RETHINKING PLANCK’S RADIATION LAW

Etkin Valeri <v_a_etkin@bezeqint.net>

Abstract

From the viewpoint of the thermodynamics of irreversible processes it shows that the Planck’s radiation law may be substantiated without assigning thermal movement parameters to radiation and without resort to hypotheses and postulates contradicting classical physics. True quantum of radiation is meant soliton – solitary structurally stable wave modulating radiation field

Keywords: Planck's law, reconsideration, radiation field, modulation, deceleration radiation, soliton as quantum, nontrivial consequences.

Introduction

In 1900 M. Planck found a formula well reproducing experimental data of the equilibrium radiation over the full range of frequencies. For this purpose he had to resort to a number of postulates contradicting the concepts of classical physics. The main one of them was an assumption that the energy of oscillators should be multiple of the integer number of portions (quantums) equal and similar for all of the oscillators. The justification of these postulates was strongly objected by Plancks’s contemporaries. However, they failed to offer a more successful solution to the problem. Moreover, any such attempts have been regarded as groundless ambitions since then.

The situation essentially changed only after thermodynamics of non-static (irreversible) processes had come to replace classical thermodynamics. It supplemented classical thermodynamics with the analysis of steady states. Radiation is known to cause not only heating of bodies, but also photoelectron emission, photosynthesis, ionization, dissociation, luminescence, fluorescence, photochemical, photonuclear reactions, etc. not reducible to heat exchange. Processes of radiant energy radiation and absorption, unlike heat exchange, are also known not to stop down to absolute zero. It is finally known that thermal equilibrium between substance and radiation in the Universe has not occurred yet for 14 billion years of its existence. All this requires reconsidering the M. Planck’s background to the heat exchange law based on the concept of thermal equilibrium between substance and radiation.

The present article is aimed at showing that, should non-equilibrium thermodynamics be used, the Planck’s radiation law may be substantiated without resort to the postulates contradicting classical physics. In this case the true quantum of radiation may be construed as soliton – a solitary structurally stable wave that modulates the radiation field. Such an approach will be shown to allow overcoming many of the difficulties existing in the comprehension and explanation of the phenomena observed.

Planck’s Approach in Essence

It is known that the thermodynamic substantiation of "successful approximation 'of Wien’s and Rayleigh’s radiation laws [1], given by Max Planck, based on the assumption of the existence of thermal equilibrium between the system of standing waves (oscillators) and the walls of an imaginary cavity having ideally reflecting surface and properties of absolutely black body (ABB). Such equilibrium assumed the radiation featured equal temperature T and specific «electromagnetic entropy» S. Therefore he focused on an expression for the second derivative of entropy S with respect to energy of oscillators E_n. He set a problem to find the dependence of d^2S/dE_n^2 on temperature T and frequency v, which in the short-wave range should result in the Wien’s law, and in the long-wave range – in the Rayleigh’s law. Planck found such dependence [2]. However, for its physical interpretation he had to back out of the concepts of classical physics and assume the oscillators could be only in certain discrete energy states with energies $E_n = nh\nu$, where $n = 1,2, \dots,\infty$. According to this hypothesis the oscillators can give or receive energy only in whole portions $E = h\nu$, where h is a universal quantity having been named as Planck’s constant. Besides Planck postulated [3,4] that the distribution of oscillators by energies E_n within the radiating cavity followed the same classical Boltzmann’s statistics

$$N_\nu/N_o = \exp(-E_n/kT) \tag{1}$$

despite the fact it is a case of distribution of energy-carrying oscillators not by frequency ν, but by numbers n. Such distribution named sometimes as “Planck’s distribution” fell also beyond the classical Boltzmann’s statistics according to which N_ν/N_o should have been construed as a fraction of oscillators with energy $E = h\nu$ differing only in frequency ν. However, this distribution allowed approximating the found statistically average energy of oscillator $\langle E_n\rangle$

$$\langle E_n\rangle = \Sigma_n E_n \exp(-E_n/kT)/\Sigma_n \exp(-E_n/kT), \text{ J} \tag{2}$$

by expression

$$\langle E_n\rangle = h\nu/[\exp(h\nu/kT) - 1] . \tag{3}$$

In such a case the spectral density of radiation $u(\nu,T) = d\langle E_n\rangle/d\nu$ could be found by integration of expression $\langle E_n\rangle dN_\nu$, where

$$dN_\nu = (8\pi\nu^2/c^3)d\nu \quad (4)$$

means number of oscillators dN_ν in a cavity of unit volume within a frequency range of $d\nu$. This is the operation resulting in the Planck's radiation law

$$u(\nu,T) = (8\pi h\nu^3/c^3)/[\exp(h\nu/kT) - 1], \text{ (W/m}^3\text{)}. \quad (5)$$

This expression describes the radiation as a continuous curve with a strongly-pronounced maximum and the form defined by a single parameter – absolute temperature T. It differs from the Rayleigh's law

$$u(\nu,T) = (8\pi\nu^2/c^3)kT \quad (6)$$

found half a year earlier from a known statement of statistical theory about equal energy distribution by degrees of freedom. Here instead of kT a more complex expression for average energy $h\nu/[\exp(h\nu/kT) - 1]$ appeared. That prevented an unlimited increase of $u(\nu,T)$ with increasing frequency ν.

However, Plank's contemporaries found a lot of contradictions in the logical and mathematical structure of the Planck's radiation law background. Some of them noted a logical inconsistency in deriving relation (6), viz. in relations (1) to (4) the oscillator energy was considered as a discrete quantity able to take only the values multiple of $h\nu$ while in relations (5) and (6) M. Planck treated it as a continuously varying quantity. Others objected the quantum hypothesis since it contradicted not only mechanics that excluded a jump of any parameters, but also electrodynamics wherein the energy of oscillators was a continuously varying quantity. Still others drew attention to the fact that a series $n = 1,2, \ldots,\infty$ used for the approximation of expression (2) would become rather limited if n interpreted as quantum numbers. There were many remarks of such a kind expressed – mere recitation of them would take too much time. Planck himself, to the end of his life, considered the problem of thermal radiation unsolved though did not cease efforts to improve its background [5].

It should be added to the above that, except for a minor part of spectrum within a wavelength range of 0.4 throughout 0.76 microns, the radiation are perceived by bodies as the work done to them, which is shown in a photo-effect, photosynthesis, ionization, polarization, dissociation, fluorescence, photochemical, photonuclear reactions, etc. It means that radiation relates to the ordered forms of energy. Therefore assigning the parameters of thermal movement (temperature T and entropy S) to it contradicts the thermodynamic method in principle. And the concept of thermal balance between radiation and substance, which, as such, formed the basis for radiant energy having been referred to heat exchange, is erroneous. The evident proof is the fact that the difference between the temperatures of stars sufficient for thermonuclear reactions therein and the space radiation with a temperature of 2.72 K has not disappeared for 14 billion years as the estimated age of the Universe.

With progress of the wave theory it has also been detected that Planck's hypothesis about proportionality of oscillator energy to linear oscillation frequency ν and about its independence on amplitude $A_в$ contradicts the expression for oscillation energy density known from the wave theory [6]:

$$\rho E_\nu = \rho A_в^2\nu^2/2 \text{ , J/m}^3, \quad (7)$$

where ρ – density of oscillating medium.

A solution to this problem, the best one and free of any contradictions, being absent, many classical concepts appeared to have been broken as a result. Only much later it became clear (and by no means to all) the situation could be avoided should the problem be considered in terms of non-equilibrium thermodynamics [7–10] and its further generalization toward the processes of transformation of the ordered forms of energy [11].

Application of Non-Equilibrium Thermodynamics to Radiation Processes

Since processes of electromagnetic energy absorption and radiation never stop, to describe them, a theory is necessary based on the energy flow concept, instead of thermostatics which substantially means classical thermodynamics. A theory of such a kind was first put forward by L. Onsager, future Nobel laureate, who in 1931 offered the theory of relaxation processes and named it as “quasi-thermodynamics” [7]. That theory was based on a principle of entropy increase in a system closed (for substance) and adiabatically isolated. In such systems speed of entropy occurrence dS/dt is conditioned exclusively by dissipation of the ordered energy brought to system in the form of work. Instead of dS/dt it is more convenient to consider the dissipative function $P \equiv TdS/dt$ which characterizes variation of internal thermal energy in the system dU/dt due to energy dissipation. Let's consider it after Onsager as a function of independent parameters α_i describing deviation of the system from equilibrium. Reduction of this parameter in time t defines the generalized speed of appropriate relaxation process $J_i \equiv - d\alpha_i/dt$ named by Onsager as “flow” J_i, while private derivative of P with respect to α_i taken with reversed sign defines thermodynamic force $X_i \equiv - (\partial U/\partial\alpha_i)$ construed as the relaxation process motive force. Then

$$TdS/dt = \Sigma_i X_i J_i, \text{ W} , \quad (8)$$

where i = 1,2, …,m – number of independent relaxation processes possible in the system investigated.

This theory has been further spread to stationary irreversible processes, where flows J_i and forces X_i have got vector character [8,9], and generalized first toward other irreversible phenomena [10] and then also toward non-static processes of useful transformation pertaining to various forms of energy [11]. In [11] forces $\mathbf{X}_i$ and flows $\mathbf{J}_i$ have got a unique meaning of negative gradients $\mathbf{X}_i = -\nabla\psi_i$ of generalized potentials ψ_i and impulses $\mathbf{J}_i = \Theta_i\bar{\boldsymbol{\upsilon}}_i$ of generalized coordinates Θ_i. Here ψ_i and Θ_i are construed as intensive and extensive carrier of the i^{th} form of energy. As a result, non-equilibrium thermodynamics has grown into a complete theory with its own method and multiple applications in various engineering spheres.

Let's find out, from the most common standpoints [11], the meaning of parameters α_i for a specific case of wave formation process with deviation of oscillating medium local density ρ from its average (equilibrium) value $\bar{\rho}$ (Fig.1).

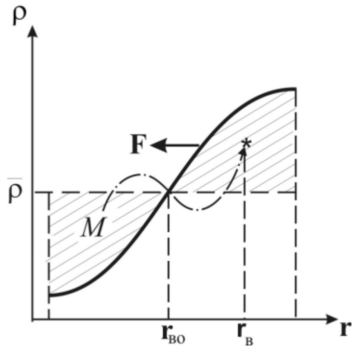

Fig.1. To Wave Formation

As follows from the figure, the half-wave is formed because some part M of its mass is transferred in the direction of the wavy arrow. This transfer is accompanied by displacement of the center of half-wave mass from the position with radius vector $\mathbf{r}_{BO}$ to position $\mathbf{r}_B$. As a result, in wave volume V with mass $M_B = \bar{\rho}V$ some "moment of distribution" of wave density $\mathbf{Z}_B$ is formed defined by expression [11]:

$$\mathbf{Z}_B = M_B(\mathbf{r}_B - \mathbf{r}_{BO}) = \int[\rho(\mathbf{r},t) - \bar{\rho}(t)]\mathbf{r}dV\ . \tag{9}$$

This moment characterizes the half-wave deviation from equilibrium (uniform) distribution of density. Should this displacement $\Delta\mathbf{r}_B = \mathbf{r}_B - \mathbf{r}_{BO}$ be taken for wave amplitude A_B (7), this moment may be applied to find the unified expression of any energy including electromagnetic wave. Since displacement of mass M occurs during half-cycle $\tau/2 = 1/2\nu$, average speed of its transfer in this oscillatory process $\bar{\boldsymbol{\upsilon}}_B = 2A_B\nu$ and its kinetic energy $M\boldsymbol{v}_B^2/2 = 2A_B^2\nu^2$. In "antinodes" of the wave its kinetic energy completely transforms into potential energy so that their sum remains constant at any time and defines full energy of the wave. After recalculating its mass as the whole M_B the average density of wave energy $\bar{\rho}E_B$ becomes

$$\bar{\rho}E_B = \bar{\rho}A_B^2\nu^2/2\ ,\ \mathrm{J/m^3} \tag{10}$$

This expression differs from the one known in the oscillation theory [6] just because in this case the oscillation parameter is the proper medium density $\rho(\mathbf{r},t)$ as a function of spatial coordinates and time. At the same time it becomes clear that only kinetic and potential energies of the medium take part in the wave formation so that the waveform movement relates to ordered forms of energy. Thus, the thermodynamic parameters of the waveform of energy may be found based on the expression for wave energy (7) or (10) with absolutely no reasons for assigning to it the same parameters as for thermal (chaotic) energy.

Differentiating (10) gives:

$$dE_B = -dW_B = A_B\nu d(\rho VA_B\nu)\ . \tag{11}$$

Similar to expressions TdS, pdV, etc. in thermodynamics, this expression may be represented as product of some wave potential $\psi_B = A_B\nu$ (m/s) meaning wave formation process speed and variation of extensive coordinate of this process $\Theta_B = \rho V_B A_B\nu$ meaning impulse of the medium in this process. The negative gradient of the wave potential $-\nabla\psi_B$ defines in this case motive force $\mathbf{X}_B$ of radiant energy transfer in absorbing medium similar to gradients of temperature, electric, chemical and kinetic potentials in Fourier's, Ohm's, Fick's, Darcy's, Newton's, etc. laws. This ensures unity in the description of transfer processes in substance and radiation field. Power character of interaction between radiation and substance also becomes obvious. It follows from the definition of thermodynamic force as derivative $\mathbf{X}_B \equiv -(\partial U/\partial\mathbf{Z}_B)$. Since this derivative is conditioned by M_B = const, force $\mathbf{X}_B = -M_B^{-1}(\partial U/\partial\mathbf{r}_B) = \mathbf{F}_B/M_B$, i.e. represents specific value of force $\mathbf{F}_B \equiv -(\partial U/\partial\mathbf{r}_B)$ in its most general interpretation as a gradient of the appropriate form of energy. This allows representing expression $\mathbf{X}_i\cdot\mathbf{J}_i = \mathbf{X}_i\cdot d\mathbf{Z}_i/dt$ in a more traditional form as the capacity of any ith process $d\boldsymbol{W}_i/dt = \mathbf{F}_i\cdot d\mathbf{r}_i/dt = \mathbf{F}_i\cdot\bar{\boldsymbol{\upsilon}}_i$. This is the way energodynamics [11] "spans" between TIP and other disciplines based on the concept of force. Thus, it becomes clear that the interaction between substance and radiation is accompanied by interconversion between ordered energy of radiation and internal disordered energy of substance, which bears power character.

From the general definition of flow $\mathbf{J}_i$ in energodynamics as derivative $d\mathbf{Z}_i/dt = \Theta_i \boldsymbol{v}_i$ it follows that for the waves spreading with speed of light $dr_в/dt = \boldsymbol{c}$ the carrier of the waveform of energy is their impulse $\boldsymbol{J}_в = \Theta_в \boldsymbol{c}$. This impulse has the same dimensions as energy E_n (J), however, it is proportional to linear frequency:

$$J_в = \rho V_в A_в c\nu, \text{ J} . \quad (12)$$

This is the circumstance that probably served the intuitive basis for the Planck's hypothesis [2] since the concept of energy carrier flow different from the concept of energy flow did not exist at that time. Difference between these concepts has not become obvious even now though proportionality of oscillator energy to frequency ν expressly contradicts the wave theory [6]. All these TIP consequences are the basis for reconsideration of the radiation law based on the concept of thermal equilibrium.

New Concept of Radiation Process

According to the law of energy conservation the total energy of atom is known to remain invariable providing the motion of electrons occurs therein only by the action of internal (central) forces [12]. Consequently, we may speak about energy radiation from atom only providing that the foreign (non-central) forces $\mathbf{F}_в$ proceeding from the surrounding radiation field act on its structural elements. This circumstance does not depend on the nature of this field and particles of substance interacting with it[1)].

If forces of external field $\mathbf{F}_в$ act "concurrently" with speeds of electrons $\boldsymbol{v}_e$ (i.e. $\mathbf{F}_в \cdot \boldsymbol{v}_e > 0$), their acceleration appears which ends when $\mathbf{F}_в \cdot \boldsymbol{v}_e = 0$. Otherwise ($\mathbf{F}_в \cdot \boldsymbol{v}_e < 0$), electrons decelerate for a time whose duration is defined by the half-cycle of their counter movement. It causes a short-term "disturbance" in the external field increasing the amplitude of its oscillations and therefore bearing the character of "elevation waves" intrinsic for solitons. Such radiation can be assigned to the "deceleration radiation" type. Thus, contrary to the N. Bohr's hypothesis about existence of stationary orbits, electron changes its motion path as many times as many events of deceleration and acceleration it undergoes. In quantum mechanics it is interpreted as "blur" of its orbit.

Let's imagine atoms of substance as oscillators which electrons move along closed or open orbits relative to atomic nucleus and external EMF and interact with this field. If frequency of the external EMF v is equal to frequency of oscillations of electrons v_e, the EMF wave will undergo one disturbance for its half-cycle. It corresponds to resonant interaction of electrons with external wave. However, if $\nu < \nu_e$, the same wave will undergo $n = \nu_e/\nu$ disturbances corresponding to the 2nd, 3rd, etc. harmonic. The EMF waves with other frequency will also undergo such disturbance if subjected to the same condition $\mathbf{F}_в \cdot \boldsymbol{v}_e < 0$. However, their interaction will bear but a non-resonant character essentially suppressed.

As a result of all these interactions, the EMF is modulated by frequency ν_e equal to the number of revolutions $\nu_e = n\nu$ the electron passes. In particular, at speed of orbital electron $\bar{\upsilon}_e$ equal to 1/137 of light velocity $\boldsymbol{c}$ and orbit diameter of the order of 10^{-8} m the number of its oscillations n reaches 10^{14} Hz. This is several orders greater than the frequency of radio-wave and optical range of the radiation field oscillations. Therefore, external disturbance looks like a ripplet on the surface of larger EMF waves caused by superposition of all disturbances from all existing sources of radiation.

At $\nu_e < \nu$ it is already not the EMF wave, but electron that is able to undergo $n_e = v/v_e$ deceleration events for half-cycle $\mathbf{F}_в \cdot \mathbf{v}_e < 0$. However, it does not alter the case which means multiple acceleration or deceleration of the oscillating particles at their interaction with the EM wave. Nevertheless, since the disconformity between the Rayleigh's and Planck's laws is aggravating with decreasing frequency, we will focus mainly on the $\nu_e > \nu$ case.

The number of the revolutions v_e electron passes moving along some orbit with length l_e and conditional diameter d_e is known to be defined by the ratio of electron average speed module v_e to orbit length l_e, then

$$\nu_e = v_e/l_e = m_e v_e / m_e l_e = p_e/m_e l_e , \quad (13)$$

where $p_e = m_e v_e$ – module of electron average impulse.

According to (13), with other conditions being equal (m_e, l_e = idem), radiation frequencies v appear to be proportional to impulse p_e of electrons and therefore depending on substance properties. This complies with de Broglie's ideas. Moreover, from (13), considering identity $\nu \equiv c/\lambda$, the de Broglie-postulated relation $\lambda = h_\nu/p_e$ directly follows.

Let's consider now, that with varying phase of incident wave the process of electron deceleration is replaced by electron acceleration so that the electron during this half-cycle does not radiate the wave energy, but absorbs it. Hence, there is a time period, other than zero, between the events of electron deceleration. Therefore, the disturbing wave modulating external EMF is a sequence of "solitary elevation" waves, which also is a characteristic feature of solitons. Their similarity increases considering that each "elevation wave" is, according to Fig.1, a pair of forces directed to opposite sides. Such waves repel when impinged, i.e. behave as tennis balls. This makes these waves "particle-like", as well as solitons. Finally, the EMF waves also feature the structural stability characteristic for solitons. It is commonly believed that solitons appear in nonlinear media where dispersion compensates "sprawl" of waves due to dissipation. However, for

---

[1)] Being specific about the interaction between the electromagnetic field (EMF) and electrons, we do not exclude the possibility of interaction between any other power field and whatever particles of substance.

media of the EMF wave type, wherein both dissipation and dispersion of light are absent, form stability is their “inherent” property. All the above allows assigning solitary structurally stable and particle-like elevation waves modulating the light wave to solitons[1)]. The number of such solitons modulating a wave with frequency ν is obviously equal to number n of deceleration events this wave makes electrons undergo.

From the above it becomes clear that the quantum nature of radiation is dictated by the character of this process as itself and by no means contradicts classical mechanics. And the concepts of force and acceleration may be readily assigned to radiation process. However, now not photon, but soliton becomes a true quantum of radiation as the product of interaction between substance and radiation.

Let now electrons of substance oscillating relative to the EMF give impulse p_e (N·s) to it. The EMF wave that has received this impulse distributes it with speed c, which is equivalent to increase of its energy by $p_e c$ (J). If the electrons decelerate n times, the EMF will thus receive energy $E_n = np_e c$. In its meaning and dimensions it is the impact from flow $J_в$ (12), then

$$J_в = E_n = np_e c = nm_e l_e c\nu = nh_\nu \nu, \text{ (J)} \tag{14}$$

where $h_\nu = m_e l_e c$ (J·s) – a proportionality factor having dimensions and meaning of the action the EMF exerts on the electron in the process of its acceleration or deceleration.

Thus, we again, as well as in (12), come to the conclusion about inconstancy of the proportionality factor between the energy of quantum and its frequency. This circumstance dictates a necessity to average values h_ν and E_ν over all j^{th} oscillators of the radiating body. Considering the accidental character of these values and their relation with electron impulse p_e one should expect that distribution of E_ν over impulses p_e follows the normal Maxwell’s – Boltzmann’s law $N_\nu/N_o = \exp(E_n/kT)$, wherefrom:

$$\langle E_\nu \rangle = \langle h_\nu \rangle \nu = h_\nu \nu \exp(-h_\nu \nu/kT)/\Sigma_j \exp(-h_\nu \nu/kT), \tag{15}$$

where $\langle h_\nu \rangle$ – the most probable value of h_ν.

This operation, which is not beyond classical statistics, results in the fact that now in all subsequent expressions, instead of Planck's constant h, average value $\langle h_\nu \rangle$ of proportionality factor h_ν will appear. It does not either contradict the universality of Kirchhoff’s function $f(\nu,T)$ [13], which in our case becomes $\langle h_\nu \rangle \nu/kT$. In this case the operation of finding $\langle E_n \rangle = n\langle E_\nu \rangle$ may be conducted by the same way of transition from infinite series $\Sigma_n \exp(-nh\nu/kT)$ to expression $[\exp(E_n/kT) - 1]$ approximating it:

$$\langle E_n \rangle = \langle h_\nu \rangle \nu/[\exp(\langle h_\nu \rangle \nu/kT) - 1], \text{ J.} \tag{16}$$

Thus, spectral density of radiation $u(\nu,T)$ will be defined by the same product $\langle E_n \rangle dN_\nu$, whose integration leads to the Planck’s radiation law (5) in the form:

$$u(\nu,T) = (8\pi \langle h_\nu \rangle \nu^3/c^3)/[\exp(\langle h_\nu \rangle \nu/kT) - 1], \text{ (W m}^3\text{).} \tag{17}$$

Since $\langle h_\nu \rangle$, as well as h, is subject to experimental definition based on any of expressions (5) or (17), their values may be considered equivalent.

Discussion

The offered solution to the problem of radiation is not based on the specific postulates of quantum-mechanical character, properties of absolutely black body and imaginary models like a cavity with ideally reflecting walls, as well as on the concepts about existence of thermal balance between substance and radiation. According to this solution the quantum nature of radiation and absorption process pertaining to radiant energy is dictated by discrete character of this process and by no means contradicts the classical concepts about the media with continuous energy spectrum existing in macrosystems. Never comes to any mind an idea that the ocean consists of drops only because such is the rain filling it up!

Considering non-equilibrium system “substance + radiation field” as a single entity for investigation makes clear there is no thermal balance in such "expanded" system and assigning the parameters of thermal form of energy to radiation is erroneous. It becomes clear that the interaction between substance and radiation field bears the power character and is connected with interconversion between ordered energy of radiation and disordered internal energy of substance. It requires replacing the thermal balance conditions by the stationarity conditions and applying to the methods of energodynamics based on the concept of energy carrier flow. Using herein the flow of solitons allows providing the process of radiation with a description uniform for all forms of energy.

Such approach makes clear that the radiation process occurs due to deceleration and acceleration of particles of substance caused by external radiation field. Though such interaction between substance and radiation field bears discrete character, it exists for all waves and particles, for which $\mathbf{F}_в \cdot \mathbf{v}_e \neq 0$, i.e. it bears non-resonant character in whole well-known in laser spectroscopy [14]. That is what dictates the continuous spectrum for absolutely black bodies.

[1)] It should be noted that with study advancing the number of entities qualified as soliton continuously increases.

One of the important results of the consideration undertaken is the elimination of “wave – particle” dualism. Indeed, expression $\lambda = h_\nu/p_e$ connects length of soliton wave λ with average impulse p_e of the electron that has generated this wave. However, the wave belongs to EMF, whereas electrons – to substance. This excludes “dualism”. Thus, particle-like properties of solitons explain why radiation shows as a wave in some cases (interference, diffraction, polarization), whereas as particles in other cases (photoeffect, Compton’s effect).

The offered approach sheds also new light on structure and physical meaning of the Planck’s “constant”. Many researchers were puzzled over the fact why quantum of energy is identical to all substances and all microprocesses in them. Now it becomes clear it is due to the statically average value of the soliton impulse as a singular disturbance of the same medium, viz. electromagnetic field.

Replacing photon by soliton allows solution to the problem of redundancy of ultrahigh-frequency photon energy. Indeed, solitons follow one after another with frequency ν_e, *n*-time exceeding frequency of photons ν. It follows from here that average energy of solitons is *n*-time lower than energy of photons. This removes the problem of redundancy of photon energy at $\nu \to \infty$, which Einstein [15] put forward.

The modulation of electromagnetic waves by solitons also explains why the waves emitted by different sources of light do not interfere. The reason is that such waves are modulated by different sets of frequencies $\nu_e = n\nu$ from these sources.

All the above denies the popular opinion that classical physics is helpless against the quantum laws of light. However, such issues are beyond the topics of this article.

Conclusions

1. The Planck’s law of radiation may be proved from the standpoint of non-equilibrium thermodynamics without resort to whatever hypotheses or postulates which are beyond the concepts of classical physics.
2. Energy of radiation field bears ordered character and is characterized by the parameters different from the parameters of thermal movement. Interaction between substance and field bears power character and is not reduced to heat exchange.
3. Process of radiation and absorption of energy runs due to deceleration or acceleration of electrons caused by external power field, but not due to electron transition from one stable orbit onto another. This process features duration and bears power character, which makes the power concept applicable also to microcosm.
4. Quantum character of this process is dictated by short-term duration of electron deceleration or acceleration when the electron interacts with external power field periodically changing.
5. True quantum of radiation is soliton as solitary structurally stable and particle-like elevation wave constrained both in space and time.
6. Energy of soliton as quantum of radiation does not increase with increasing frequency and may be many orders lower than energy of photon. It removes the problem of redundancy of ultrahigh-frequency photon energy.
7. Planck's constant has a meaning of the most probable action the power field exerts on electron at a single event of its acceleration or deceleration.
8. Spectral density of radiation is proportional to the number and average energy of the solitons the radiating body emits at frequency ν.
9. Specific properties of solitons as particle-like waves explain why they behave as wave in some cases, but as particles in other cases. It removes the problem of “wave – particle” dualism.

References

[1] Planck M. Über eine Verbesserung der Wienschen Spektralgleichung. //Verhandl. Dtsch. Phys. Ges., 1900, **2**, 237 – 245.

[2] Planck M. Zur Theorie des Gesetzes der Energieverteilung im Normalspectrum. // Verhandl. Dtsch. Phys. Ges., 1900, **2**, 237–245.

[3] Planck M. Über irreversible Strahlungsvorgänge. //Annalen der Physik, 1900, **306** (1), 69–122.

[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] Crawford F. Waves. Berkeley Physics course. Vol. 3.- McGraw-Hill, 1968.

[7] Onsager L. Reciprocal relations in irreversible processes.//Phys. Rev., 1931.- **237**(14).-P.405-426; **238**(12).- P.2265-2279.

[8] Prigogine I. Etude Thermodynamique des Phenomenes Irreversibles. – Liege, 1947, 143 p.

[9] Denbigh K. G. Thermodynamics of the Steady State. - L.: Methuen, 1951.

[10] De Groot S.R., Mazur P. Non-Equilibrium Thermodynamics. – Amsterdam, 1962.

[11] Etkin V. Energodynamics (Thermodynamic Fundamentals of Synergetics).– New York, 2011, 479 p.

[12] Landau L.D., Livshits E.M. Theoretical Physics. V.1.Mechanics. Edn 5.– M.: Fizmashlit, 2004.

[13] Kirchhoff G. Untersuchungen über das Sonnenspectrum und die Spectra der chemischen Elemente.- Berlin,1861.

[14] Demtroder W. Laser Spectroscopy: Basic Concepts and Instrumentation, New York: Springer, 2003.

[15] Einstein A., Infeld L. Evolution of Physics. – Cambridge, 1938.