

Fig. 2. Spectrum of neutrons at  $90^\circ$ , in the form  $\log(N/\sqrt{E}) = f(E)$ , where  $N$  is the number of neutrons and  $E$  is the neutron energy.

group of neutrons is produced by decay of  ${}^5\text{He}$  into  ${}^4\text{He}$  and  $n^0$ , then it is easy to show that the average energy of the decaying  ${}^5\text{He}$  is equal to  $7.9 \pm 0.5$  MeV. The disparity with the data of [2] can be attributed to geometric factors. The fact that the lifetime of  ${}^5\text{He}$  is quite small ( $\sim 8 \times 10^{-22}$  sec) gives grounds for hoping that in processes of this kind it can be used as a "clock" of sorts for the investigation of the peculiarities of processes occurring in ternary fission.

The neutron spectrum at  $90^\circ$  agrees well with a Maxwellian spectrum with mean energy  $\bar{E} = 1.96 \pm 0.08$  MeV (Fig. 2). This

indicates that the ternary-fission process is similar in many respects to binary fission, and in a plane perpendicular to the  $\alpha$ -particle emission direction the difference between the neutron spectra lies only in the difference between the mean energies. For binary fission,  $\bar{E} = 2.1 \pm 0.8$  MeV [1]. We have thus confirmed the fact that in ternary fission of  ${}^{252}\text{Cf}$  there exists a group of neutrons that is genetically connected with emission of a third particle, which can be regarded as  ${}^5\text{He}$  decaying into  ${}^4\text{He}$  and  $n^0$  in a time  $\sim 8 \times 10^{-22}$  sec during the course of acceleration in the Coulomb field of the fragments.

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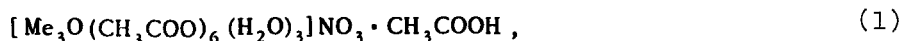
- [1] A.P. Graevskii, B.A. Bochagov, and L.N. Kupriyanova, ZhETF Pis. Red. 15, 572 (1972) [JETP Lett. 15, 407 (1972)].  
 [2] Z. Fruenkel et al., Phys. Rev. Lett. 29, 805 (1972).  
 [3] V.I. Nefedov et al., Yad. Fiz. 3, 465 (1966) [Sov. J. Nuc. Phys. 3, 337 (1966)].

#### PARAMAGNETIC RESONANCE OF MIXED TRIADS OF CHROMIUM AND IRON

Yu.V. Yablokov, V.A. Gaponenko, M.V. Eremin, V.V. Zelentsov, and T.A. Zhemchuzhnikova  
 Kazan' Physico-technical Institute, USSR Academy of Sciences  
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The parametric resonance of three-nucleus clusters of the type  $[\text{Me}_3\text{O}(\text{CH}_3\text{COO})_6(\text{H}_2\text{O})]\text{NO}_3\text{CH}_3\text{COOH}$ , where  $\text{Me} = \text{Cr}_2\text{Fe}$  (A) or  $\text{CrFe}_2$  (B) was investigated. It is shown that the exchange integral  $J_{\text{Cr-Fe}} > J_{\text{Cr-Cr}}$  in the triad Cr-Cr-Fe and  $J_{\text{Cr-Fe}} < J_{\text{Fe-Fe}}$  in the triad Cr-Fe-Fe.

One of the pressing problems in the physics of magnetic phenomena is the study of the simplest systems capable of simulating to a certain degree the phenomena of anti- and ferromagnetism. Among various systems of this kind, undoubted interest attaches to mixed triads of  $\text{Cr}^{3+}$  and  $\text{Fe}^{3+}$ , which are produced in joint synthesis of isostructural acetates of chromium and iron [1, 2], and which can be described by the formula



where  $\text{Me}_3 = \text{Cr}_2\text{Fe}$  (A) and  $\text{CrFe}_2$  (B). The complicated extended EPR spectrum of

these substances, which is observed at high temperatures, is transformed at liquid-helium temperature into a single rather narrow line. The signals of a finely-crystalline sample of "A" shown in the figure were recorded by a spectrometer with  $\nu = 9450$  MHz. The single signal at  $4.2^\circ\text{K}$  corresponds to  $g_{\text{eff}} = 1.93$  and  $\delta H = 125$  Oe. The compound "B" is characterized by  $g_{\text{eff}} = 1.95$  and  $\delta H = 179$  Oe. In both cases, the values of  $g_{\text{eff}}$  differ noticeably from the g-factor typical of the isolated ions  $\text{Cr}^{3+}$  and  $\text{Fe}^{3+}$  [3].

The reasons for this are easily seen. Indeed, it is most probable a priori that in the triads Cr-Cr-Fe (A) and Cr-Fe-Fe (B) the exchange integrals are different:  $J_{\text{Cr-Cr}} \neq J_{\text{Cr-Fe}} \neq J_{\text{Fe-Fe}}$ . Then in the approximation of the isotropic exchange Hamiltonian

$$\hat{H} = J(\hat{S}_1\hat{S}_2 + \hat{S}_2\hat{S}_3 + \hat{S}_3\hat{S}_1) + J'(\hat{S}_1\hat{S}_2) \quad (2)$$

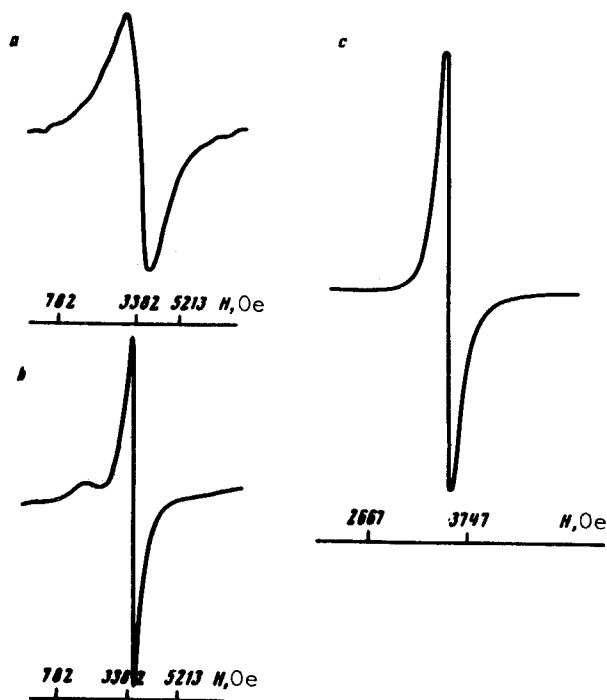
in the case of antiferromagnetic exchange ( $J_{\text{Cr-Fe}} > 0$ ) the lowest states of the cluster are in our case two Kramers doublets with a total cluster spin  $S = 1/2$ , separated by an amount proportional to  $J' \gg g\beta H$ . Using standard methods of the operator technique of atomic spectroscopy [4, 5] we can show that for both doublets

$$g = g_3 + (g_3 - g_2) \frac{S_3(S_3 + 1) - S_{12}(S_{12} + 1) - S(S + 1)}{2S(S + 1)}, \quad (3)$$

where  $g_i$  are the values of the g factors of the individual ions, and  $S_{12}$  is the summary spin of the like ions of the cluster.

In the case of triad "A", the doublet spin states for the assumed order of addition of the angular momenta have  $S_{12} = 3$  and 2. The state with  $S_{12} = 2$  cannot be the lower one, since we obtain for it  $g > 2$  in accord with (3). To the contrary, for the doublet with  $S_{12} = 3$  the experimental value  $g_{\text{eff}} = 1.93$  is obtained immediately if one takes  $g_{\text{Fe}} = 2.003$  and  $g_{\text{Cr}} = 1.973$ . The non-equivalence of the exchange interactions in the triad "A" is taken into account by the term  $J'(S_1S_2) = J_{\text{Cr-Cr}} - J_{\text{Cr-Fe}}(S_1S_2)$ . In order for the state with  $S_{12}$  to be the ground state, it is necessary to have an energy  $E = (12)J'[S_{12}(S_{12} + 1) - 2S_1(S_1 + 1)] < 0$ . It follows therefore that in the triad Cr-Cr-Fe the exchange integral  $J_{\text{Cr-Fe}} > J_{\text{Cr-Cr}}$ .

Similar reasoning shows that  $J_{\text{Fe-Fe}} > J_{\text{Cr-Fe}}$  for the triad Cr-Fe-Fe ( $S_{12} = 1$  and 2). It must be emphasized that in this case the experimental value  $g_{\text{eff}} = 1.95$  can be



EPR spectrum of  $[\text{Cr}_2\text{FeO}(\text{CH}_3\text{COO})_6(\text{H}_2\text{O})_3]\text{NO}_3 \cdot \text{CH}_3\text{COOH}$  at the frequency 9450 MHz and at temperatures  $300^\circ\text{K}$  (a),  $77^\circ\text{K}$  (b), and  $4.2^\circ\text{K}$  (c).

obtained from formula (3) at the same values of the individual g-factors of the chromium and iron ions.

Thus, a study of the paramagnetic resonance of mixed three-nucleus clusters makes it possible to establish the genealogy of the lower energy states and determine uniquely the comparative magnitude and character of the exchange interactions between the ions of the cluster. Moreover, it becomes possible to study the dependences of the value of the exchange between the localized spins on the number of electrons in the unfilled 3d shells.

- [1] Chang-Shi-Chi and G.A. Jeffrey, *Cryst., Sec. B*, 26, 673 (1970).
- [2] B.N. Figgis and G.B. Robertson, *Nature* 205, 694 (1965).
- [3] S.A. Al'tshuler and B.M. Kozyrev, *Elektronnyi paramagnitnyi rezonans soedinenii elementov perekhodnykh grupp* (Electron Paramagnetic Resonances of Compounds of Transition Group Elements), Nauka, 1972.
- [4] B.R. Judd, *Operator Techniques in Atomic Spectroscopy*, N.Y. 1963.
- [5] I.I. Sobel'man, *Vvedenie v teoriyu atomnykh spektrov* (Introduction to the Theory of Atomic Spectra, GIFML, 1963).

#### SEMICONDUCTOR - METAL TRANSITION INDUCED BY ELECTROSTATIC IMAGE FORCES

V.M. Agranovich and Yu.E. Lozovik  
Spectroscopy Institute, USSR Academy of Sciences  
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In connection with searches for high-temperature superconductors, inhomogeneous systems of the sandwich type, and also granulated semiconductor + metal systems have been extensively discussed and experimentally investigated of late [1]. In semiconductors with small dimensions placed in a metallic matrix, an important role should be played by electrostatic image forces. We shall show that their role can become decisive for semiconductors with small forbidden band width  $2\Delta$ .

Since the energy of the electrostatic image forces ( $-V_0$ ) for one quasi-particle does not depend on the sign of its charge, the energy needed to produce one unbound electron-hole pair is  $2\Delta - 2V_0$  (the minimal gap  $2\Delta$  can correspond also to an indirect transition). Therefore when  $V_0 > \Delta$  the ground state of a semiconductor with a completely filled valence band becomes unstable against the formation of electron-hole pairs.

Wishing to discuss only the qualitative aspect of the problem, we consider (at  $T = 0$ ) first the simplest model of a monomolecular planar<sup>1)</sup> semiconductor layer located at a distance  $d$  from a metallic surface. In the effective-mass approximation for electrons and holes, the energy  $E$  per unit surface of the superconducting layer, as a function of their concentration  $n_e = n_h = n$  (we have in mind here an intrinsic semiconductor), at an average distance  $\rho \sim n^{-1/2} \ll d$  between particles, is given by

$$E(n) = \frac{\pi \hbar^2}{2m^*} n^2 - 2(V_0 - \Delta)n, \quad (1)$$

where  $m^* = m_e m_h / (m_e + m_h)$  is the reduced effective mass. We have left out of (1) the total interaction energy  $\bar{V}_{int}$  of the quasiparticles with each other:

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<sup>1)</sup> Analogous effects take place for (quasi)one-dimensional structures.