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 is 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.

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SEMICONDUCTOR - METAL TRANSITION INDUCED BY ELECTROSTATIC IMAGE FORCES

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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 2Δ.

Since the energy of the electrostatic image forces ($-V_0$) for one quasiparticle 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 2Δ 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[1)] 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 $\rho \sim n^{-1/2} << d$ 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 $\overline{V}_{int}$ of the quasiparticles with each other:

[1)] Analogous effects take place for (quasi)one-dimensional structures.

This energy vanishes in the considered self-consistent-field approximation (without exchange). Indeed,

$$\bar{V}_{int} = n^2 \int dx dx' \left[V_{eh} + \frac{1}{2}(V_{ee} + V_{hh}) \right].$$

The integrand vanishes, since $V_{ee} = V_{hh} = -V_{eh} \equiv V$. Allowance for the image forces leads to a weakening of the interaction of two quasiparticles in accordance with Coulomb's law: $V(x) = e^2/x - e^2[X^2 + 4d^2]^{1/2}$, $V(x) \simeq E^2/x$ (if $x << d$), $V(x) - 2d^2e^2/x^3$ (if $x >> d$). We note that this attenuation can, in particular, be appreciable when transitions into the superconducting state are considered. The minimum energy corresponds to a quasiparticle concentration $n = n_0$, where $n_0 = (2m^*/\pi\hbar^2)(V_0 - \Delta)$. Thus, the electrostatic image forces at $V_0 > \Delta$ indeed lead to a nonzero electron and hole concentration in the ground (non-realigned) state. The resultant picture of the filling of the intersecting bands in the realigned ground state corresponds to metallic conductivity[2].

We note that the realignment in question give rise to the appearance, at sufficiently close distances, of additional metal-semiconductor cohesion forces since, as follows from the expression for $E(n_0)$, the energy of the layer in the realigned ground state depends on the distance d between the metal and the semiconductor: $E_0(d) = (2m/\pi\hbar)(e^2/4d - \Delta)^2$ when $d < e^2/4\Delta$ and $E_0(d) = 0$ for $d > e^2/4\Delta$.

We present now a numerical estimate. At d = 5 Å the energy of the electrostatis image forces is $V_0 = e^2/4d \simeq 0.7$ eV. Therefore the indicated transition for the idealized model considered here occurs at band widths $\Delta < 0.7$ eV.

In the two-dimensional model of the semiconductor there was no screening of the electrostatic image forces. For three-dimensional formations, the influence of the screening becomes already quite significant in our problem. Thus, for example, in a semiconductor layer of thickness d having both surfaces in contact with metal, the characteristic energy of the electrostatic image forces is $\bar{V}_0 = \alpha(e^2/\varepsilon d)$, where $\alpha \sim 1$ (ε is the dielectric constant). Therefore the effects discussed above can appear[3] only for such values of d and ε for which $\alpha(e^2/\varepsilon d) > \Delta$. It must be borne in mind, however, that the realignment can change also ε itself, thus weakening the interaction of the quasiparticles of the semiconductor with the metal. The influence of the quasiparticles on the screening of the electrostatic interaction can nevertheless still be disregarded if the condition $r_D \gtrsim d$ is satisfied, where r_D is the corresponding Debye screening length. In this case[4] we obtain in lieu of (1)

$$E(n) = \frac{3}{5m^*}(3\pi)^{2/3}\hbar^2 n^{5/3} - 2(\bar{V}_0 - \Delta)\, n \tag{2}$$

so that $n_0 = (1/3\pi^2\hbar^3)[2m^*(V_0 - \Delta)]^{3/2}$. The smaller d, the better is the inequality $r_d \gtrsim d$ satisfied. At small d, however, the situation becomes more

[2] The realigned state is stable in the single-particle approximation. The question of its stability when account is taken of correlation interaction will be considered separately. We note only that the appearance of instability connected with the correlations requires special conditions.

[3] These effects remain in force if the metallic parts of the sandwich are replaced by a semiconductor having a dielectric constant $\varepsilon' > \varepsilon$. In this case $\bar{V}_0 = \alpha(e^2/\varepsilon d)[(\varepsilon' - \varepsilon)/(\varepsilon' + \varepsilon)]$.

[4] The double electric layer produced in the contact region causes only a bending of the bands, without changing qualitatively the realignment picture.

favorable because of the quantization of the electron motion in the transverse direction. If $\hbar^2/m^*d^2 > V_0 - \Delta$, then all the quasiparticles produced under the influence of the electrostatic image forces populate only the lower level of the transverse motion. We then return to the already discussed case of a two-dimensional semiconductor.

The realignment of the ground state of a semiconductor under the influence of electrostatic image forces can take place also for extrinsic semiconductors (with impurity concentration $N \ll 1/d^3$ and with a ground-state radius $\rho_0 \ll d$). The electrostatic-image forces decrease the impurity ionization energy and accordingly increase the radius of the impurity state[5]. If the impurity-band broadening due to the overlap of the impurity orbitals were to become comparable with the decreased ionization energy, a semiconductor - metal transition would take place.

We note that in the case of extrinsic semiconductors with a large width of the forbidden band (and hence with small ε) and with a donor or acceptor depth $\Delta \sim 10^{-2}$ eV, the electrostatic image forces become appreciable even for layers several hundred Angstrom thick. This circumstance would facilitate the observation of the realignment in question.

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ACCELERATION OF ATOMS BY A STATIONARY FIELD

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This paper deals with a special resonant-field configuration in which the atom is acted upon by a spatially constant field. The excited atom can be accelerated in this case to an energy of 1 keV. This effect can be used for spatial separation of excited and non-excited atoms in an atomic beam.

In a strong resonant field, the atom is acted upon by an appreciable force, on the order of $10^2 - 10^3$ eV/cm. This estimate follows from the general formula for the force F acting on the dipole moment of the atom p in an inhomogeneous field E

$$F = p\nabla \overset{*}{E} + \text{c.c.} \tag{1}$$

If we put $p \sim 1$ Debye, $k \sim 10^{-5}$ cm^{-1} for the wave number, and $E \sim 3 \times 10^5 - 3 \times 10^6$ V/cm. Formula (1) has been written out in the resonance approximation, and the frequencies of the field and of the dipole moment are reckoned from the frequency of the working transition.

In a quasistationary field, the induced dipole moment follows the field adiabatically, and the force (1) takes the form

$$F = \nabla \langle \hat{H} \rangle \tag{2}$$

[5])Similar effects can probably take place also for adsorbed atoms.