FEB 14 1967

MASTER

20338

STRENGTH OF THE s-f EXCHANGE
INTERACTION IN RARE-EARTH INTERMETALLICS

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Measurement of the sign and magnitude of the indirect exchange interaction, $\mathcal{H}_{\text{ex}} = -\mathcal{J}_{\text{sf}} \vec{S} \cdot \vec{s}$, which couples the rare earth spins $\vec{S}$ via the conduction electron spins $\vec{s}$ in metallic substances, has been the subject of numerous investigations. In particular, the temperature dependence of the Knight shift of the nmr of a "non-magnetic" nucleus (Al^{27}) in the rare-earth intermetallics, RAl_2 , was first observed and interpreted in terms of $\mathcal{H}_{\text{ex}}$ by Jaccarino et al., who employed the so-called "uniform-polarization" model. On the basis of this model, the exchange constant $\mathcal{J}_{\text{sf}}$ is determined from the measured temperature dependence of the isotropic Knight shift K and susceptibility according to:

$$\mathcal{J}_{\text{sf}} = \left[2g_J\beta^2 / (g_J - 1) \right] K_0^{-1} (dK/d\chi_{\text{at}})$$

where K_0 is the isotropic component of the Knight shift in the absence of

^{*}Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission. Contribution No. 2037.

[†]Work was supported by the U. S. Atomic Energy Commission.

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polarization effects, χ_{at} is the susceptibility per rare-earth ion, and the other symbols have their usual meanings. It is clear that values of $\mathcal{J}_{sf}$ determined in this manner depend rather sensitively on the value of K_0 . In their determination of $\mathcal{J}_{sf}$ for the rare earth di-aluminides, Jaccarino et al.,¹ used the value $K_0 = +0.13\%$ derived from the Al^{27} nmr in the non-magnetic compound $LaAl_2$.

The Al^{27} nmr spectra in all these compounds presents complicated features involving the nuclear quadrupole coupling of the Al^{27} as well as Knight shift anisotropy, so that extensive field-dependent measurements are required.² Investigation of the Al^{27} nmr spectrum in the non-magnetic compounds YAl_2 , $LaAl_2$, and $LuAl_2$ has recently been completed,³ and the K_0 values obtained for these compounds are: for YAl_2 , $+0.026\%$; for $LaAl_2$, $+0.055\%$; for $LuAl_2$, $+0.028\%$. An additional value for K_0 was previously obtained from a similar study of the temperature dependence of the Al^{27} nmr in $PrAl_2$ which yielded for the temperature-independent isotropic Knight shift, $K_0 = +0.053\%$.⁴ These four measurements indicate that K_0 is considerably smaller than the $K_0 = +0.13\%$ which has been used in previous analyses of Al^{27} Knight shift data in RAl_2 . It is thus not unreasonable to assume that $K_0 \cong +0.055\%$ is to be used in interpreting Knight shift data for the RAl_2 compounds. The values of K_0 cited above suggest that for the heavy rare-earth di-aluminides $K_0 \cong +0.03\%$ might be more appropriate. However, at this time and for the purposes of this Letter, the data are still insufficient to warrant such a distinction. This change in K_0 has the effect of increasing the previous estimates¹ of $\mathcal{J}_{sf}$ by about a factor of 2.4.

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An interesting consequence of this change in the value of K_0 for the rare-earth di-aluminides is that the values of $\mathcal{J}_{sf}$ agree well with those obtained by Jones from the P^{31} and As^{75} nmr in rare-earth monophosphides and monoarsenides.⁵ These compounds have the NaCl structure so that quadrupolar and shift anisotropy effects are avoided. In addition, P^{31} has spin one-half. Thus, determination of the shifts is more straightforward than in the di-aluminides.

In Table I are presented some representative results for the several sequences of compounds, illustrating the good agreement between the $\mathcal{J}_{sf}$ values derived from the Knight shifts. Also included in Table I are values of the nearest neighbor rare-earth distances d_{nn} for the di-aluminides and monophosphides, which show that the values of $\mathcal{J}_{sf}$ are relatively insensitive to significant changes in d_{nn} . Although the uniform polarization model lacks the theoretical sophistication of more recent calculations,⁶ it also avoids the introduction of additional parameters (principally, the Fermi momentum, k_F) which must also be estimated. On the basis of the results reported here, it appears that with an interaction strength of roughly -0.4 eV the uniform polarization model affords a consistent interpretation of the Knight shifts in several different sequences of rare-earth intermetallics.

Table I. Values of the s-f exchange interaction parameter $\mathcal{J}_{sf}$ derived from Knight shifts on the basis of the uniform polarization model. The nearest neighbor rare-earth distance d_{nn} in the di-aluminides and phosphides are also tabulated. Values of $\mathcal{J}_{sf}$ are in electron-volts and of d_{nn} in Ångstroms.

R	$\mathcal{J}_{sf}$ RAl ₂	$\mathcal{J}_{sf}$ RP	$\mathcal{J}_{sf}$ RAs	d_{nn} RAl ₂	d_{nn} RP
Ce	-0.57	-1.0	---	3.490	4.179
Pr	-0.43	-0.66	---	3.475	4.153
Gd	-0.31(a)	-0.38	-0.31	3.420	4.047
Tm	-0.29	-0.18	-0.13	3.369	3.941

(a) This value has been corrected from that reported by E. D. Jones and J. I. Budnick, J. Appl. Phys. 37, 1250 (1966).

Abstract

Recently determined values of the temperature-independent isotropic Knight shift in the non-magnetic rare-earth di-aluminides, YAl_2 , LaAl_2 , and LuAl_2 , indicate that previous estimates of the s-f exchange interaction parameter $\mathcal{J}_{\text{sf}}$ in the RAl_2 series (R = rare earth) should be increased approximately 2.5 times. The new $\mathcal{J}_{\text{sf}}$ values are in good agreement with those obtained in similar fashion for the rare-earth phosphides and arsenides. These results re-affirm the usefulness of the uniform polarization model as a description of magnetic interactions in rare-earth intermetallics.

Neulich gewonnene Werte der temperaturunabhängigen isotropen Knight-shift der nicht-magnetischen Verbindungen, YAl_2 , LaAl_2 , und LuAl_2 , zeigen dass frühere Abschätzungen der s-f Austauschwechselwirkungskonstante $\mathcal{J}_{\text{sf}}$ der RAl_2 Verbindungen (R = seltene Erde) um etwa 2.5-mal erhöht werden sollen. Die neuen $\mathcal{J}_{\text{sf}}$ Werte stehen in guter Übereinstimmung mit den auf ähnlicher Weise erhaltenen Werten der Phosphiden und Arseniden der seltenen Erden. Diese Ergebnisse bestätigen die Brauchbarkeit des Modells gleichmässiger Polarisierung als Beschreibung magnetischer Wechselwirkungen in metallischen Verbindungen der seltenen Erden.

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