Comment on "Analog of Planck's formula and effective temperature in classical statistical mechanics far from equilibrium"

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The attempt of Carati and Galgani [Phys. Rev. E **61**, 4791 (2000)] to derive the Planck formula as though it were due to long relaxation times is shown to be correct only if there is a single temperature and therefore no transients.

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Any attempt to derive some results of quantum mechanics from classical mechanics is interesting and worthwhile. This is the case of the recent paper by Carati and Galgani [1] where an analog of Planck's formula is derived from classical statistical mechanics far from equilibrium. The equilibrium distribution function of the power spectral density $\rho(\omega)$ of a blackbody should therefore be that of Rayleigh and Jeans. The idea of Ref. [1] is that the low frequencies are rapidly excited because of collisions and they therefore rather quickly reach equilibrium. Actually, for $\hbar\omega \ll kT$, the Rayleigh-Jeans formula is very close to that of Planck. In high frequencies, the relaxation times increase exponentially with ω, with the consequence that an analog of the Planck's formula is obtained. Another consequence of Ref. [1] is that their spectrum $\rho_{\mathrm{CG}}(\omega)$ should gradually vary in time as it approaches the Rayleigh-Jeans spectrum ρ_{RJ}. This variation should be measurable in correspondence with the drastic departure of ρ_{CG} from the Planck ρ_{P}, roughly starting from $\omega \simeq kT/\hbar$. An experimental apparatus of the kind used in the COBE satellite, able to measure the whole $\rho(\omega)$ in a few seconds, should detect the variation by repeating the measurements in the ω region $0.3 < \hbar\omega/kT < 1$. To address the measurement in the most convenient ω range, it would be very useful if Carati and Galgani gave some order of magnitude for the relaxation times as functions of ω for a given T value.

There are, however, two criticisms against the work of Ref. [1]. The COBE satellite has found a perfect ρ_{P} for the cosmic background microwave radiation (CBMR) at 2.73 K in spite of the fact that the CBMR has the whole age of the universe to approach equilibrium, at least for $1 < \hbar\omega/kT < 2$. Moreover, astrophysical observations are in agreement with ρ_{P} starting from an age of $\sim 2\times 10^9$ yr. The electromagnetic (e.m.) spectrum could significantly differ from ρ_{P} in the first minutes of the existence of the universe, corresponding to the nucleosynthesis era. But, contrary to the predictions of Ref. [1], the differences should regard low frequencies, less than the plasma frequency [2].

The second criticism regards rapid variations of temperatures, since even if Carati and Galgani do not at present succeed in predicting values for the relaxation times, the latter must be symmetric for excitation and deexcitation, i.e., for heating and cooling down. According to Carati and Galgani, the relaxation times increase exponentially with the angular frequency ω and, for $\omega \geqslant \omega_M$, where $\omega_M \simeq 2.82 kT_1/\hbar$ is the ω value at which $\rho_{\mathrm{P}}(\omega)$ is maximum at T_1, they should be very long. Consequently, the predicted $\rho_{\mathrm{CG}}(\omega,T)$ should be almost insensitive to rapid variations of temperature T for $\omega \geqslant \omega_M$. Let us consider a cavity with a small hole (that approximates rather well with a blackbody) at a temperature T_1. The relevant observed spectrum is $\rho_{\mathrm{P}}(\omega,T_1)$. It is easy to cool down the cavity in a minute to a new $T_2 < T_1$ (for instance, $T_2 \simeq T_1/2$), for which the new $\rho_{\mathrm{CG}}(\omega,T_2)$ should be practically equal to ρ_{RJ} for

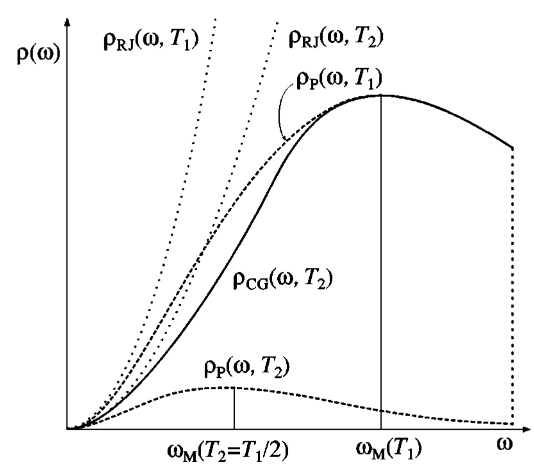

FIG. 1. Power spectral densities $\rho(\omega,T)$ (erg s cm^{-3}) vs angular frequency ω (s^{-1}) for two temperatures, T_1 and $T_2 = T_1/2$ [in kelvin (K)]. The subscript RJ denotes Rayleigh-Jeans, CG stands for Carati-Galgani, and P for Planck. A rapid cooling down from T_1 to T_2 should leave $\rho_{\mathrm{CG}}[\omega > \omega_M(T_1), T_2]$ practically equal to $\rho_{\mathrm{P}}(\omega,T_1)$, while for $\omega < \omega_M(T_2)$, it is $\rho_{\mathrm{CG}} \simeq \rho_{\mathrm{RJ}}$. The connection $\rho_{\mathrm{CG}}(\omega,T_2)$ between these two regions is shown by a continuous line.

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$\omega \ll kT_2/\hbar$, but (see Fig. 1) $\rho_{\rm CG}[\omega_M(T_1),T_2] \simeq \rho_{\rm CG}[\omega_M(T_1),T_1] \gg \rho_P[\omega_M(T_1),T_2]$.

This suggested experiment should be performed to show that there is no appreciable delay in reaching the Planck distribution. Although not aimed at accurately measuring hypothetical relaxation times, the ovens in which temperatures from 800 °C to 3000 °C are measured by means of the color [corresponding to the maximum $\rho(\omega)$ value in the Planck distribution] reach their maximum, steady brightness with no appreciable delay with respect to the temperature measured by a thermocouple (which is sensitive to the low frequency part of the Planck distribution, i.e., the one common to the Rayleigh-Jeans distribution). It is also a common observation that when we turn on an incandescent lamp, its brightness, related to the spectrum of the emitted light, reaches its steady value in a fraction of a second. The Carati-Galgani theory is therefore valid and correct only if a single temperature is considered (without transients).

This drastic criticism is not at all against any attempt to derive $\rho_{\rm P}$ from classical physics. First of all, Carati and Galgani can improve their treatment and overcome the above difficulty. Moreover, all the criticisms raised against classical physics in textbooks of quantum mechanics are actually against an incomplete classical physics. The latter, in fact, requires that all the particles of the universe, having an accelerated motion, radiate so that there is a ubiquitous, stochastic electromagnetic field [3]. Assuming that the *zitterbewegung*, or spin motion, is the realistic version of the solution for a free electron derivable from the Dirac equation according to Barut and Zanghi [4], it turns out that the spin radiation is larger than 10^{12} times the atomic radiation.[1] Moreover, in our expanding universe, the spin motion, which is almost monochromatic, brings about [5] a power spectral density $\rho_{\rm ZPF}(\omega)$ for the ubiquitous, stochastic e.m. field proportional to ω^3 up to and including the spin frequency ω_s,

$$\rho_{\rm ZPF}(\omega)=A\omega^3\theta(\omega_s-\omega), \tag{1}$$

where $\theta(x)=1$ for $x>0$ and $\theta(x)=0$ for $x<0$. For $\omega<\omega_s$, spectrum (1) is Lorentz invariant and special relativity can be derived from it since both sizes and atomic frequencies depend on it [5]. The proportionality constant A appearing in Eq. (1) turns out to be expressed in terms of the Hubble constant, the electron charge, the electron average density in the universe, and the speed of light c [5]. Comparing Eq. (1) with the expression of the zero-point field (ZPF) of QED,

$$\rho_{\rm QED}(\omega)=\hbar\omega^3(2\pi^2c^3)^{-1}, \tag{2}$$

it is therefore possible to relate $\hbar$ to the above-mentioned cosmological quantities [5]. Moreover, while $\rho_{\rm QED}\to\infty$ for $\omega\to\infty$ (it is one of the divergences of QED), $\rho_{\rm ZPF}$ given by Eq. (1) is truncated at ω_s. The spin motion together with Eq. (1) allows one to derive the Schrödinger equation [5,8], and from that $\rho_{\rm P}(\omega)$. In this treatment, there is no problem of time since equilibrium is reached in a very short time because the $\rho_{\rm ZPF}(\omega)$ increases very strongly with ω.

[1]To obtain a completely classical treatment, the spin motion must be derived and not only hypothesized. This is what one of us is trying to do by means of a new model of particles and fields mentioned in Ref. [5] and using the recently found laws of refraction in moving media [6]. See also Ref. [7].

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