

This Week's Citation Classic

Yosida K. Magnetic properties of Cu-Mn alloys. *Phys. Rev.* **106**:893-8, 1957.
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The polarization of conduction electrons due to s-d interaction in CuMn alloys is investigated. The uniform polarization due to the first-order perturbed energy corresponding to the Fröhlich-Nabarro and Zener mechanism is shown to be completely modified by the first order perturbation of the wave functions and the polarization is concentrated in the neighborhood of the Mn ions.¹² At the same time it is shown that the Zener interaction is included in the Ruderman-Kittel result as one component.³ [The SC¹® indicates that this paper has been cited over 540 times since 1961.]

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"I wrote this paper in 1957 while at the University of California, Berkeley with Professor C. Kittel's group studying solid state physics. The investigation of physical properties of dilute magnetic alloys represented by CuMn in which transition-metal impurities carry localized spins was one of the central subjects of this group, and I myself had become interested in this subject also.

"In those days, two mechanisms had already been proposed regarding indirect interaction acting between two localized spins in metals each of which is induced by s-

d exchange coupling of conduction electrons with their localized spins. One was by H. Fröhlich, F.R.N. Nabarro,¹ and C. Zener² who derived interaction independent of distance r between two localized spins. The other was by M.A. Ruderman and C. Kittel.³ They derived interaction which damps in $1/r^3$ with the distance oscillating with a period of the reciprocal diameter of the Fermi sphere. At that time it had been mostly believed that these two mechanisms were independent of each other, and there had been some confusion about the interpretation of the experimental results on CuMn dilute alloys.

"In this paper I removed the confusion by showing that the Zener interaction should be included in the Ruderman-Kittel interaction as one Fourier-component of $q = 0$. However, the reason why this paper was cited so frequently seems not to be in the fact that the problem was so controversial.

"In discussing the indirect interaction between two localized spins in this paper, I took into consideration one impurity spin and its environment and focused my attention to the spatial extension of the spin-polarization of conduction electrons induced by s-d exchange interaction. I believe that the conduction-electron spin-polarization associated with a localized spin which is oscillating is the fundamental aspect for the localized spin in metals. In later developments of the research on iron-group metal and also rare-earth metal alloys, the concept of the spin polarization played an essential role. At present, I suppose that a primary importance of the paper was in the introduction of the concept of 'spin-polarization' associated with a localized spin."

1. Fröhlich H & Nabarro F R N. Orientation of nuclear spins in metals. *Proc. Roy. Soc. London A* **175**:382-91, 1940.

2. Zener C. Interaction between the d-shells in the transition metals. *Phys. Rev.* **81**:440-4, 1951.

3. Ruderman M A & Kittel C. Indirect exchange coupling of nuclear magnetic moments by conduction electrons. *Phys. Rev.* **96**:99-102, 1954.