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ЛАБОРАТОРИЯ НЕЙТРОННОЙ ФИЗИКИ

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COMMENT ON THE LETTER OF J.T. DEHN "ON THE DISTINCTION BETWEEN MASS-CHANGE SHIFT AND SECOND-ORDER DOPPLER SHIFT IN THE MOSSBAUER EFFECT"

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COMMENT ON THE LETTER OF J.T. DEHN "ON THE DISTINCTION BETWEEN MASS-CHANGE SHIFT AND SECOND-ORDER DOPPLER SHIFT IN THE MOSSBAUER EFFECT"

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Шапиро Ф.Л. E4-4827

Комментарий по поводу статьи Дж. Т. Дена "О различии между смещением, вызванным изменением массы, и смещением из-за эффекта Допплера второго порядка в эффекте Мёссбауэра

В настоящей работе доказывается, что нельзя проводить различие между смещением, вызванным изменением массы, и смещением из-за эффекта Допплера 2-го порядка, как это делает Дж. Т. Ден в своей работе в Phys. Lett., 29A (1969) 132, так как это лишь разные названия для одного и того же явления.

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Shapiro F.L. E4-4827

Comment on the Letter of J.T. Dehn "On the Distinction Between Mass-Change Shift and Second-Order Doppler Shift in the Mössbauer Effect"

It is being proved that one cannot distinguish between the mass-change shift and the second-order Doppler shift (as it is done by J.T. Dehn in his paper (see Phys.Lett., 29A (1963) 132)) because of their being different lebels for one and the same phenomenon.

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Considering the emission of a Mössbauer gamma-ray as a quantum transition between initial and final energy levels of a nucleus bound in a crystal, one obtains for the energy of the emitted quantum the well-known relation

$$E = E_0 \left(1 - \frac{1}{2} \langle v^2 \rangle / c^2 \right). \qquad (1)$$

Here E_0 is the transition energy for a rigidly bound nucleus and $E_0 \frac{1}{2} \langle v^2 \rangle / c^2$ is the change in the energy of atomic vibrations due to the difference E_0/c^2 between the masses of the nucleus in its isomeric and ground states[1].

In an alternative picture of the Mössbauer effect, the excited nucleus is considered as a classical oscillator having a proper frequency $\omega_0 = E_0/h$. Atomic vibrations modulate via Doppler shift the frequency of the emitted radiation splitting the line into a central one (the Mössbauer line) and a great number of satellites. In this approach the frequency of the Mössbauer line $\omega = E/h$ is given by the same equation (I), the second term in the brackets appearing this time as manifestation of the relativistic time dilatation or, equivalently, of the second-order Doppler shift([2]; for more detailed discussion see[3]).

In a recent letter[4], J.T. Dehn comes back to the procedure of obtaining the Mössbauer line frequency ω by time averaging of the Doppler-shifted frequency ω_1 :

$$\omega_1 = \omega_0 \frac{(1 - v^2/c^2)^{1/2}}{1-(v/c)\cos\alpha}, \tag{2}$$

where α is the angle in the laboratory frame between the direction of emission of the radiation and the velocity v of the source.

Unfortunately, Dehn comes to a result (a wrong one) which differs from (I). This difference has probably provoked the erroneous opinion expressed by the title of his paper. In fact, as it is clear from the previous discussion, "mass-change shift" and "second-order Doppler shift" are two different labels for one and the same shift caused by thermal and zero-point motion of the emitting nucleus. The point missed by Dehn is that the frequency ω_1, at the point of detection at time t is determined by the velocity which the nucleus had at earlier time τ connected with t by the relation

$$t = \tau + \frac{X - x(\tau)}{c}. \tag{3}$$

Here X is the distance between the detector and the mean position of the source (we suppose that $X \to \infty$) and $x(\tau)$ is the projection of the displacement of the source on the direction of emission. Taking this into account, one has for the average frequency acting on the detector

$$\omega = \frac{1}{T}\int_0^T \omega(t)\,dt = \frac{1}{T}\int_{\tau_1}^{\tau_2} \omega_1(\tau)\frac{dt}{d\tau}\,d\tau. \tag{4}$$

Combining (4) with (2) and (3) ($\frac{dt}{d\tau} = 1 - \frac{v(\tau)\cos\alpha}{c}$) and observing that for an atom confined in a crystal $\tau_2 - \tau_1 \to T$ as $T \to \infty$, one immediately comes to the relation (I).

References

1. B.D. Josephson. Phys.Rev.Lett., 4, 341 (1960).
2. R.V. Pound and G.A. Rebka. Phys.Rev.Lett., 4, 274 (1960).
3. F.L. Shapiro. Uspechi Phys.Nauk, 72, 685 (1960).
4. J.T. Dehn. Phys.Lett., 29A, 132 (1969).

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Note added at proof: The same conclusions as in this letter were obtained by J.Trooster and N.Benczer-Koller. Phys.Lett., 30A, 27 (1969) and by M.C.Clark and A.J.Stone. Phys.Lett., 30A, 144 (1969).