For the iron d-ions having two and more magnetic neighbors in the immediate surroundings, the inter-sublattice exchange interaction is dominant, and the magnetic moments of these ions are apparently collinear.

We have plotted several $\bar{H}^{Sn}(x)$ curves calculated from (2) for different variants of the angles θ_k. At definite values of θ_k, the experimental $\bar{H}^{Sn}(x)$ plot is satisfactorily described by formula (2) (see Fig. 2). Some deviations are due to the statistical character of the phenomenon in question and indicate that the angles θ_k depend apparently somewhat on x.

For fixed x, from the experimental values of H^{Sn}_{eff} and with allowance for the assumptions made above we found the most probable values of the angles θ_k:

$$x = 0.7 \qquad \theta_3 \approx \theta_2 \approx 0°, \quad \theta_1 \approx 63°, \quad \theta_0 \approx 180°.$$
$$x = 0.9 \qquad \theta_3 \approx \theta_2 \approx 0°, \quad \theta_1 \approx 108°, \quad \theta_0 \approx 180°$$

Quite recently Bauminger et al. [11] analyzed the γ-resonance spectra of europium in europium iron garnets substituted with scandium, and concluded that noncollinear spin configurations probably exist in these garnets.

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[1] S. Geller, H.J. Williams, G.P. Espinosa, and R.C. Sherwood, Bell System Techn. J. 43, 565 (1964).
[2] I. Nowik, J. Appl. Phys. 40, 5184 (1969).
[3] I.S. Lyubutin, V.A. Makarov, E.F. Makarov, and V.A. Povitskii, ZhETF Pis. Red. 7, 370 (1968) [JETP Lett. 7, 291 (1968)].
[4] I.S. Lyubutin, Proceedings of the Conference on the Application of Mossbauer Effect, Hungary, Tihany, 1969.
[5] I. Nowik, E.R. Bauminger, J. Hess, A. Mustachi, and S. Ofer, Phys. Lett. 34A, 155 (1971).
[6] I.B. Bersuker and I.Ya. Ogurtsov, Zh. Teor. Eksp. Khim. 4, 48 (1968).
[7] B.V. Mill', in: Magnitnye i kristallokhimicheskie issledovaniya ferritov (Magnetic and Crystal-chemistry Investigations of Ferrites), Moscow State Univ. Press, 1971, p. 56.
[8] I.S. Lyubutin, Fiz. Tverd. Tela 8, 643 (1966) [Sov. Phys.-Solid State 8, 519 (1966)].
[9] I.S. Lyubutin, E.F. Makarov, and V.A. Povitskii, Zh. Eksp. Teor. Fiz. 53, 65 (1967) [Sov. Phys.-JETP 26, 44 (1968)].
[10] I. Nowik, Phys. Rev. 171, 550 (1968).
[11] E.R. Bauminger, I. Nowik, and S. Ofer, Phys. Lett. 29A, 328 (1969).

CAN LIQUID MOLECULAR HYDROGEN BE SUPERFLUID?

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Any Bose liquid should apparently become superfluid at a certain temperature T_λ, provided it does not solidify at a higher temperature $T_m > T_\lambda$. This is corroborated by liquid helium as the example (it does not solidify at all at P < 25 atm), and does not contradict the estimates for molecular hydrogen H_2. In fact, for an ideal Bose gas

$$T_{\lambda_0} = \frac{3.31\hbar^2}{g^{2/3}Mk} n^{2/3} \approx 112\left(\frac{M}{M_p}\right)^{-5/3} \rho^{2/3}, \tag{1}$$

where M is the mass of the atom (molecule), M_p the proton mass, n the concentration, ρ = Mn the density, and g is set equal to unity in the second half of the equation. For He, according to (1), we have $T_{\lambda_0} \simeq 3°K$ whereas $T_\lambda = 2.17°$. For H_2, according to (1), putting g = 1 (para-hydrogen), $T_{\lambda_0} \simeq 6°$ and $T_m = 14°$ (T_m = 13.806°K at the triple point).

In view of the foregoing, it can be assumed that H_2 can become superfluid provided its solidification can be delayed to T ∿ 6°.[1] It is therefore necessary to prevent supercooling of the liquid H_2, to use tension (i.e., to produce negative pressure), and to investigate films on different substrates. In addition, the value of T_m is influenced by the presence of impurities (we have in mind primarily He), by the appearance of vacancies, and by replacement of certain H_2 molecules by H atoms (this can be done by neutron irradiation)[2]. We cannot estimate reliably the limits to which T_m can be lowered, but to call the experimenters' attention to the problem of superfluidity of H_2 (more accurately, to the observation of a λ transition in metastable liquid hydrogen), we make a few remarks concerning this subject.

Since liquid H_2 wets most surfaces, supercooling may be hindered by the formation of a layer of solid H_2 at the wall, with subsequent growth of this layer. We can hope to get around this difficulty, in particular, by using solid walls of D_2 (T_m = 18.7°) or Ne (T_m = 24.57°). The point is that for D_2 and Ne the parameter ε in formula (2) is equal to or is somewhat smaller than for H_2. Nor can we exclude the use of some other non-wettable substances. Unfortunately, rough estimates indicate that in the absence of nuclei on the walls, only 2 - 3° of supercooling is possible for H_2 (the supercooling for liquid water does not exceed 40°). The negative pressure attained for water in practice is 280 atm (see [4]). The estimated negative pressure for H_2, $|P_{max}| \sim \varepsilon/\sigma^3$, is about 200 atm. This estimate may be too low, but even a pressure P = -200 atm would lower T_m by approximately 7° (according to [5],

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1) The intermolecular interaction is frequently described by the Lennard-Jones potential

$$V(r) = 4\epsilon\left[(\sigma/r)^{12} - (\sigma/r)^6\right], \tag{2}$$

with ε = 10.2°K and σ = 2.56 Å for He and ε = 37°K and σ = 2.92 Å for H_2. Using formula (2) and the experimental data on the radial distribution function, a value T_λ = 2.15° was obtained for He. In the case of H_2 we did not perform a complete calculation in accordance with the scheme of [2], and such a calculation could be hardly reliable, particularly because the necessary information on the radial distribution function at $T \sim T_\lambda$ are lacking. It is qualitatively clear from [2], however, that the value of T_β expected for H_2 is close to T_{λ_0} (and in principle may even exceed T_{λ_0}), since T_λ increases with increasing ε, and $\varepsilon(H_2) \gg \varepsilon(He)$.

2) We do not concern ourselves here with the feasibility of producing a film (particularly a superfluid one) of atomic hydrogen (see [3]).

dT_m/dp = 29 atm/deg at the triple point). If $dT_\lambda/dp \sim -100$ atm/deg for H_2, just as for He, then, in view of the approximate character of the estimates, we can hope to raise T_λ to 6 - 8°, and T_m also to 6 - 8°. In other words, attainment of a λ transition in liquid H_2 is not excluded (particularly if account is taken of the decrease of the derivative dT_m/dp with decreasing temperature). On the basis of calculations similar to those in [6] we can hope to obtain a more accurate lower limit for T_m in pure H_2, but we cannot dispense with experiments in any case, particularly when account is taken of the possible influence of He impurities, vacancies, etc.

The results of [7] point to the possibility of obtaining non-dense homogeneous He films on sufficiently smooth surfaces. It is of interest in this connection to ascertain the possibility of obtaining analogous H_2 films.[3] This way, if the density of H_2 can be made noticeably smaller than the density of ordinary liquid hydrogen, there are grounds for expecting the appearance of a λ transition, and perhaps also superfluidity of the quasi-two-dimensional type. One can hardly doubt that the problems touched upon here are worthy of study.

[1] R.J. Corruccini, Pure and Applied Cryogenics, Vol. 5, Liquid Hydrogen, Chap. 2, Pergamon Press, 1966.
[2] G. Chaplin, Phys. Rev. A, 3, 1671 (1971).
[3] C.E. Hecht, Physica 25, 1159 (1959).
[4] A.T.J. Hayward, American Scientist 59, 434 (1971).
[5] R.D. Goodwin and H.M. Roder, Cryogenics 3, 12 (1963).
[6] J. Tsuzuki, J. Phys. Soc. (Japan) 21, 2132 (1966).
[7] M. Bretz and I.G. Dash, Phys. Rev. Lett. 26, 963; 27, 647 (1971).

EXCITATION OF A REGULAR PLASMA WAVE BY A MODULATED BEAM WITH HIGH ENERGY DENSITY

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As shown in [1, 2], the excitation of one-dimensional plasma oscillations by a monoenergetic relativistic electron beam is characterized by the fact that an appreciable fraction of the beam energy is transformed into the energy of the oscillation field. This produces in the plasma large field intensities, so that an important role may be assumed by the effect of variation of the waveguide properties of the plasma [3] as a result of the dependence of the electron density on the electric field amplitude [4]. We report here investigations of the interaction of a relativistic beam with a nonlinear plasma, which point to the possibility of synchronism between the beam and the wave during the nonlinear stage of instability development if the beam and plasma parameters are so chosen that the beam velocity and the phase velocity of the wave decrease with time in accordance with an identical law. In this case the energy transferred from the beam to the field greatly exceeds the value obtained in [1, 2].

[3] Interest attaches to both films and macroscopic volumes of H_2, D_2, T_2, HD, HT, and DT, for this would reveal the influence of both the mass and of the statistics. This pertains, of course, also to the problem of hydrogen metallization.