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MAXIMUM TEMPERATURE OF THERMAL RADIATION

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American investigators have recently observed cosmic radio emission with effective temperature 3.5°K at a wavelength 7.3 cm [1]. If the assumed thermal character of this radiation (maximum at 0.1 cm) is confirmed, then it will be most natural to regard it as the residual photon field remaining from the initial singular state of the expanding universe, which in this case must be assumed to possess an infinite entropy density ("hot" model of expanding universe; in this model it is necessary to postulate, besides the presence of the photon field, also the presence of a residual graviton gas and of gas made up of pairs of two species of neutrinos with approximately the same average energy and nonthermal spectrum).

In connection with these hypotheses it is of interest to consider the properties of hot matter at very high densities, including such that the gravitational interaction of the photons is significant (the number of photons per unit volume is of the order of the gravitational unit $n_0 = c^{3/2}\hbar^{3/2}G^{-3/2} = 2.4 \times 10^{+98}$ cm^{-3}; cf. paper [2] by the author, where cold matter is considered).

We denote the energy density by ϵ. The total energy in a sphere of radius R, separated in isotropic space, contains terms proportional to different powers of R

$$E = \frac{4\pi}{5} R^3 \dot{R}^2 \epsilon - \frac{32\pi^2 G R^5}{15} \epsilon^2 + \frac{4\pi}{3} \epsilon R^3$$

(we put $c = 1$).

The first two terms are $\sim R^5$ (their sum vanishes for flat space). To find the value of ϵ it is necessary to separate the terms proportional to the volume in the gravitational interaction between particles (correlation and exchange interactions).

Neglecting for simplicity all effects of production of baryon and lepton pairs, we have within the framework of gravitational perturbation theory the following power expansion

$$(n/n_0)^{2/3} = G \hbar^{-1} c^{-1} n^{2/3}$$

(we put below $\hbar = c = 1$, $n_0 = G^{-3/2}$) and

$$\epsilon = A n^{4/3} - B G n^2 - C G^2 n^{8/3}. \tag{1}$$

The first term is the Stefan-Boltzmann expression; the second is an exchange correlation which decreases the energy for the attracted bosons. The next terms make up the correlation correction, which decreases the energy by virtue of the variational principle (for both bosons and fermions). The coefficients A, B, and C are ~1 and > 0.

For n of the order of n_0 and more, perturbation theory is not valid, but there is no doubt that the energy per photon ϵ/n cannot have a smaller order of magnitude than the energy of the gravitational interaction of two "neighboring" photons with energy ϵ/n

$$(\epsilon/n) \gtrsim G(\epsilon/n)^2 n^{1/3},$$

i.e.,

$$\epsilon \lesssim n^{2/3} n_0^{2/3}. \qquad (2)$$

Thus, at high photon-gas densities the increase of ϵ like $n^{4/3}$ gives way to a slower growth, like $n^{2/3}$, and the derivative $d\epsilon/dn$ reaches a maximum at a certain point $n \sim n_0$, after which it decreases (the inequality (2) does not exclude likewise a decrease of the quantity ϵ itself; this question, which is of importance in cosmology, is more complicated than the question of the derivative $d\epsilon/dn$).

Neglecting photon interaction we get $n = 0.244T^3$ and the entropy density is $S = 0.874T^3$ (the temperature T is in cm^{-1}), i.e., $S = 3.58n$. This proportionality of S to n remains in force also in the presence of photon interaction, since the total number of photons is an adiabatic invariant of the compression and consequently the density of the photons and the entropy density are inversely proportional to the volume during adiabatic contraction.

According to thermodynamics, $T = \left.\frac{\partial\epsilon}{\partial S}\right|_V$, i.e., (for thermal radiation) $T = (d\epsilon/dn)/3.58$ and reaches a maximum $T_{\max}$ of the order of the gravitational unit T_0 when n is of the order of n_0

$$T_0 = k^{-1}c^{5/2}\hbar^{1/2}G^{-1/2} = 1.42 \times 10^{32} \text{ degrees}.$$

$T_{\max}$ of the order of T_0 must be regarded as the absolute maximum of the temperature of any substance in equilibrium with radiation.

The foregoing reasoning may, of course, turn out to be inconsistent if it becomes necessary to review the fundamental principles or the fundamental premises of physics at $n \sim n_0$.

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GALLIUM ARSENIDE LASER OPERATING AT ROOM TEMPERATURE

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Investigations have been made of semiconductor lasers based on diffusion p-n junctions [1] operating at 300°K. The diodes were excited either with a pulse generator with strip line and controlled gas discharge (current up to 4000 A, pulse duration 20 nsec) or with a genera-