Nuclear Magnetic Resonance Investigations in Liquid In-Ni Alloys

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Z. Naturforsch. **39 a**, 203–204 (1984);
received November 23, 1983

Measurements of the ^{115}In Knight shift and the NMR linewidth in liquid In-Ni have been carried out over the concentration range (0–50) at.% Ni at high temperatures. With changes of the Ni concentration important changes occur in the hyperfine interactions referring to ^{115}In. The experimental results for higher Ni concentrations are in good agreement with a model involving a significant d-d exchange interaction.

In liquid alloys of simple metals with 3 d elements (magnetic impurities) the polarization of the surrounding electrons, caused by the magnetic moment of the impurities, influences both the Knight shift of the solvent nucleus and the relaxation time of the NMR process.

Recent NMR studies on liquid Bi-Mn [1] show that the Mn impurities possess a local magnetic moment. The impurities affect very strongly the ^{209}Bi-Knight shift $K_{^{209}\text{Bi}}$. A concentration of 3 at% Mn causes a relative change $\Delta K_{^{209}\text{Bi}}/K_{^{209}\text{Bi}} = 33\%$, which is indeed a very strong effect.

In this work we present measurements concerning the concentration dependence of the ^{115}In-Knight shift and the NMR linewidth in liquid In-Ni for concentrations up to 50 at% Ni at high temperatures. To our knowledge this is the first investigation of the ^{115}In-Knight shift in the liquid In-Ni system.

For the relatively difficult sample preparation we used metals with a purity of 99.999% (Ventron Corporation). Alloys of the required composition, particularly those with higher Ni concentration, were left several hours at 1850 *K* in an Al_2O_3 container sealed under vacuum, to get a uniform distribution of the components. The measurements were carried out using a high temperature NMR spectrometer, of which details are given elsewhere [2, 3].

Figure 1 shows our experimental results. We plotted the relative change of $K_{^{115}\text{In}}$ defined as $\Delta K/K_0 = (K(c) - K_0)/K_0$, where $K(c)$ and K_0 are the ^{115}In-Knight shifts in the alloy and in pure Indium at the melting point, respectively.

The function $\Delta K(c)/K_0$ shows a pronounced maximum at $c = 20$ at% Ni and becomes negative at $c = 50$ at% Ni. In this respect it is interesting to consider earlier NMR investigations on binary liquid alloys of simple with transition metals [1, 4–6]. In most of these systems the transition metal concentration was about 6 at% and the relative Knight shift of the simple metal was found to increase linearly with the concentration of the transition metal. NMR investigations of liquid systems with higher transition metal concentrations have been reported for Bi-Mn (up to 12 at% Mn) [1] and Bi-Ni (up to 30 at% Ni) [6]. In both cases the function $\Delta K(c)/K_0$ becomes nonlinear at high c values but still increases with increasing c.

Now an increase of $\Delta K(c)/K_0$ with c can be explained with a concept referring to the density of states $N(E_F)$ at the Fermi energy E_F. An increasing Ni concentration causes an increase of $N(E_F)$ and therefore an increase of $\Delta K(c)/K_0$. This is because $N(E_F)$ in liquid pure Nickel is one order of magnitude higher than $N(E_F)$ in liquid indium [7, 8]. A possible interpretation of the decrease of $\Delta K(c)/K_0$ of high c-values can be based on a model involving a negative core polarization contribution to the total Knight shift and a d-d interatomic exchange interaction between Ni atoms. This model has been used earlier

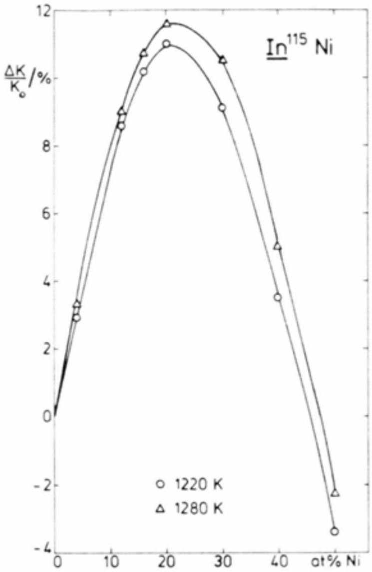

Fig. 1. The relative change of the ^{115}In-Knight shift in the liquid In-Ni system as a function of the Ni concentration.

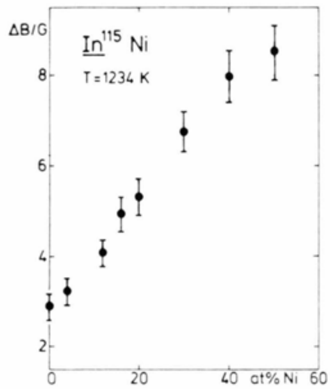

Fig. 2. The ^{115}In-NMR linewidth in the liquid In-Ni system as a function of the Ni concentration.

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in an other form in order to explain Knight shift experimental results in transition metal systems [9, 10].

With increasing Nickel concentration the distance between Ni atoms decreases. Consequently a d-d-exchange interaction appears and causes an increasing polarization of the magnetic moments of the Ni atoms. This then causes an increasing conduction electrons polarization, but also a polarization of inner core s electrons of the In atom. The last mechanism yields a negative hyperfine field at the position of the In nucleus and therefore a negative contribution to the total Knight shift. Now at $c = 20$ at% the positive contribution to the total Knight shift does not increase any more, but with further increase of c the negative core polarization contribution increases further because of the increase in the d-d exchange interaction. In this way our experimental results shown in Fig. 1 can be explained.

For the liquid In-Ni system our measurements give $\Delta K_{In}/K_{In} = 2.3\%$ for 3 at% Ni. For the liquid Bi-Mn system, in which the Mn atoms possess a local magnetic moment [1], one fields $\Delta K_{Bi}/K_{Bi} = 33\%$ for 3 at% Mn. Thus, this striking difference of $\Delta K/K$ gives a first suggestion that the Ni atoms in liquid In-Ni do not possess a local magnetic moment.

The measured concentration dependence of the ^{115}In-NMR-linewidth ΔB in liquid In-Ni over the range (0–50) at% Ni at 1234 K is shown in Figure 2. We determined the linewidth from the cw-NMR signal. So, particularly for higher concentrations, the average error is considerable. Nevertheless, as Fig. 2 shows, the linewidth can be considered, particularly for lower concentrations, to be a linear function of the Ni concentration. As we have reported earlier [6], the ^{209}Bi-NMR-linewidth in liquid Bi-Ni shows a nonlinear behavior in the concentration range (20–35) at% Ni. At present we carry out ^{115}In-NMR-linewidth measurement in liquid In-Ni for concentrations higher than 50 at% Ni in order to see how far the slight deviation from linearity at 50 at% Ni will be verified (see Figure 2). Nonlinearity at higher Ni concentrations is expected from considerations referring to a direct interaction between the Ni moments or to an indirect exchange coupling through the electron gas [11, 12].

Acknowledgement

The support of this work by the DFG (Deutsche Forschungsgemeinschaft) is gratefully acknowledged.

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Verantwortlich für den Inhalt: A. Klemm
Satz und Druck: Konrad Triltsch, Würzburg