BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXI No. 1/2009	101 - 108	Seria Matematică - Informatică - Fizică

The Planck Law in Quantum Physics and Stochastic Physics

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Abstract

In the present paper the compatibility of Einstein method to obtain de spectral energy density law (Planck's Law) with the existence of the zero point field radiation is investigated. It is demonstrated that this compatibility exists only if we consider the interaction of half parts of photons, with the same frequencies determined by the thermal radiation from the unit volume, with the cavity's oscillators. The quantum physics is based on Planck and Einstein's hypotheses (energy-momentum and action quantification) generalized by L. de Broglie for all particles and he develops a formalism that can be used to obtain material waves modes in a cavity defined by the potential energy space-time dependence. As a consequence, the quantum physics establish a virtual field of zero point quantum fluctuation (ZPF – Zero Point Field). The stochastic physics is based on the fundamental hypothesis that the quantum properties of macroscopic systems are the consequences of classical interactions of these systems with a real electromagnetic field at $T = 0$ *(CZPF – Classical Zero Point Field)*

Keywords: *stochastic physics, Planck law, spectral energy density, zero point quantum fluctuation*

Introduction

To analyze the deduction problems of spectral density law (Planck's Law) in this work the quantum physics and stochastic physics methods are analyzed.

In the first two paragraphs the Einstein's method is analyzed, for Planck's Law deduction, and we demonstrate that this method is compatible with the existence of the zero point field if the spontaneous emission is interpreted as stimulated emission induced by this external field. Also, we obtain the correct expression of the spectral density of thermal radiation if we consider only the half part of thermal radiation's photons that interact with the atoms from cavity. In the last paragraph we analyze the possibility for deduction of the spectral density for thermal radiation and zero point radiation using stochastic physics hypotheses.

Einstein's Method

In 1916 Einstein [1, 2 cp. 11.3] obtain the spectral energy density for the black body radiation (thermal equilibrium radiation), using a model of the interaction processes between a system of identical atoms and electromagnetic radiation considered as a system of quantum particles (photons).

Let us consider a cavity (enclosure) with walls consisting of a single type of atoms and an electromagnetic thermal radiation in interior. The system is in thermal equilibrium at temperature T . Consider N_n atoms in the state characterized with the energy E_n (degenerated state). This number represents the population of state. The atoms, in interaction with the electromagnetic radiation, transitioning from state n to state m . The absorption rate (the rate of change for N_n) dN_{nm}/dt is proportional to the number of atoms in state n , N_n , and to the spectral density of radiation $\rho(\omega)$:

$$\frac{dN_{nm}}{dt} = B_{nm} N_n \rho(\omega_{nm}) , \quad (1)$$

where B_{nm} is the Einstein coefficient for absorption.

The rate of stimulated emission is proportional to N_n and $\rho(\omega_{nm})$:

$$\frac{dN_{mn}}{dt} = B_{mn} N_m \rho(\omega_{nm}) . \quad (2)$$

The transition from state m to state n (deexcitation) is realized through spontaneous emission. The rate of spontaneous emission is proportional only with N_m :

$$\frac{dN_{mn}^{s}}{dt} = A_{mn} N_m , \quad (3)$$

where A_{mn} is Einstein's coefficient of spontaneous emission. The transition rate, from state m to state n , is the sum of the spontaneous emission and the stimulated emission

$$\left(\frac{dN_{mn}}{dt}\right)_{\text{emis.}} = \left(\frac{dN_{mn}^{s}}{dt}\right)_{\text{emis.}} + \left(\frac{dN_{mn}}{dt}\right)_{\text{emis.}} .$$

At equilibrium (when N_n and N_m are unchanging), the absorption rate is equal with the emission rate

$$\frac{dN_{nm}}{dt} \equiv \frac{dN_{mn}}{dt} = \frac{dN_{nm}^{s}}{dt} + \frac{dN_{nm}}{dt} . \quad (4)$$

Replacing (1), (2) and (3) in (4), it results

$$N_n B_{nm} \rho(\omega_{mn}) = N_m A_{mn} + N_m B_{mn} \rho(\omega_{mn}) \quad (5a)$$

or $$\frac{N_n}{N_m} = \frac{A_{mn} + B_{mn}\rho(\omega_{mn})}{B_{nm}\rho(\omega_{mn})} . \quad (5b)$$

At thermal equilibrium, the distribution of the atoms states is a Boltzmann distribution

$$N_n \propto \exp(-E_n / kT) \quad (6)$$

and using the electromagnetic radiation energy quantification hypothesis, it results

$$\frac{N_n}{N_m} = \left[\exp[-(E_n - E_m)/(kT)\right] = \exp\left[\hbar\omega_{mn}/(kT)\right] . \quad (7)$$

Replacing (7) in (5b), it results

$$\rho\left(\omega_{mn}\right)=\frac{A_{mn}}{B_{nm}\exp\left[\hbar\omega_{mn}/\left(kT\right)\right]-B_{mn}}. \tag{8}$$

If $B_{nm}=B_{mn}$, with (8), it results:

$$\rho\left(\omega_{mn}\right)=\frac{A_{mn}}{B_{mn}\left[\exp\left(\hbar\omega_{mn}/\left(kT\right)\right)-1\right]}. \tag{9}$$

Comparing (9) with the Planck formula

$$\rho\left(\omega_{mn}\right)=\frac{\hbar\omega_{mn}^{3}}{\pi^{2}c^{3}\left[\exp\left(\hbar\omega_{mn}/\left(kT\right)\right)-1\right]}, \tag{10}$$

it results

$$\frac{A_{mn}}{B_{mn}}=\frac{\hbar\omega_{mn}^{3}}{\pi^{2}c^{3}}.$$

It interesting to remark that de emission rate

$$\left(dN_{mn}/dt\right)=\left[\left(A_{mn}/B_{mn}\right)+\rho\left(\omega_{mn}\right)\right]B_{mn}N_{m} \tag{11}$$

can be expressed, using (10), under the form:

$$\frac{dN_{mn}}{dt}=B_{mn}N_{m}\left(\frac{\hbar\omega_{mn}^{3}}{\pi^{2}c^{3}}+\rho\left(\omega_{mn}\right)\right). \tag{12}$$

Relation (12) points out that the emission is produced only in stimulated way under the action of a stationary electromagnetic radiation with density

$$\rho'\left(\omega,T\right)=\rho\left(\omega,T\right)+\frac{\hbar\omega^{3}}{\pi^{2}c^{3}}. \tag{13}$$

The physical meaning of density $\hbar\omega^{3}/\left(\pi^{2}c^{3}\right)$ is obtained through passing to the limit $T\to 0$

$$\lim_{T\to 0}\rho'\left(\omega,T\right)=\frac{\hbar\omega^{3}}{\pi^{2}c^{3}}=2\rho_{0}\left(\omega\right). \tag{14}$$

The term $\rho_{0}\left(\omega\right)$ is the spectral density of the isotropic background radiation with zero temperature. This background radiation is interpreted in quantum physics as background oscillations / fluctuations of zero (ZPF - Zero Point Field) of vacuum (modeled as a background virtual oscillations - which can not be detected directly by devices, but only through nonlinear effects induced - the Casimir effect and Lamb shift [5]), and in stochastic physics as a real background radiations (electromagnetic waves) in equilibrium at temperature $T=0$ (CZPF - Classical Zero Point Field) [3, 4].

The question is, to explain why using Einstein's method we obtain for the Zero Point Field density doubled value $\rho'\left(\omega,0\right)=2\rho_{0}\left(\omega\right)$.

To solve this problem, we should resume Einstein's method where spontaneous emission is replaced by stimulated emission of the background fluctuations to zero. In this new vision, the rate of spontaneous emission is written as stimulated emission of radiation background with density

$$\frac{dN_{mn}}{dt} = B_{mn} N_m \rho_0 (\omega_{nm}) . \quad (15)$$

With this new consideration the total emission rate becomes

$$\frac{dN_{mn}}{dt} = B_{mn} N_m \left[\rho_0 (\omega_{mn}) + \rho(\omega_{mn}) \right] . \quad (16)$$

From the condition of equal rates for absorption and emission, at equilibrium, the expression (16) with expression (1) are equalized, resulting

$$B_{mn} N_m \rho(\omega_{nm}) = B_{nm} N_n \left[\rho_0 (\omega) + \rho(\omega, T) \right] \quad (17a)$$

or, with $B_{nm} = B_{mn}$ and equation (7), it results

$$\rho(\omega_{nm}, T) = \frac{\rho_0 (\omega_{nm})}{\exp\left[\hbar\omega_{mn} / (kT)\right] - 1} . \quad (17b)$$

By comparison with the Planck expression, we found again that the spectral density of the Zero Point Field is double than the accepted value. It follows that there is a mistake in how the interaction is modeled physico-mathematically at thermal equilibrium of radiation, ZPF - radiation and the atoms.

The Equilibrium of Radiation with the Cavities Atoms

Both the experimental study and physic-mathematical models of the thermal radiation equilibrium is considered a cavity with walls made up of atoms, which interact with thermal radiation equilibrium that arises in it. If we take into account the hypothesis that spontaneously emitted radiation is a radiation induced by interaction with the zero point field, the atoms are involved in interaction with this radiation which is different from the interaction with thermal radiation. In the process of interaction with zero-point radiation, with density $\rho_0 (\omega_{nm})$, the atoms are immersed in this field and all interact with that (both radiation from outside the cavity and from the cavity). In the process of interaction with thermal radiation in equilibrium $\rho(\omega_{nm}, T)$, the atoms of cavity interact only with half of the thermal radiation flux. The atoms only absorb thermal radiation from the cavity and emit both inside and outside the cavity. At equilibrium, half of the cavity atoms, $N_m/2$, emit radiation, stimulated by thermal radiation to the interior, emitted radiation that contributes to thermal equilibrium. With these clarifications, the rate of absorption (2) is

$$\frac{dN_{nm}}{dt} = B_{nm} N_n \frac{\rho(\omega_{nm})}{2} , \quad (18)$$

the rate of emission, stimulated by the thermal radiation, become

$$\frac{dN_{mn}}{dt} = B_{mn} N_m \frac{\rho(\omega_{nm})}{2} \quad (19)$$

and the total emission rate is

$$\frac{dN_{mn}}{dt} = B_{mn} N_m \left[\rho_0\left(\omega_{mn}\right) + \frac{\rho\left(\omega_{mn}\right)}{2} \right]. \tag{20}$$

At equilibrium, with $B_{nm} = B_{mn}$, it results

$$N_m \frac{\rho\left(\omega_{nm}\right)}{2} = N_n \left[\rho_0\left(\omega\right) + \frac{\rho\left(\omega, T\right)}{2} \right] \tag{21a}$$

or, taking into account the equation (7),

$$\rho\left(\omega_{nm}, T\right) = \frac{2\rho_0\left(\omega_{nm}\right)}{\exp\left[\hbar\omega_{mn} / \left(kT\right)\right] - 1}. \tag{21b}$$

In these circumstances, is obtained a correct expression of the spectral density of Zero Point Field radiation and zero thermal radiation at equilibrium.

Deduction of the Spectral Density in Stochastic Physics

To deduce the expression of the spectral density of thermal radiation at equilibrium $\rho\left(\omega_{nm}, T\right)$, in the stochastic electrodynamics (SED), we use the expression of the ZPF radiation density $\rho_0\left(\omega_{nm}\right)$ which, in the SED is derived [3,4] only from classical considerations (invariant to Lorentz transformations) and the energy balance of interaction between stationary electromagnetic radiation and cavity atoms. The exchange of energy between radiation and atoms is resonant. The atoms are considered coupled oscillators in ground state (N_n number of atoms with energetic state E_n and frequency ω_n) and excited state (N_m number of atoms in state with energy E_m and frequency ω_m). The coupled oscillators exchange resonant energy in interaction with electromagnetic radiation, from the two fields at a frequency corresponding to beat frequencies [6]:

$$\omega_{mn} = \omega_m - \omega_n. \tag{22}$$

The interaction between atoms and electromagnetic radiation is modeled classically, according to the paper [7]. An atom in the fundamental state, absorb the mean power $b_{nm}\,\rho\left(\omega_{nm}, T\right)/2$ from thermal radiation and $b_{nm0}\rho_0\left(\omega_{nm}\right)$ from the ZPF. The N_n atoms will absorb the power

$$P_{na} = N_n b_{nm}\,\rho\left(\omega_{nm}, T\right)/2 + N_n b_{nm0}\rho_0\left(\omega_{nm}\right). \tag{23}$$

The atoms in the fundamental state have emission power stimulated by the ZPF

$$P_{ne} = N_n b_{mn0}\rho_0\left(\omega_{nm}\right). \tag{24}$$

An excited atom has the stimulated emission power by thermal radiation $b_{mn}\,\rho\left(\omega_{nm}, T\right)/2$ and thermal power emission stimulated by the ZPF $b_{mn0}\rho_0\left(\omega_{nm}\right)$. For atoms in the excited state of the total emission power is

$$P_{me} = N_m b_{mn}\,\rho\left(\omega_{nm}, T\right)/2 + N_m b_{mn0}\rho_0\left(\omega_{nm}\right). \tag{25}$$

The emission total power is obtained from (24) and (25):

$$P_e = P_{ne} + P_{me} = N_n b_{mn0}\rho_0(\omega_{nm}) + N_m b_{mn}\,\rho(\omega_{nm},T)/2 + N_m b_{mn0}\rho_0(\omega_{nm}) \quad . \tag{26}$$

At equilibrium the absorption power is equal with the emission power

$$N_n b_{nm}\frac{\rho(\omega_{nm},T)}{2} + N_n b_{nm0}\rho_0(\omega_{nm}) = N_n b_{mn0}\rho_0(\omega_{nm}) + N_m b_{mn}\frac{\rho(\omega_{nm},T)}{2} + N_m b_{mn0}\rho_0(\omega_{nm}) \quad .(27)$$

If $T \to 0$, the thermal radiation density becomes zero, $\rho(\omega_{nm},T) \to 0$ and the number of atoms in the excited state tends to zero $N_m \to 0$. In these circumstances, from the equation (26) it results

$$b_{nm0} = b_{mn0} \tag{28}$$

and therefore, in the fundamental state, the absorbed power from the ZPF is equal to the emitted power and therefore this state is a stationary one.

Taking into acount the equality of coefficients given by (28) in equation (27), it results

$$N_n b_{nm}\frac{\rho(\omega_{nm},T)}{2} = N_m b_{mn}\frac{\rho(\omega_{nm},T)}{2} + N_m b_{mn0}\rho_0(\omega_{nm}) \tag{29a}$$

or, replacing the ratio N_n/N_m given by equation (7),

$$\rho(\omega_{nm},T) = \frac{2b_{mn0}\rho_0(\omega_{nm})}{b_{mn}\left\{\frac{b_{nm}}{b_{mn}}\exp\left[(E_m - E_n)/(kT)\right] - 1\right\}} \quad . \tag{29b}$$

Imposing the condition for $T \to \infty$, $\rho(\omega_{nm},T) \to \infty$, to expression (29b) of spectral density, it results $b_{nm} = b_{mn}$. Because the radiation is of electromagnetic type and the atoms of the same type, the absorption coefficients related to thermal radiation and ZPF radiation are equals

$$b_{mn0} = b_{mn} = b_{nm} \quad . \tag{30}$$

With these equalities, the spectral density of thermal radiation (29b) becomes

$$\rho(\omega_{nm},T) = \frac{2\rho_0(\omega_{nm})}{\exp\left[(E_m - E_n)/(kT)\right] - 1} \quad . \tag{31}$$

From resonance condition, the absorbed and emitted energies have the expression

$$\Delta E_m = E_m - E_n = f(\omega_m - \omega_n) \quad . \tag{32}$$

In the same way, the energies of the two states are functions of frequencies i.e., $E_m = g(\omega_m)$ and $E_n = g(\omega_n)$. The functions which satisfy this condition are linear

$$E_j = g(\omega_j) = H\omega_j + E_0 \quad , \tag{33}$$

with H and E_0 are real constants, i.e. the condition imposed by Planck to the cavity oscillators energy ($H = \hbar$), and hence the exchanged energies of atoms have the form

$$\Delta E_{mn} = H \cdot \left(\omega_m - \omega_n\right) = H\omega_{mn} = \hbar\omega_{mn} \quad . \tag{34}$$

Therefore, the absorbed and emitted energies electromagnetic radiation forms are the expression proposed by Einstein, in the study of photoelectric effect. Substituting in (31), it results

$$\rho\left(\omega_{nm}, T\right) = \frac{2\rho_0\left(\omega_{nm}\right)}{\exp\left[\left(\hbar\omega_{mn}\right)/\left(kT\right)\right]-1} \quad . \tag{35}$$

As it was expected, we found the conditions imposed by Planck and Einstein to electromagnetic radiation emission and absorption by the atoms (modeled as oscillators). The origin of these properties, proportionality of the oscillators energies with frequencies and the implicitly the energy changed (photon energy) is that the oscillators have a zero point energy or the minimum action is different from zero (and vice versa). In the SED, the oscillators, as microscopic systems, are in interaction with ZPF which they produce a periodic motion of period T_0 and total energy $E_0 \neq 0$. The action corresponding to a period (the minimum time that defines a full cycle) is different from zero $E_0 T_0 = H_0 \neq 0$ and is the minimum action corresponding microscopic systems and composite systems formed from them. It results that the microscopic systems interacting with ZPF require both a minimum energy and a minimal action, if the movement is cyclical. Quantifying energy and action for the microscopic and macroscopic systems is the consequence of the interaction of these with the ZPF.

Conclusions

In this paper, we investigated the compatibility of Einstein's method for deducting the expression of spectral density for thermal radiation, with the existence of a ZPF. We demonstrated that it is compatible when considering the interaction asymmetry of oscillators from cavity with the two types of radiation. Only half of the quanta, the same frequency, of thermal radiation from the unit volume interact with cavity’s oscillators.

Quantum physics is based on assumptions of Planck and Einstein (quantifying energy-impulse and action) generalized by L. de Broglie for all particles and develop a formalism that allows finding the modes of matter waves in cavities defined by dependency of the potential energy in space and time [8]. As a consequence, quantum physics establish the existence zero point field of virtual quantum fluctuations (ZPF).

Stochastic physics have the fundamental assumption that the quantum properties of microscopic systems are a consequence of classical interaction with a real zero point field of electromagnetic waves at $T = 0$ (CZPF - Classical Zero Point Field).

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Proprietățile optice ale vacuumului în prezența fondului stocastic electromagnetic

Rezumat

În lucrare am investigat compatibilitatea metodei lui Einstein pentru a deduce expresia densității spectrale a radiației termice (legea lui Planck) cu existența unui fond de radiație zero. Am demonstrat că această compatibilitate există dacă doar jumătate din cuantele, de aceeaşi pulsație, ale radiației termice din unitatea de volum, interacționează cu oscilatorii cavității. Fizica cuantică se fundamentează pe ipotezele lui Planck şi Einstein (cuantificarea energiei-impulsului şi acțiunii) generalizate de L. de Broglie pentru toate particulele şi dezvoltă un formalism care îi permite aflarea modurilor undelor de materie în cavități definite prin modul cum variază energia potențială în spațiu şi timp. Ca o consecință, fizica cuantică stabileşte şi existența unui fond virtual de fluctuații cuantice de zero (ZPF). Fizica stocastică are ca ipoteză fundamentală faptul că proprietățile cuantice ale sistemelor microscopice sunt o consecință a interacțiunii clasice a acestora cu un fond real de unde electromagnetice la $T = 0$ *(CZPF – Classical Zero Point Field).*