WAVE AS A REAL QUANTUM OF RADIATION

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Abstract

This article is intended to show that from the standpoint of non-equilibrium thermodynamics the radiation law may be approached without resort to the thermal equilibrium conditions, quantum-mechanical considerations and Planck's constant. In this case the radiation appears to be a process of ambient medium modulation with the oscillation frequencies intrinsic in the radiator with subsequent transfer of this excitation through the medium. In this case the excited wave, but not the particle named as photon, becomes the real quantum of radiation. The intensity of this quantum is found and the possibility is shown to thus overcome a number of the existing difficulties in comprehending and explaining the optical phenomena observed.

Key words: non-equilibrium thermodynamics, radiant flux, stationary process, radiation law, wave as a quantum, ambient medium modulation,
non-trivial consequences.

Preface

In 1900, M. Planck, known for his work in the field of thermodynamics, found, in his words, an "appropriate approximation" to the Wien's and Rayleigh's radiation laws and obtained a formula well reproducing an experimental data of equilibrium radiation through the entire frequency band [1]. To do so, he had to use a number of postulates being inconsistent with the concepts of classical physics. The main of them was the concept of the radiation contained in an imaginary cavity having an ideally reflecting surface and properties of absolutely black body and construed as something being in thermal equilibrium with the radiator inside of it. In that case the radiation was described with a certain temperature T and entropy S, i.e. the parameters intrinsic in a material object. Thus, the thermal radiation has changed from a kind of energy exchange processes into a kind of substance whose properties are described with the same parameters as the radiator.

The inconsistency of such a model with classical thermodynamics lies not only in the non-distinction between the functions of state and process. According to the first law of thermodynamics the variation of the intrinsic (internal) energy of the radiator and cavity is accompanied by not only thermal exchange, but also work, which manifests itself in such phenomena as photo-effect, photosynthesis, ionization, dissociation, fluorescence, photochemical, photonuclear and the like conversions. These forms of the ordered energy exchange are accompanied by energy conversion in the radiator not stopping at occurrence of the so-called stationary state. As for the "thermal radiation", it includes only a part of the radiant energy exchange within a narrow wavelength range of 0.4 through 0.76 microns, which is dissipated by bodies with its conversion into the thermal form of energy followed by the re-radiation with other spectral characteristics. This process never ceases despite the constancy of the radiator and cavity parameters, which requires the process to be described by thermodynamics of stationary processes [2].

Another no less important inconsistency was connected with classical physics as a whole which assumed energy to be a permanently changing value[1]. M. Planck postulated that the energy levels of the oscillators were discrete and formed an "equidistant" spectrum of frequencies ν with the same difference $h\nu$ between any two neighboring levels. That is why they can give and receive energy by indivisible portions $\varepsilon = h\nu$ only, where h is a universal value named as "Planck's constant". Thereby the foundation was laid for "another physics" that denied the applicability of the classical laws to the microcosm.

To justify the Planck's radiation law, a number of other assumptions were used. In particular: (a) quantum radiation energy $\varepsilon = h\nu$ is independent of wave amplitude A_B; (b) quantum energy ε can infinite-

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[1] It would never occur to somebody to claim the ocean consists of separate drops just because the rain and snow replenish it in the form of discrete drops or snowflakes!

ly grow with frequency v; (c) a "Planck's statistics" different from the classical Maxwell-Boltzmann's statistics is applicable; (d) principle of equipartition of energy by degrees of freedom and particular properties of ideal gases in calculation of the Planck's constant from the Boltzmann's constant k may be used, etc. [3]. Therefore, the justification of the interpolation formula M. Planck gave "post factum" [4] caused a bitter frustration not only in his contemporaries and their successors, but also in Planck himself [5].

The situation significantly changed when classical thermodynamics was replaced by thermodynamics of non-static (irreversible) processes [6 – 11]. That theory supplemented classical thermodynamics with the analysis of stationary processes characterized by equality between the flows of absorbed and radiated energy. It became clear that the never ceasing radiation process could not be identified with equilibrium requiring breakdown of the energy exchange and demanded therefore the introduction of the process parameters – energy flows, including radiant flux $J_л$. It also became necessary to introduce the flows of material media for radiant energy, as well as the wave propagation medium, no matter how it may be called – ether, electromagnetic field or non-baryonic matter. The successes non-equilibrium thermodynamics has achieved in studying the kinetics of energy exchange processes and explaining a number of phenomena looked fancy from the standpoint of classical thermodynamics promote an attempt to give the new grounds for the radiation law not based on the model representations and quantum-mechanical postulates, especially those contradicting classical physics. Such attempts have attained especially convincing grounds in thermokinetics as a modern version of non-equilibrium thermodynamics that combined the methods of equilibrium and non-equilibrium thermodynamics and made them applicable to any forms of energy [12]. This article will describe the most successful attempt of such a kind which allows not only to obtain the law of radiation from real bodies as a result, but also to offer a new parameter as the quantum of radiation – energy of solitary wave.

Thermokinetic Verification of the Planck's Radiation Law

The fundamental distinction of the thermokinetic approach starts with the fact that the radiation frequency v is construed therein as a function of the radiation process involving an oscillatory motion energy exchange between the body and ambient medium without transfer of their masses. According to such approach the radiation frequency v is construed as a flow of waves excited in the ambient medium per unit time by the particles of the radiating body oscillating at resonant frequency v. Then the stationary state of the radiating body means total derivative of internal energy density of radiating body $u(\mathbf{r},t)$ with respect to time t is equal to zero:

$$du/dt = (\partial u/\partial t)_\mathbf{r} + (\mathbf{v}\cdot\nabla)u = 0, \text{W m}^{-3}, \qquad (1)$$

where $\mathbf{v} \equiv c$ – energy transfer rate in this particular medium; u – density of its energy, J m^{-3}.

The augend in the right-hand side of (1) describes the local variation of the body internal energy, while the addend – its variation due to radiant energy exchange. According to this expression the stationary state of the radiator ($du/dt = (\partial u/\partial t)_\mathbf{r} = 0$) is a result of equality between absorbed $J_л' = (\mathbf{v}\cdot\nabla)u$ and radiated $J_л'' = (\mathbf{v}\cdot\nabla)u$ flows of the radiant energy with their spectral characteristics (frequencies, phases, amplitudes, etc.) being different. Here the specific feature of the radiant energy exchange consists in the transfer of energy through space without transfer of its mass. The radiant energy flow $J_л''$ being of interest to us is evidently proportional to the flow of running waves $J_в$ the radiator creates in the ambient medium, i.e. to the radiation frequency v. Thus, the radiation frequency, from the standpoint of thermokinetics, now means the flow of waves created in the ambient medium by a solitary oscillator. The spectral density of this flow $u_v = dJ_л''/dV$ (J m^{-3}) is evidently defined as the product of wave average energy $\overline{\varepsilon}_v$ with frequency v by number of oscillators N_v, (m^{-3}) contained in unit volume of the radiating body and radiating at this frequency v:

$$u_v = \overline{\varepsilon}_v N_v, \text{ (J m}^{-3}) \qquad (2)$$

The number of the oscillators N_v radiating at frequency v will evidently be less than their total number N and will decrease as the energy ε_v of the oscillator at this frequency increases. This number N_v can be found from the classical Maxwell-Boltzmann's statistics. According to it the share N_v/N of the oscillators with the energy ε_v per each obeys the exponential law:

$$N_v/N = \exp(-\varepsilon_v/kT). \qquad (3)$$

where $k = R_\mu/N_A$ – Boltzmann's constant that is ratio of the universal constant R_μ for the ideal gas to the Avogadro's number (the number of atoms per a mole).

In the above expression the exponential factor $(-\varepsilon_v/kT)$ describes the ratio of the oscillatory energy ε_v to the energy of ideal gas random (thermal) motion under its uniform distribution by degrees of freedom in motion of gas molecules, i.e. the above factor relates to particular properties of ideal gas. Meanwhile, for absolutely black bodies the Kirchhoff's function $f(v/T)$ describing the energy distribution by frequency and temperature has a universal form without regard for the nature of the radiating bodies [13]. To satisfy this requirement, take into consideration that the radiant energy flow $J_л''$ at stationary states is exactly equal to the power of dissipative processes $(\partial u/\partial t)_r$ leading to re-radiation of the exciting impact $J_л'$. In non-equilibrium thermodynamics this power is described by the dissipative function $\Psi = \sigma TN$ (W m^{-3}), where σT – energy dissipation rate per one oscillator. In such a case in the distribution (3) the dissipation power share σ_v/σ should be present being contingent on the radiation at frequency v, where $\sigma_v = T^{-1}\varepsilon_v v$ means power of the radiant flux of the energy radiated by solitary radiator at frequency v:

$$\sigma_v T = \varepsilon_v v = \varepsilon_v J_в. \tag{4}$$

Then the Maxwell-Boltzmann's distribution takes the form:

$$N_v/N = \exp(-\sigma_v/\sigma) = \exp(-\varepsilon_v v/\sigma T). \tag{5}$$

This expression describes the ratio of the ordered (oscillatory) motion power in the radiator to the power of dissipation processes therein regardless of its nature. It complies with the universal character of the Kirchhoff's function $f(v/T)$ whose numerical value is subject to further determination.

Allowing for (5), the expression (2) takes the form:

$$u_v \exp(\sigma_v/\sigma)\, dv = \overline{\varepsilon}_v N dv = \overline{\varepsilon}_v dn_v,\ (\text{W m}^{-3}), \tag{6}$$

where n_v – number of the oscillators at frequency v in the radiator of unit volume.

This expression describes the density of the energy radiant flux within infinitesimal frequency band dv. Within a frequency band of $0 < v < \infty$ typical for any real body the left-hand side of the (6) after some average value $\overline{u}_v$ and $(\overline{\varepsilon}_v/\sigma T)^{-1}$ have been factored outside the integral sign will consequently take the form:

$$\int_o^v u_v e^{\overline{\varepsilon}_v v/\sigma T}(\overline{\varepsilon}_v/\sigma T)^{-1} d(\overline{\varepsilon}_v v/\sigma T). \tag{7}$$

After some average value $\overline{u}_v$ of parameter u_v and $(\overline{\varepsilon}_v/\sigma T)^{-1}$ have been factored outside the integral sign and considering that by substitution of $x = \varepsilon_v v/\sigma T$ the rest part may be reduced to a definite integral of $\int_o^v e^x dx = e^x - 1$, the following expression will be obtained:

$$\overline{u}_v = \sigma T n_v/(e^{\overline{\varepsilon}_v v/\sigma T} - 1),\ \text{J m}^{-3}. \tag{8}$$

Since according to (2)

$$\sigma T n_v = \sigma_v T = \overline{\varepsilon}_v v, \tag{9}$$

while $n_v = 2\pi v^2/c^3$, the final expression will be:

$$\overline{u}_v = 2\pi v^3 c^{-3}(e^{\overline{\varepsilon}_v v/\sigma T} - 1),\quad \text{J m}^{-3} \tag{10}$$

This expression is different from the Planck's radiation law in only that the Planck's constant h (J s) is herein replaced by the wave average energy $\overline{\varepsilon}_v$ (J), while the Boltzmann's constant k (J K^{-1}) – by the power of single dissipation event σ (WK^{-1}). In this case the ratio $\overline{\varepsilon}_v/\sigma$ in the Kirchhoff's function $\overline{\varepsilon}_v v/\sigma T$ has the same dimensionality as the ratio of constants h/k in the Planck's law. Let's show now that these two laws are, nevertheless, equivalent since both ratios are subject to experimental determination. For this use the aforementioned substitution $x = \varepsilon_v v/\sigma T$ which reduces both radiation laws to the same form similar to the Stefan-Boltzmann's law aT^4:

$$J_л = \int_o^\infty \overline{u}_v dv = \frac{2\pi}{c^3}\overline{\varepsilon}_v T^4\left(\frac{\sigma}{\overline{\varepsilon}_v}\right)^4 \int_o^\infty \frac{x^3 dx}{e^x - 1}. \tag{11}$$

Providing that the Kirchhoff's function is invariable in both representations (through $\bar{\varepsilon}_\nu/\sigma$ and through $h/k = 4{,}8 \cdot 10^{-11}$ [s K^{-1}]), the integral $\int_o^\infty \dfrac{x^3 dx}{e^x - 1}$ will be the same in both cases and equal to $\pi^4/15$. Then the wave energy $\bar{\varepsilon}_\nu$ can be found by making the (11) equal to the expression aT^4, where $a = =5.67 \cdot 10^{-8}$ W m^{-2} K^{-4}:

$$\bar{\varepsilon}_\nu = a \frac{15c^3}{2\pi^5}\left(\frac{\bar{\varepsilon}_\nu}{\sigma}\right)^4 \approx 2 \cdot 10^{-25} \text{ Дж}. \tag{12}$$

Thus, the approach from the standpoint of thermokinetics allows not only giving a merely thermodynamic justification of the radiation law, but also finding the value of the real quantum of radiation.

Summary of Results and Conclusions

The offered approach to the radiation law proceeds from the general concepts of its wave nature and is not based on whatever quantum-mechanical postulates or physical models like a cavity with perfectly reflecting walls, i.e. was of a merely thermodynamic nature. At the same time it is not either based on the concepts of classical thermodynamics claiming thermal equilibrium existing between matter and radiation, as well as on particular properties of radiating bodies like ideal gases. In this case the radiation is not either described by such properties of matter as temperature and entropy and its particle – by whatever particular electrical and the like properties. In short, the proof bears the most general character. That is why it can be successfully shown that the radiation from bodies has, strictly speaking, nothing to do with equilibrium, thermal, black body or electromagnetic nature, since it involves any particles of matter executing oscillatory motion.

Another not less important specific feature of the approach undertaken consists in the proof that the quantum nature of radiation is contingent on the nature of the wave process itself. Therefore, the discreteness of the process in itself by no means contradicts the classical concepts which claim there is no any specific quantum physics with its special laws, but rather a section of general physics studying discrete processes. With such an approach it becomes clear that the real quantum of radiation may be construed as the usual wave definitely discrete in both time and space!

It becomes clear that its appearance is caused by the erroneous concept that quantum energy increases with frequency. Actually, the energy released by any oscillator at single radiation event cannot increase without limit with frequency ν increasing simply because in this case it can exceed the energy of this oscillator itself. This fact was first noticed by A. Einstein, who showed through a simple calculation that for a wave length of 0.5 micron at an absolute temperature of $T = 1700$ K the quantum energy $\varepsilon = h\nu$ exceeds the energy of the oscillator $6.5 \cdot 10^7$ times [14]. Unfortunately, this fact has not been duly respected up to date. Moreover, it has left unnoticeable that the energy of the particle as an oscillator with an invariable amplitude of A_B can only decrease with frequency ν increasing. To make sure of that, it is enough to divide the density of wave energy ρ_ν defined for a medium with density ρ from the known expression [15]

$$\rho_\nu = \rho A_B^2 \nu^2 / 2 \text{ , J m}^{-3} \tag{13}$$

by the known number of oscillators $N_\nu = 2\pi\nu^3/c^3$ contained in the unit volume of the radiator and oscillating at frequency ν:

$$\varepsilon_\nu = \rho_\nu / N_\nu = \rho A_B^2 c^3 / 4\pi\nu. \tag{14}$$

As follows from (14), at $A_B = const$ the number of the oscillators within the unit volume N_ν increases with frequency ν faster than the density of their energy ρ_ν. This is what prevents the "violet catastrophe" predicted by the Rayleigh's radiation law (1900) in view of unlimited rise of the radiation density [16]. Meanwhile, according to the Planck's postulate the quantum energy $\varepsilon = h\nu$ keeps steadily growing with frequency ν increasing. Yet within the radio-wave frequency band the photon energy becomes comparable with the above-found average energy of solitary wave $\bar{\varepsilon}_\nu \approx 2 \cdot 10^{-25}$ J many orders

exceeding it within the visible and ultraviolet band. Thus, for the wave as a quantum of radiation the problem involving the excessiveness of photon energy does not appear.

We put aside here the problems in interpreting the value *h* that de Broglie called a "mysterious constant". All the attempts to derive this constant from the primary principles of mechanics or electrodynamics are known to have failed hitherto. The arguments mentioned above evidence that Planck's postulating about this constant as a state function was not based on any provisions of fundamental theories. Moreover, the idea of studying the radiation process by considering the equilibrium state of the radiator (in the absence of energy exchange process) excluded the possibility to contribute the meaning of process parameters to the parameters of the radiator. The fact the frequency ν of the running wave excited in the ambient medium as a function of radiating process was replaced by the oscillator frequency ν as a function of radiator state and following interpretation of constant *h* as a factor of proportionality between oscillator energy ε and its frequency ν as parameters of the oscillator denied the possibility to comprehend not only the meaning of the above constant, but also the reason why the high-frequency photon energy could exceed the oscillatory frequency. Only considering the radiation as the energy exchange process allowed its description with the help of the process parameters such as $\overline{\varepsilon}_v$ and $J_в$ having a simple and clear meaning of the average wave energy and its flow. Then the approach to the radiation law did not require from us whatever hypotheses, postulates and quantum-mechanical considerations. All this denies the cliché declaring impotence of classical physics against the quantum laws of luminous effect. However, there are many problems left unsolved and involving reconsideration and redefinition of a number of values connected with the Planck's constant. Therefore, this article bears an explicitly polemical character targeting problems for the future generations of physicists.

References
[1]   Planck M. Über irreversible Strahlungsvorgänge. //Annalen der Physik, 1900, **306** (1), 69–122.
[2]   Denbigh K. G. Thermodynamics of the Steady State. - L.: Methuen, 1951.
[3]   Etkin V.A. A new submission of the Planck's radiation law. http://viXra.org/abs/1508.0302. 2015.
[4]   Planck, M. Über das Gesetz der Energieverteilung im Normalspektrum. //Annalen der Physik, 1901, 4, 553.
[5]   Planck, M. Zur Geschichte der Auffindung des physikalischen Wirkungsquantums. //Naturwissenschaften, 1943, 31 (14–15), 153–159.
[6]   Prigogine I. Etude Thermodynamique des Phenomenes Irreversibles. – Liege, 1947, 143 p.
[7]   De Groot S.R.,Mazur P. Non-Equilibrium Thermodynamics. – Amsterdam, 1962
[8]   Haase R. Termodynamik der irreversiblen prozesse. – Darmstadt, 1963.
[9]   Gyarmati I. Неравновесная термодинамика. Теория поля и вариационные принципы. М.: Мир, 1974. 304 с.
[10] Jou D., Casas-Vazquez J., Lebon G. Extended irreversible thermodynamics. Berlin-Heidelberg. 2001.
[11] Kondepudi D., Prigogine I. Modern Thermodynamics: From Heat Engines to Dissipative Structures. Wiley. 1998.
[12] Etkin V.Thermokinetics (Synthesis of Heat Engineering Theoretical Grounds).- Haifa, 2010. 334 p.
[13] Kirchhoff G. Untersuchungen über das Sonnenspectrum und die Spectra der chemischen Elemente.- Berlin,1861.
[14] Einstein A., Infeld L. Evolution of Physics. – Cambridge, 1938 [15]
[15]   Crawford F. Waves. Berkeley Physics course. Vol. 3.- McGraw-Hill, 1968.