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EXCITATIONS OF NEODYMIUM IONS IN PRASEODYMIUM

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The excitations of Nd ions dissolved in Pr have been studied by inelastic neutron scattering. A crystal-field level at about 1.2 meV interferes strongly with the host excitations. In the antiferromagnetic phase, another level is observed about 0.5 meV above the ground-state, which is split by the molecular field.

The introduction of a small concentration of Nd ions into Pr modifies the magnetic properties substantially [1]. In a previous paper [2] we have shown that a Pr–2.5% Nd crystal orders antiferromagnetically at about 3.5 K, and that the ordering is preceded by intense magnetic fluctuations. In this note we present the results of inelastic neutron-scattering experiments which give information on the energy levels of the Nd ions in this alloy.

In fig. 1 are shown inelastic scans for $\mathbf{q} = (-0.13, 0, 3)$, corresponding to the minimum in the dispersion relation for the excitations in Pr [3]. Compared with these observations on pure Pr, there are indications at 13 K of extra magnetic scattering at about 1.2 meV. As the temperature is lowered, the Pr excitations renormalize downwards and interfere with the impurity scattering. The lowest excitation of the host is pushed down in energy, as shown in the figure. It is interesting that little change is observed in the excitation spectrum between 6.5 K and 4.3 K, over which range very intense magnetic fluctuations develop [2]. Below the Néel temperature of about 3.5 K the impurity scattering appears to decrease in energy relative to the host excitations, and at 1.8 K there are clear signs of a peak in the valley between the quasi-elastic scattering and the host excitations. The dispersion relations for the alloy are compared with those for pure Pr in fig. 2.

In order to interpret these measurements, we have calculated the energy levels of a Nd ion in the Pr host, in the paramagnetic phase, using a crystal-field model [4]. With an appropriate choice of parameters [5], we find that there is indeed a $|J_z = \pm\frac{1}{2}\rangle$ doublet roughly 1.2 meV above the predominantly $|\pm\frac{3}{2}\rangle$ ground state.

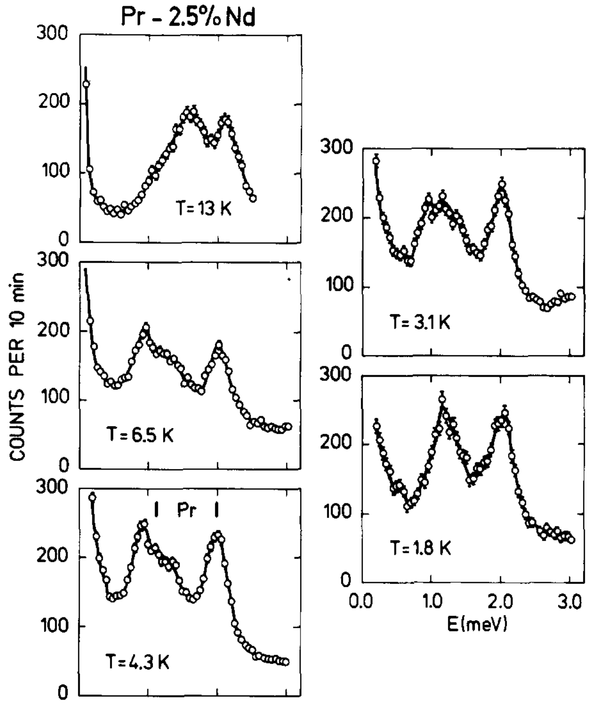

Fig. 1. Inelastic neutron-scattering scans at $\mathbf{q} = (-0.13, 0, 3)$ in Pr–2.5% Nd. The energies of the corresponding excitations in pure Pr are also shown as bars in the lower-left frame.

There is furthermore a predominantly $|\pm\frac{5}{2}\rangle$ excited state at about 0.3 meV, and it is natural to associate this with the low-energy scattering just visible at 4.3 K and clearly developed at 1.8 K. To study this level further, we have measured the scattering as a function of temperature at low temperatures, with the results shown in fig. 3.

All of the Kramers-doublet states of the Nd ions will be shifted and split in the non-uniform antiferromagnetic molecular field. The temperature-dependence of

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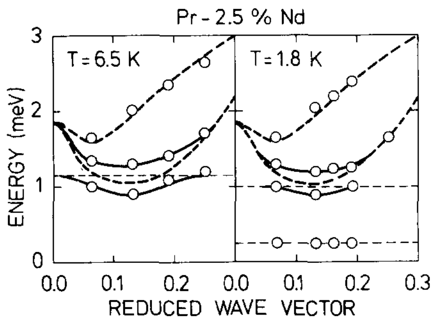

Fig. 2. Excitation energies in Pr–2.5% Nd along the ΓM direction in the paramagnetic and antiferromagnetic phases (open circles). The dispersion relations for pure Pr at 6 K are indicated by the thick dashed lines.

the antiferromagnetic moment indicates that the splitting of the ground state is about 0.1 meV, so that only the lower level is significantly occupied at 0.2 K [2]. The scattering which peaks at about 0.5 meV at this temperature is attributed to transitions between this lower level and the $|\pm\frac{5}{2}\rangle$ excited levels. As the temperature is increased, the upper level of the ground-state doublet becomes populated, the moment decreases and extra scattering is observed at low energy, due to transitions between this upper level and the $|\pm\frac{5}{2}\rangle$ excited states.

In order to study further the crystal-field states of Nd in Pr, we have carried out preliminary measurements in a magnetic field [5], which are generally consitent with the picture presented here. The details of these experiments and their interpretation will be published elsewhere, together with a discussion of their implications for the process of magnetic ordering in this material.

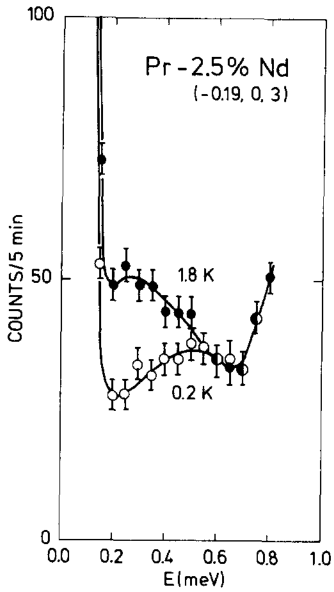

Fig. 3. Inelastic neutron scattering in Pr–2.5% Nd at low temperatures. The corresponding results for pure Pr have a deep valley between 0.2 and 0.7 meV.

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