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Mossbauer Effect in the Smectic Mesophase

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Recently there has been a report[1] on the observation of the Mossbauer effect in the smectic phase of the liquid crystal 4,4′-*bis*(heptyloxy)azoxybenzene. Due to experimental difficulties, it was not possible to determine the directional anisotropy of the emitted radiation. In this note we wish to propose a qualitative prediction for this quantity.

The model we choose is that of a lattice whose restorative forces in the z direction (the ordered smectic direction) are many times stronger than the restorative forces in the x and y directions (the directions of random ordering in the smectic crystal). An alternative model, e.g., no restorative forces in the z, but one in the x, y directions, will give no Mossbauer effect. This point will be commented on shortly.

The probability of a Mossbauer line is given by the Debye–Waller factor[2,3] e^{-2W}, where

$$W = \cos^2\theta W_z + \sin^2\theta W_x \tag{1}$$

$$W_z = \sum_s \frac{p^2}{2NM\omega_s}[\hat{k}\cdot\epsilon_s](2N_s+1) \tag{2}$$

$$W_x = \sum_s \frac{p^2}{2NM\omega_s}[\hat{\imath}\cdot\epsilon_s](2N_s+1) \tag{3}$$

$$pc = E_0 = \text{energy of emitted photon}$$

$$M = \text{mass of molecule}$$

$$N_s = (e^{\hbar\omega_s/kT} - 1)^{-1}$$

and θ measures the angle between the z axis (smectic axis) and the direction of the emitted photon.

We note that Eq. (1) can be rewritten as

$$e^{-2W} = e^{-2W_z} e^{-2\sin^2\theta[W_x/W_z - 1]} \tag{4}$$

W_x as defined by Eq. (3) will be large because there will be in the "s" sum a high density of states for small ω_s (lattice modes in the x, y plane will all be of low energy) times a factor ω_s^{-2} for low frequencies arising from the factor $(2N_s + 1)\omega_s^{-1}$. W_x will be approximately the same as W in the mematic phase where no Mossbauer line has been observed.

W_z will be smaller than W_x because the density of states will be very low for small ω_s since typical phonons with a z component of polarization will have large energies. Formally, Eq. (2) interpreted instead as arising from a one-dimensional crystal would be infinite because

$$\sum_s \frac{1}{\omega_s}(2N_s + 1) \sim \int \frac{d\omega}{\omega^2},$$

which diverges due to the behaviour of the integrand for small ω. The appearance of the Mossbauer effect in the smectic phase is an indication that the smectic phase is technically not a one-dimensional system.

An experimental fit to Eq. (4) will give both W_z and W_x.

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