Physics – Uspekhi **48** (1) 95 – 96 (2005)

LETTERS TO THE EDITORS

PACS numbers: **01.55.+b**, **03.30.+p**

Cosmic microwave background and the Aristotelian ideas of motion

A V Shepelev

DOI: 10.1070/PU2005v048n01ABEH001815

Abstract. Accounting for cosmic microwave background radiation leads to a curious situation where macroscopic motion relative to an isotropic background frame of reference is formally consistent with the Aristotelian picture of motion.

Immediately after the discovery of microwave background radiation (the relic radiation) in 1965, Ya B Zel'dovich pointed out that it can be used for introducing a peculiar, universal, distinguished frame of reference [1]. This is the frame of reference in which the background radiation is isotropic [1] (the so-called co-moving frame of reference). It expands together with the Universe and is therefore common for all its parts. It has been reliably proven that in this frame of reference the Sun moves towards the constellation of Leo with a velocity of about 400 km s^{-1}. A formal description of macroscopic motion relative to this frame of reference reveals two additional peculiarities. Together with the aforementioned one, these peculiarities are in curious coincidence with the Aristotelian ideas of motion, even if the Universe is assumed to be free from matter and gravity. According to the Aristotelian picture, any moving object will stop with time unless it is put in motion by something or contains a cause of motion in itself [3]. If the motion is considered relative to the isotropic microwave background, i.e., in the chosen 'absolute' frame of reference, one should take into account the nonzero energy density of the background, which, in the case of macroscopic objects, virtually reduces to inclusion of light pressure. As a result, the Aristotelian picture of motion is formally confirmed in a certain sense.

The exact relation between light pressure and velocity can be obtained in the framework of Maxwell's electrodynamics. There is no need to directly use the Lorentz-invariance conditions, although with their help, this relation can be derived much more elegantly [4]. For a plane monochromatic wave incident on a mirror that moves with a velocity V, the light pressure is given by

$$P = A^2 \frac{(\cos\alpha - V/c)^2}{1 - (V/c)^2} \, ,$$

[1] The anisotropy of the microwave background radiation is very weak (well below 10^{-6} on average or slightly higher in some directions) [2] and is disregarded here.

A V Shepelev A N Kosygin Moscow State Textile University,
ul. Malaya Kaluzhskaya 1, 117918 Moscow, Russian Federation
Tel. (7-095) 955 37 54
E-mail: shepelev@rambler.ru

Received 17 November 2004
Uspekhi Fizicheskikh Nauk **175** (1) 105 – 106 (2005)
Translated by M V Chekhova; edited by A Radzig

where A is the amplitude of the incident wave, and α is the angle between the normal to the wave front and the velocity of the mirror. The light pressure is smaller if the mirror moves in the direction of the wave propagation, and larger if it moves in the opposite direction. In the frame of reference attached to the mirror, this fact has an evident explanation in terms of the Doppler effect (it is noteworthy that, as shown in Ref. [4], the value of the light pressure is invariant). If an object with an arbitrary reflection coefficient moves relative to isotropic radiation with a volume energy density u, the total value of the light pressure can be obtained by taking an expression similar to the one given above and integrating it over all angles. This value depends on the shape of the object. However, in the case of a black body, the light pressure exerted by isotropic radiation can be found in an easier way, by directly calculating the momentum transferred to the black body from the radiation. The exact expression for the pressure is rather cumbersome but expanding it in a power series of $\beta = |V/c|$, one obtains, in the case of a small area moving in the direction of its normal, the following formulas

$$P_1 = u\left(\frac{1}{3} + \frac{1}{4}\,\beta + \frac{1}{15}\,\beta^2 - \frac{1}{24}\,\beta^3 + \ldots\right),$$

$$P_2 = u\left(\frac{1}{3} - \frac{1}{4}\,\beta + \frac{1}{15}\,\beta^2 - \frac{7}{24}\,\beta^3 + \ldots\right)$$

for light pressures in the directions opposite to the velocity of travel and towards it, respectively. At $\beta = 0$, both P_1 and P_2 are equal to $u/3$, the known light pressure of an equilibrium photon gas [5].

The pressure difference, $\Delta P = P_1 - P_2$, is defined as

$$u\left(\frac{1}{2}\,\frac{V}{c} + \frac{1}{4}\,\frac{V^3}{c^3}\right)$$

and is directed oppositely to the velocity vector. As a result, an object moving relative to the isotropic microwave background will gradually reduce its velocity, similarly to the way it would slow down in a usual viscous medium with the dissipative force given by the Stokes law. This 'background deceleration' [2], though nonzero, is still extremely small: even in the case of a cosmic speck of dust and the background temperature $T \approx 3$ K, it will take billions of years for the velocity to be reduced by several dozen percent. The 'background deceleration' of individual hydrogen atoms (in fact, radiation cooling) probably played an important role immediately after the recombination of the primordial electron – proton plasma, i.e., when the background tempera-

[2] This deceleration has no relation to the known retardation effect caused by the cosmological expansion: the latter does not depend on the mass and size of the object [6].

ture became below 3000 K but the energy density of the background radiation (proportional to T^4) was many orders of magnitude higher than now. This hypothesis requires a separate consideration, with an account for the discrete absorption spectra of atoms and the inclusion of all possible processes of inelastic (Raman) scattering of light. As mentioned in Ref. [7], such an analysis appears to be rather complicated.

The other curious fact is that, taking into account the interaction with the background, one formally comes to the conclusion that a closed body can move due the forces acting inside it. This does not contradict to the momentum conservation law, since it is necessary to consider the momentum of the body together with the momentum of the background. Let the mass distribution inside the body periodically vary. As a result, the body moves with respect to the co-moving system: first, with the velocity V in one direction, and then with the smaller velocity v in the opposite direction. Due to the dependence of the light pressure on the velocity (see the equations given above), during each cycle the black body gets a portion of momentum from the background. This momentum is proportional to

$$\frac{u}{c^3}\left(V^2 - v^2\right),$$

and its direction coincides with the one in which the velocity is smaller [3]. The same momentum (but directed oppositely) is acquired by the microwave background radiation.

Although these effects are extremely small, the existence of microwave background formally leads to three statements confirming Aristotle's picture of motion: it is possible to choose a universal frame of reference; a body can move infinitely long due to the forces acting inside it, and in the absence of such forces or any external influence, the motion of the body relative to this frame of reference will cease with time. Certainly, all above peculiarities will be valid not only for the microwave background but for any isotropic radiation. Therefore, they can be formally applied to any system that is in thermodynamic equilibrium with the environment, inasmuch as the energy density of the equilibrium radiation in such a system is no less than the energy density of the microwave background.

Certainly, the aforesaid is by no means at variance with the relativity principle or the Lorentz-invariance conditions. But maybe it is something more than just a curious coincidence?

References

1. Zel'dovich Ya B *Usp. Fiz. Nauk* **89** 647 (1966) [*Sov. Phys. Usp.* **9** 602 (1967)]
2. Novikov I D *Usp. Fiz. Nauk* **171** 859 (2001) [*Phys. Usp.* **44** 817 (2001)]
3. Aristotle *The Works of Aristotle* Vol. 3 *Physics. Metaphysics. On the Soul. Short Physical Treaties* (Ed. W D Ross) (Franklin Center, Pa.: Franklin Library, 1980) [Translated into Russian (Moscow: Mysl', 1981)]
4. Pauli W *Relativitätstheorie* (Encyklopädie der mathematischen Wissenschaften, Bd. 19, Ed. A Sommerfeld) (Leipzig: Teubner, 1921) [Translated into English (New York: Dover Publ., 1958); Translated into Russian (Moscow: Nauka, 1983)]
5. Landau L D, Lifshitz E M *Statisticheskaya Fizika* (Statistical Physics) Pt. 1 (Moscow: Nauka, 1976) [Translated into English (Oxford: Pergamon Press, 1980)]
6. Landau L D, Lifshitz E M *Teoriya Polya* (The Classical Field Theory) (Moscow: Nauka, 1988) [Translated into English (Oxford: Pergamon Press, 1983)]
7. Phillips W D *Rev. Mod. Phys.* **70** 721 (1998); *Usp. Fiz. Nauk* **169** 305 (1999)

[3] It should be emphasized that Aristotle, by means of mathematical rather than physical reasoning, presented a convincing argument that the 'proper motion' of a closed body is only possible if the body possesses an internal structure.