The sedimentation of photons and gluons in the Svedberg ultracentrifuge

Miroslav Pardy
Department of Physical Electronics
Masaryk University
Kotlářská 2, 611 37 Brno, Czech Republic
e-mail:pamir@physics.muni.cz

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Abstract

We consider the case of rotating black body (including the rotation of the black bath with gluons) where photons and gluons can perform the settling and sedimentation. The Planck formula for photons must be, in this situation, replaced by the Exner solution of the Lamm equation for photons.

1 Introduction

Sedimentation is the physical process of the deposition of sediments. This is due to their motion through the fluid in response to the forces acting on them. These forces can be due to gravity, centrifugal acceleration, or electromagnetism. Settling is the falling of suspended particles through the liquid, whereas sedimentation is the final result of the settling process. The rate of sedimentation can be expressed mathematically by the Exner equation (Exner, 1925).

We consider here the case of rotating black body (including the rotation of the gluon black body) where photons, or, gluons can perform the settling and sedimentation. The Planck formula must be, in this situation, replaced by the Exner solution of the Lamm equation for photons.

Sedimentation of photons is in no case Bose-Einstein-condensation (BEC), because the characteristic of BEC is different. BEC is a state of matter that is typically formed when a gas of bosons at low densitiesis cooled to temperatures very close to absolute zero (273.15 C, or, 459.67 F).

2 Lamm equation

The Lamm equation (Lamm, 1929) describes the sedimentation and diffusion of a solute under ultracentrifugation in traditional sector-shaped cells. (Cells of other shapes require much more complex equations). It was named after Ole Lamm from physical chemistry at the Royal Institute of Technology, who derived it under Svedberg pedagogical directory at Uppsala University. The Lamm equation can be written as follows (Rubinov, 2002; Mazumdar, 1999):

$$\frac{\partial c}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(Dr\frac{\partial c}{\partial r} - s\omega^2 r^2 c\right), \tag{1}$$

where c is the solute concentration, t and r are the time and radius, and the parameters D, s, ω represent the solute diffusion constant, sedimentation coefficient and the rotor angular velocity, respectively.

The first and second terms on the right-hand side of the Lamm equation are proportional to D and ω^2, respectively, and describe the competing processes of diffusion and sedimentation.

Whereas sedimentation seeks to concentrate the solute near the outer radius of the cell, diffusion seeks to equalize the solute concentration throughout the cell. The diffusion constant D can be estimated from the hydrodynamic radius and shape of the solute, whereas the buoyant mass m can be determined from the ratio of s and D,

$$\frac{s}{D} = \frac{m}{kT}, \tag{2}$$

where kT is the thermal energy, i.e., Boltzmann's constant k multiplied by the temperature T in kelvins.

Solute molecules cannot pass through the inner and outer walls of the cell, resulting in the boundary conditions on the Lamm equation

$$D\left(\frac{\partial c}{\partial r}\right) - s\omega^2 rc = 0 \tag{3}$$

at the inner and outer radii, r_a and r_b, respectively. By spinning samples at constant angular velocity ω and observing the variation in the concentration $c(r,t)$, one may estimate the parameters s and D, and, thence, the (effective or equivalent) buoyant mass of the solute.

It is physically meaningful to consider the rotating the black-body with photons of different relativistic mass

$$m = \frac{\hbar\omega}{c^2} \tag{4}$$

in order to get the sedimentation of photons according to the Lamm equation as the analogue of sedimentation of cells in the biochemistry. At the same time it is physically meaningful to consider, dielectric crystalline medium with photons which is inserted in the Planck blackbody photon gas. It means that photon gas of the blackbody surrounding the dielectric crystalline medium with index of refraction n folows into such crystal and initiate the quantum sedimentation of photons (gluons) in case that the crystalline medium is in the rotating state.

The dielectric crystal with photons is called here by term Planck dielectric blackbody. Inside of the dielectric medium with index of refraction n, the spectral radiation formula must be modified in order to form the spectrum of such dielectric black body. The derivation of the spectral formula must be based on the original Planck spectral formula which was rederived by Einstein (1917).

3 The Blackbody formula by Einstein

Let us review the Einstein derivation of the Planck black body spectral formula. The distribution of the blackbody photons was derived by Planck (1900) from modification of the thermodynamical entropy, and later, Einstein (1919) derived the Planck formula from the Bohr model of atom which was based on two postulates: 1. every atom can exist in the discrete series of states in which electrons do not radiate even if they are moving at acceleration (the postulate of the stationary states), 2. transiting electron from the stationary state to other, emits the energy according to the law $\hbar\omega = E_m - E_n$, called the Bohr formula, where E_m is the energy of an electron in the initial state, and E_n is the energy of the final state of an electron to which the transition is made and $E_m > E_n$.

Let us remark still that the Bohr theory does not involve the physical mechanism of creation of photons and the adequate model of photon. However, it follows from quantum theory of fields, that photon is excited state of vacuum and at the same time also an electron is the excited state of vacuum, which follows from the elementary experimental equation $\gamma + \gamma \rightleftharpoons e^+ + e^-$ (Berestetzkii et al., 1999). At present time we know from the most general quantum field theory that all matter and antimatter in universe are excited states of vacuum.

Einstein introduced coefficients of spontaneous and stimulated emission A_{mn}, B_{mn}, B_{nm}. In case of spontaneous emission, the excited atomic state decays without external stimulus as an analogue of the natural radioactivity decay. The energy of the emitted photon is given by the Bohr formula. In the process of the stimulated emission the atom is induced by the external stimulus to make the same transition. The external stimulus is a blackbody photon that has an energy given by the Bohr formula.

If the number of the excited atoms is equal to N_m, the emission energy per unit time conditioned by the spontaneous transition from energy level E_m to energy level E_m is

$$P_{spont.\ emiss.} = N_m A_{mn} \hbar\omega, \tag{5}$$

where A_{mn} is the coefficient of the spontaneous emission.

In case of the stimulated emission, the coefficient B_{mn} corresponds to the transition of an electron from energy level E_m to energy level E_n and coefficient B_{nm} corresponds to the transition of an electron from energy level E_n to energy level E_m. So, for the energy of the stimulated emission per unit time we have two formulas :

$$P_{stimul.\ emiss.} = \varrho_\omega N_m B_{mn} \hbar\omega \tag{6}$$

$$P_{stimul.\ absorption} = \varrho_\omega N_n B_{nm} \hbar\omega. \tag{7}$$

If the blackbody is in thermal equilibrium, then the number of transitions from E_m to E_n is the same as from E_n to E_m and we write:

$$N_m A_{mn} \hbar\omega + N_m \varrho_\omega B_{mn} \hbar\omega = N_n \varrho_\omega B_{nm} \hbar\omega, \tag{8}$$

where ϱ_ω is the density of the photon energy of the blackbody.

Then, using the Maxwell statistics

$$N_n = De^{-\frac{E_n}{kT}}, \quad N_m = De^{-\frac{E_m}{kT}}, \tag{9}$$

we get:

$$\varrho_\omega = \frac{\frac{A_{mn}}{B_{mn}}}{\frac{B_{nm}}{B_{mn}}e^{\frac{\hbar\omega}{kT}} - 1}. \tag{10}$$

The spectral distribution of the blackbody does not depend on the specific atomic composition of the blackbody and it means the formula (10) must be so called the Planck formula:

$$\varrho_\omega = \frac{\hbar\omega^3}{\pi^2 c^3}\frac{1}{e^{\frac{\hbar\omega}{kT}} - 1}. \tag{11}$$

After comparison of eq. (10) with eq. (11) we get:

$$B_{mn} = B_{nm} = \frac{\pi^2 c^3}{\hbar\omega^3}A_{mn}. \tag{12}$$

It means that the probabilities of the stimulated transitions from E_m to E_n and from E_n to E_m are proportional to the probability of the spontaneous transition A_{mn}. So, it is sufficient to determine only one of the coefficient in the description of the radiation of atoms.

The internal density energy of the blackbody gas is given by integration of the last equation over all frequencies ω, or

$$u = \int_0^\infty \varrho(\omega)d\omega = aT^4; \quad a = \frac{\pi^2 k^4}{15\hbar^3 c^3} \tag{13}$$

and the pressure of photons inside the blackbody follows from the electrodymanic situation inside blackbody as follows:

$$p = \frac{u}{3}. \tag{14}$$

Let us remark that coefficients A_{mn} of the so called spontaneous emission cannot be specified in the framework of the classical thermodynamics, or, statistical physics. They can be determined only by the methods of quantum electrodynamics as the consequences of the so called radiative corrections. So, the radiative corrections are hidden external stimulus, which explains the spontaneous emission.

4 The black body formed by oscillators

We know that the relation between average energy of oscillator $< E >$ and the spectral density ϱ_ω of radiation of electromagnetic energy is expressed in the form (Sokolov et al.)

$$\varrho_\omega = \frac{\omega^2}{\pi^2 c^3} < E > . \tag{15}$$

The distribution of particles with energy E in the thermal bath is given according to statistical physics as follows:

$$N(E) = Ae^{-\alpha E}, \tag{16}$$

where $\alpha = 1/kT, k = 1.38.10^{-16} erg.grad^{-1}$ is the Boltzmann constant.

With regard to these facts, we get that the average energy $< E >$ of the system is as follows:

$$< E >= \frac{A \int_0^\infty e^{-\alpha E} E dE}{A \int_0^\infty e^{-\alpha E} dE} = \tag{17}$$

$$-\frac{\partial}{\partial \alpha} \ln \int_0^\infty e^{-\alpha E} dE = \tag{18}$$

$$= \frac{\partial}{\partial \alpha} \ln \alpha = kT. \tag{19}$$

After inserting $< E >$ from (17-19) into ϱ_ω in (15), we get the formula of Rayleigh-Jeans

$$\varrho_\omega = \frac{\omega^2}{\pi^2 c^3} kT. \tag{20}$$

In case of the quantization of energy of oscillators in harmony with the formula

$$E = n\varepsilon;\ n = 1, 2, ... \tag{21}$$

we are forced to replace the integral in (19) by summation, or

$$< E >= -\frac{\partial}{\partial \alpha} \ln \sum_0^\infty \varepsilon e^{-\alpha n \varepsilon} = \tag{22}$$

$$-\frac{\partial}{\partial \alpha} \ln \frac{\varepsilon}{1 - e^{-\alpha\varepsilon}} = \frac{\varepsilon}{e^{\alpha\varepsilon - 1}}. \tag{23}$$

So, after insertion of eq. (23) in eq. (15), we get

$$\varrho_\omega = \frac{\omega^2}{\pi^2 c^3} \frac{\varepsilon}{e^{\alpha\varepsilon - 1}}. \tag{24}$$

After the historical convention quantum energy was expressed as

$$\varepsilon = \hbar\omega. \tag{25}$$

and it means tha thefinal Planck formula for the photon distribution is as follows

$$\varrho_\omega = \frac{\hbar\omega^3}{\pi^2 c^3}\frac{1}{e^{\frac{\hbar\omega}{kT}} - 1}, \tag{26}$$

where $\hbar = 1,05.10^{-27} erg.s$ is the so called Planck constant.

For $\hbar\omega/kT \ll 1$, we have

$$e^{\frac{\hbar\omega}{kT}} \approx 1 + \frac{\hbar\omega}{kT} \tag{27}$$

and we get the Rayleigh-Jeans formula (20).

5 The dielectric crystal in he blackbody

We suppose here that inside of the Planck blackbody there is the dielectric crystal with the index of refraction $n(\omega)$. Then, the wave vector of photon inside the dielectric medium is given by known formula

$$q = n(\omega)\frac{\omega}{c}. \tag{28}$$

The number of light modes in the interval $q, q+dq$ inside of the dielectric in the volume V is Vq^2dq/π^2. After differentiation of formula (28) we get with $d\ln\omega = d\omega/\omega$

$$dq = \frac{1}{c}[n(\omega) + \omega\frac{dn(\omega)}{d\omega}]d\omega = \frac{n(\omega)}{c}\frac{d\ln[n(\omega)\omega]}{d\ln\omega}d\omega. \tag{29}$$

Then, it is easy to see that the number of states in the interval $\omega, \omega+d\omega$ of the electromagnetic vibrations in the volume V is

$$Vg(\omega)d\omega = \frac{V}{\pi^2}\left(\frac{n(\omega)}{c}\right)^3\frac{d\ln[n(\omega)\omega]}{d\ln\omega}d\omega. \tag{30}$$

If we multiply the last formula by the average energy of the harmonic oscillator (30), we get the Planck formula for the blackbody with dielectric medium:

$$\varrho(\omega) = \frac{n^3(\omega)\omega^2}{\pi^2c^3}\frac{d\ln[n(\omega)\omega]}{d\ln\omega}\frac{\hbar\omega}{e^{\frac{\hbar\omega}{kT}} - 1}, \tag{31}$$

where for $n = 1$, we get exactly formula (11).

6 Discussion

We suppose here that it is physically meaningful to consider the rotating the black-body with photons of different relativistic mass $m = \frac{\hbar\omega}{c^2}$ in order to get the sedimentation of photons according to the Lamm equation as the analogue of sedimentation of cells in the biochemistry. At the same time it is physically meaningful to consider, dielectric crystalline medium with photons which is inserted in the Planck blackbody photon gas. It means that photon gas of the blackbody surrounding the dielectric crystalline medium with with index of refraction n flows into such crystal and initiate the quantum sedimentation of photons (gluons) in case that the crystalline medium is in the rotating state.

The theory of photon dielectric blackbody is the preamble for experiments for the determination of the sedimentation process as the consequence of the quantum properties of the photon gas in crystal medium. The role of photon osmosis also is crucial. The photon osmotic pressure plays probably substantional negative role in the formation and in the development of skin cancer.

It is not excluded, that the experiments with the photons in the Svedberg ultracentrifuge will form in the future new deal of photonics and elementary particle physics. It is realistic idea to consider all elementary particles of CERN as the integral part of the Svedberg ultracentrifuge instead of only photons and gluons (Veltman, 2003). It is not excluded that the Svedberg ultracentrifuge will be in future integral part of the CERN laboratory, forming the new deal of Sweden physics in CERN.

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