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ON THE ORIGIN OF FERROMAGNETISM IN DIVALENT EUROPIUM SALTS*

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In this note we show that the Bloembergen-Rowland (B-R) indirect interaction between localized magnetic moments in insulators, [1] can in principle account for the occurrence of ferromagnetism in the divalent europium salts: [2, 3] EuO, EuS and EuSe.

The B-R interaction, E_{ij}, between two spins $\underset{\sim}{S}_i$ and $\underset{\sim}{S}_j$ (considering Eu^{++} to be in a ^8S state) at lattice positions $\underset{\sim}{R}_i$ and $\underset{\sim}{R}_j$, is given by

$$E_{ij} = A_{ij}\, \underset{\sim}{S}_i\, \underset{\sim}{S}_j \,, \qquad (1)$$

with

$$A_{ij} = \left(\Gamma^2 \Omega^2 m k_t^4 / \pi^3 \hbar^2 \right) F\, k_t R_{ij} \quad \exp\left[-(2mE_g/\hbar^2)^{\frac{1}{2}} R_{ij} \right]. \qquad (2)$$

Here m is the electron mass in the conduction band, $k_t = 2\pi(3/4\pi\Omega)^{1/3}$ and Ω is the atomic volume of the diamagnetic lattice. E_g is the energy gap between the valence band of the diamagnetic lattice and the conduction band, while Γ is a measure of the exchange interaction between the 4f-electrons and the diamagnetic ions. $F(x) = x^{-4}(x \cos x - \sin x)$ is the Ruderman-Kittel function.

The interaction E_{ij}, when applied to the magnetic f.c.c. lattice

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of the divalent europium salts, turns out to favour ferromagnetism. In fact, the nearest neighbour interaction is negative, whereas the next-nearest neighbour interaction is positive and much weaker. In the case of EuS we can estimate Γ and E_g, by using the experimental values: [4] $A_{01} = -0{,}20 \pm 0{,}01\ ^{o}K$ and $A_{02} = +0{,}08 \pm 0{,}02\ ^{o}K$. We find $\Gamma \approx 0{,}36$ eV and $E_g = 5{,}2$ eV, using for m the free electron mass and 5,968 Å for the lattice parameter. Those values are reasonable. The values of A_{01} and A_{02} are also compatible with an observed paramagnetic Curie point of $19^{o}K$.

Eq. (2) has been derived using the Wigner-Seitz approximation and neglecting the $\underset{\sim}{k}$-dependence of the periodic part of the Bloch functions. Further, it has been assumed that the width of the valence band is small compared to E_g. We have tried to remove these limitations and find that it is still possible to consider Eq. (2) a good approximation. [5]

Anderson's theory of superexchange in insulators [6] predicts three magnetic interactions: kinetic exchange, which normally dominates and is antiferromagnetic; direct exchange, which is an order of magnitude smaller and ferromagnetic; and the B-R interaction, which usually can be neglected. However, kinetic exchange and direct exchange decrease more rapidly with decreasing covalency between the magnetic electrons and the diamagnetic ions, than the B-R interaction. Thus in cases where the degree of covalency is very low - such as in the europium salts - the B-R interaction may dominate. Along the series EuO, EuS, EuSe, and EuTe, we expect an increase in covalency, thus making the effect of kinetic exchange

gradually more important. Since EuTe is already antiferromagnetic, we believe that here the kinetic exchange can overcome the direct interaction and the B-R interaction.

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