that "**heat rays**," like light rays, propagate in straight lines and that their intensity changes inversely with the square of the distance. **M. van Marum** (1750–1837), in 1786, established a connection between heat and the electric spark. **M. A. Pictet** (1752–1825) carried out the first more complete investigations of the properties of thermal radiation (1790). **P. Prevost** (1751–1839), based on Pictet's experiments, proposed his theory of the "equilibrium of fire" - thermal equilibrium. **W.Nicholson** (1753–1815), in 1802, discovered the luminous effect of electric current. **A. F. de Fourcroy** (1755–1809), in 1800, discovered the heating effect of electric current. **F. W. Herschel** (1738–1822), in 1800, discovered infrared rays in the solar spectrum. **V. V. Petrov** (1761–1834), in 1802, discovered the electric arc and carried out a series of experiments using it to melt metals and burn various substances. **J. Ritter** (1776–1810), in 1801, established that silver chloride blackens under the action of radiation belonging to the invisible part of the spectrum — later recognized as the discovery of ultraviolet rays. **J. Leslie** (1766–1832) obtained relative values for the emissive power of various bodies (with respect to soot) and, in 1804, demonstrated that radiation depends on direction. **H. C. Ørsted** (1777–1851), in 1820, discovered the magnetic effect of electric current (revealing the vortex state of matter). **K. Matteucci (**1811–1868), in 1833, showed that heat rays interfere with one another. **J. D. Forbes** (1809-1868), in 1833, confirmed the interference of heat rays using an apparatus with two Fresnel mirrors and, in 1834, observed the polarization of thermal radiation. **J. C. A. Peltier** (1785-1845), in 1834, discovered the phenomenon of heat release or absorption during the passage of electric current. **M. Melloni** (1798–1854), in 1833, constructed a thermomultiplier; in 1835, he proposed that heat rays and light rays have the same nature and differ only in wavelength; in 1836, he confirmed the existence of polarization of thermal radiation; and in 1841, demonstrated the identity of thermal and light rays.

In 1841, **J. P. Joule** (1818–1889) established the law of the heating effect of electric current, and in 1843 carried out the first measurement of the mechanical equivalent of heat. In 1842, the law of the heating effect of electric current was also discovered by **E. H. Lenz**. **J. R. von Mayer** (1814–1878), in 1842, was the first to formulate the law of equivalence between mechanical work and heat and calculated the mechanical equivalent of heat. Independently of him, J. Joule reached the same discovery in 1843, and in 1847 **H. Helmholtz** expanded the scope of this law, extending its application beyond mechanical and thermal energy to include other forms of energy.

However, the scientific community reacted in a particular way to the results of M. Melloni's work on radiant heat. By that time, the corpuscular theory of light, whose origins had been laid by the founder of optics - the Arab scholar **Ibn al-Haytham** (Latinized: **Alhazen**) (965-1039) - had been replaced by the wave theory of Young and Fresnel. Supporters of the wave theory of light believed that light consisted of oscillations of the ether. The wave theory of light had already become almost universally accepted; therefore, the complete identity of thermal rays and light rays was interpreted as proof of the **wave nature of heat**. On this basis, all thermal effects were explained, and at the same time the **caloric theory** (the concept of heat as a substance) was abandoned.

Thus, the concept of the existence of a material (substantial) medium composed of corpuscles - "*imperceptible particles*", much finer than air and moving rapidly, accompanying light and propagating in straight lines similarly to light - on the basis of which measuring instruments were created that made it possible to begin quantitative (calorimetric) studies of thermal phenomena, was abandoned and replaced by the concept of the **kinetic nature of heat**, i.e., the **molecular-kinetic theory of J. Bernoulli**, whose development he began in 1738 (Section X [8]). It was this theory that formed the foundation of the modern understanding of the nature of heat.

However, neither the wave theory nor the molecular-kinetic theory of heat is capable of explaining:

a) the physical nature of temperature;

b) the physical nature of heat;

c) the rectilinear propagation of radiant heat — its principal property;

d) the ability of heat to propagate through a vacuum.

Earlier, in our works [6–7, 9], we showed that any charge Q - gravitational, electrostatic, or magnetic - as a carrier of interaction consists of flows of substance emitted by a body, i.e., vortex-like stream structures composed of flows of isolated convective cells - photons of a specific wavelength - carrying the mass inherent to them and the corresponding quanta of action.

The existence of an identity between light rays and thermal rays, established by **Melloni** in 1835–1842, allows one to assert that the carrier involved in thermal interactions is caloric - responsible for heat transfer and measurable by calorimetric methods - which, according to the authors, was unjustifiably discarded in the middle of the 19th century and replaced by Schrödinger's wave function in 1926. It is precisely this "*caloric*", which provides heat and mass transfer during radiative heat exchange across different regions of the electromagnetic spectrum, that is considered to be a photon moving in a straight line and which, according to modern views, is regarded as massless.

Let us return to the law of the heating effect of electric current established by **J. Joule** in 1841 and confirmed by **E. H. Lenz** in 1842. This law states that the quantity of heat Q released during the passage of a current J through a conductor with resistance R over a time interval t is:

$$Q = J^2Rt \quad (1)$$

Let us express the current $J = Q/t$ and the resistance $R = U/J$ in equation (1) through the quantity of charge found by us in [6]:

$$Q = \sqrt{mv_m^2 r_m} \quad (2)$$

where m is the mass of the substance of a liquid rotating spherical atom-vortex, v_m is the speed of azimuthal rotation around its own axis, r_m is the radius of the atom-vortex. Substitution gives:

$$Q = \varphi \cdot mv_m^2 , \quad (3)$$

where

$$\varphi = c/v_R, \quad (4)$$

here the dimensionless factor φ characterizes the degree of excitation of the radiating medium and c is the speed of light, v_R is the speed of current propagation through a conductor with resistance R.

The resulting expression (3) represents the law of radiation of heat from an atom-vortex. From it, it follows that the quantity of heat released Q is directly proportional to the square of the azimuthal rotation speed around the atom-vortex axis, i.e., proportional to twice the kinetic energy of rotation of the vortex forming the atom. According to the authors, this demonstrates how correct **M. V. Lomonosov's** assertion was that the release of heat is connected with the rotational motion of individual "*imperceptible particles*" - atoms forming matter. Dividing in expression (3) the product of mass by the square of the azimuthal velocity by the **Boltzmann constant** k, one can directly proceed to determining the temperature of the atom-vortex in degrees:

$$T = mv_m^2/k . \quad (5)$$

It should also be noted that already at that time M. V. Lomonosov stated: "There must exist a greatest and final degree of cold, which should consist in the complete cessation of the rotational motion of particles" [10]. Applying this thesis to the formulas obtained above (3–5) shows that, in the absence of rotational motion of an atom or of a larger body, radiation also ceases, i.e., the atom or body becomes cold, neutral, non-interacting - that is, "dark."

Table 1.

Mass Values of Photons of Different Wavelengths

Radiation type	Symbol	Mass	Wavelength, λ	Frequency w	Class
γ-radiation	γ	10^{-27} g	$\sim 10^{-11}$ cm	$\sim 10^{21}$ s^{-1}	Photons
X-ray radiation	γ_{ret}	10^{-30} g	$\sim 10^{-8}$ cm	$\sim 10^{18}$ s^{-1}	
Ultraviolet rad.	γ_{uv}	10^{-32} g	$\sim 10^{-6}$ cm	$\sim 10^{16}$ s^{-1}	
Visible light	γ_v	10^{-33} g	$\sim 10^{-5}$ cm	$\sim 10^{15}$ s^{-1}	
Infrared radiation	γ_{if}	10^{-35} g	$\sim 10^{-3}$ cm	$\sim 10^{13}$ s^{-1}	
Radio radiation	γ_{rad}	10^{-37} g	$\sim 10^{-1}$ cm	$\sim 10^{11}$ s^{-1}	
Relic radiation	γ_{rel}	$10^{-40} \div 10^{-43}$ g	$\sim 10^{2} \div 10^{5}$ cm	$\sim 10^{8} \div 10^{5}$ s^{-1}	

The identity of thermal and light rays, established by the works of **M. Melloni** in 1835–1842, makes it possible to consider that heat–mass transfer is carried out by caloric particles — photons of different wavelengths. *This makes it possible to calculate the number of photons involved in heat transfer*. Since the energy carried by a photon of a given wavelength is determined by

$$E_{\phi\lambda} = m_{\phi\lambda}c^2 ,$$

the number of photons carrying it will be equal to

$$N_{\phi\lambda} = Q/E_{\phi\lambda} .$$

The total amount of emitted heat over all wavelengths is determined by the equation:

$$Q = \sum\nolimits_{\lambda} Q_{\lambda} = N_{\phi\lambda} \cdot m_{\phi\lambda} \cdot c^2 \quad (6)$$

Using Planck's constant $h = mc\lambda$ one can calculate the mass of a photon of any wavelength. The results of these calculations are presented in Table 1.

It follows from Table 1 that, as temperature decreases and the radiation shifts from the ultraviolet to the infrared region, the mass of the emitted photon also decreases. The smallest photon mass corresponding to relic (background) radiation is not relic radiation left over from the Big Bang, but rather indicates that this radiation originates from extremely weakly heated bodies.

The mechanism of radiation emission by matter from a rotating vortex was considered earlier by us in works [6–7]; therefore, due to the limited scope of this article, it is not discussed here. Thus, all of the above allows the following conclusions to be drawn:

- Heat–mass transfer is carried out by caloric particles — photons of different wavelengths.
- A direct relationship has been established between the amount of heat released Q, and consequently the temperature T, and the speed of the azimuthal self-rotation about its own axis of the radiating substance - atom-vortices - which, according to the authors, confirms the material nature of heat.
- Temperature T is an energetic criterion of the rotational (rotation about its own axis) state of individual masses of matter [9].
- A non-rotating mass is cold -neutral, does not radiate and, consequently, neither emits nor interacts; that is, such a mass is “dark.”

The obtained results require a revision of the principles of modern heat physics and thermodynamics in which heat participates.

References:

1. Heat and Mass Transfer: Lecture Course / M.S. Lobasova, K.A. Finnikov, T.A. Milovidova et al. Krasnoyarsk: Siberian Federal University Continuing Education Institute (IPK SFU), 2009.
2. Petukhov, B.S.; Polyakov, A.F. Heat Transfer in Nuclear Power Engineering Installations. Moscow: Atomizdat, 1974.
3. Mikheev, M.A.; Mikheeva, I.M. Fundamentals of Heat Transfer. Moscow: Energiya, 1977.
4. Melloni, M. Sur l’identité des diverses radiations lumineuses, calorifiques, et chimiques. Paris, Comptes Rendus, XV, 1842, pp. 454–460.
5. Lomonosov, M.V. Essay on the Theory of Imperceptible Particles of Bodies and in General on the Causes of Particular Qualities, 1743–1744 // In: Selected Works, Vol. 1: Natural Sciences and Philosophy. Moscow: Nauka, 1986. - pp. 37–57.
6. Milyute, E., Milyus, A. Vortex Dynamics of Substance in an Isolated Spheroidal Vortex and its Relationship with a Charge. DIZZW, **48**, 2023.
7. Milyute E., Milyuvene V., Milyus A.J.V. On the Key Role of Vortical Motion in Mechanism of Appearance and Transfer of a Convective Cell of an Emitted Substance // in the book: The Selected Papers of International Conference “Fluxes and Structures in Fluids: Physics of Geospheres”, devoted to the 75th Anniversary of the Physics Department of the M.V. Lomonosov MSU. June 24–27, 2009, Moscow, pp. 263–268.
8. Bernoulli, D. Hydrodynamics, or Notes on the Forces and Motions of Fluids (1738). Moscow: Publishing House of the USSR Academy of Sciences, 1959.
9. Milyute, E. Temperature is a Criterion of the Vortical State of Matter // Abstracts of the 15th International Conference “Fluxes and Structures in Fluids: Physics of Geospheres”, MSU, Moscow, Russia, June 24–27, 2009, Vol. 2, pp. 142–143.
10. Lomonosov, M.V. Reflections on the Cause of Heat and Cold (1749) // In: Selected Works, Vol. 1: Natural Sciences and Philosophy. Moscow: Nauka, 1986. - pp. 74–90.