New Fundamental *Light Particle* and Breakdown of Stefan-Boltzmann's Law

Vahan Minasyan and Valentin Samoilov
Scientific Center of Applied Research, JINR, Dubna, 141980, Russia
E-mails: mvahan@scar.jinr.ru; scar@off-serv.jinr.ru

Recently, we predicted the existence of fundamental particles in Nature, neutral *Light Particles* with spin 1 and rest mass $m = 1.8{\times}10^{-4} m_e$, in addition to electrons, neutrons and protons. We call these particles Light Bosons because they create electromagnetic field which represents Planck's gas of massless photons together with a gas of *Light Particles* in the condensate. Such reasoning leads to a breakdown of Stefan–Boltzmann's law at low temperature. On the other hand, the existence of new fundamental neutral *Light Particles* leads to correction of such physical concepts as Bose-Einstein condensation of photons, polaritons and exciton polaritons.

1 Introduction

First, the quantization scheme for the local electromagnetic field in vacuum was presented by Planck in his black body radiation studies [1]. In this context, the classical Maxwell equations lead to appearance of the so-called ultraviolet catastrophe; to remove this problem, Planck proposed the model of the electromagnetic field as an ideal Bose gas of massless photons with spin one. However, Dirac [2] showed the Planck photon-gas could be obtained through a quantization scheme for the local electromagnetic field, presenting a theoretical description of the quantization of the local electromagnetic field in vacuum by use of a model Bose-gas of local plane electromagnetic waves propagating by speed c in vacuum.

In a different way, in regard to Plank and Dirac's models, we consider the structure of the electromagnetic field [3] as a non-ideal gas consisting of N neutral *Light Bose Particles* with spin 1 and finite mass m, confined in a box of volume V. The form of potential interaction between *Light Particles* is defined by introduction of the principle of wave-particle duality of de Broglie [4] and principle of gauge invariance. In this respect, a non-ideal Bose-gas consisting of *Light Particles* with spin 1 and non-zero rest mass is described by Planck's gas of massless photons together with a gas consisting of *Light Particles* in the condensate. In this context, we defined the *Light Particle* by the model of hard sphere particles [5]. Such definition of *Light Particles* leads to cutting off the spectrum of the electromagnetic wave by the boundary wave number $k_0 = \frac{mc}{\hbar}$ or boundary frequency $\omega_\gamma = 10^{18}$ Hz of gamma radiation at the value of the rest mass of the *Light Particle* $m = 1.8 \times 10^{-4} m_e$. On the other hand, the existence of the boundary wave number $k_0 = \frac{mc}{\hbar}$ for the electromagnetic field in vacuum is connected with the characteristic length of the interaction between two neighboring *Light Bosons* in the coordinate space with the minimal distance $d = \frac{1}{k_0} = \frac{\hbar}{mc} = 2{\times}10^{-9} m$. This reasoning determines the density of *Light Bosons* $\frac{N}{V}$ as $\frac{N}{V} = \frac{3}{4\pi d^3} = 0.3{\times}10^{26} m^{-3}$.

It is well known that Stefan-Boltzmann's law [6] for thermal radiation, presented by Planck's formula [1], determines the average energy density $\frac{U}{V}$ as

$$\frac{U}{V} = \frac{2}{V} \sum_{0 \le k < \infty} \hbar k c \overline{\vec{i}^{+}_{\vec{k}} \vec{i}_{\vec{k}}} = \sigma T^4, \tag{1}$$

where $\hbar$ is the Planck constant; σ is the Stefan-Boltzmann constant; $\overline{\vec{i}^{+}_{\vec{k}} \vec{i}_{\vec{k}}}$ is the average number of photons with the wave vector $\vec{k}$ at the temperature T:

$$\overline{\vec{i}^{+}_{\vec{k}} \vec{i}_{\vec{k}}} = \frac{1}{e^{\frac{\hbar k c}{kT}} - 1}. \tag{2}$$

Obviously, at $T = 0$, the average energy density vanishes in Eq.(1), i.e. $\frac{U}{V} = 0$, which follows from Stefan-Boltzmann's law.

However, as we show, the existence of the predicted *Light Particles* breaks Stefan-Boltzmann's law for black body radiation at low temperature.

2 Breakdown of Stefan-Boltzmann's law

Now, we consider the results of letter [3], where the average energy density of black radiation $\frac{U}{V}$ is represented as:

$$\frac{U}{V} = \frac{mc^2 N_{0,T}}{V} + \frac{2}{V} \sum_{0 \le k < k_0} \hbar k c \overline{\vec{i}^{+}_{\vec{k}} \vec{i}_{\vec{k}}}, \tag{3}$$

where $\frac{mc^2 N_{0,T}}{V}$ is a new term, in regard to Plank's formula (1), which determines the energy density of *Light Particles* in the condensate; $\frac{N_{0,T}}{V}$ is the density of *Light Particles* in the condensate.

In this respect, the equation for the density of *Light Particles* in the condensate $\frac{N_{0,T}}{V}$ represents as

$$\frac{N_{0,T}}{V} = \frac{N}{V} - \frac{1}{V} \sum_{0 < k < k_0} \frac{L^2_{\vec{k}}}{1 - L^2_{\vec{k}}} - \frac{1}{V} \sum_{0 < k < k_0} \frac{1 + L^2_{\vec{k}}}{1 - L^2_{\vec{k}}} \overline{\vec{i}^{+}_{\vec{k}} \vec{i}_{\vec{k}}} \tag{4}$$

with the real symmetrical function $L_{\vec{k}}$ from the wave vector $\vec{k}$:

$$L_{\vec{k}}^2 = \frac{\frac{\hbar^2 k^2}{2m} + \frac{mc^2}{2} - \hbar kc}{\frac{\hbar^2 k^2}{2m} + \frac{mc^2}{2} + \hbar kc}. \tag{5}$$

Our calculation shows that at absolute zero the value of $\overline{\vec{i}_{\vec{k}}^{+}\vec{i}_{\vec{k}}} = 0$, and therefore the average energy density of black radiation $\frac{U}{V}$ reduces to

$$\frac{U}{V} = \frac{mc^2 N_{0,T=0}}{V} = \frac{mc^2 N}{V} - \frac{m^4 c^5 B(2,3)}{4\pi^2\hbar^3} \approx \frac{mc^2 N}{V}, \tag{6}$$

where $B(2,3) = \int_0^1 x(1-x)^2 dx = 0.1$ is the beta function.

Thus, the average energy density of black radiation $\frac{U}{V}$ is a constant at absolute zero. In fact, there is a breakdown of Stefan-Boltzmann's law for thermal radiation.

In conclusion, it should be also noted that *Light Bosons* in vacuum create photons, while *Light Bosons* in a homogeneous medium generate the so-called polaritons. This fact implies that photons and polaritons are quasiparticles, therefore, Bose-Einstein condensation of photons [7], polaritons [8] and exciton polaritons [9] has no physical sense.

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