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Nuclear Magnetic Relaxation Times of Mn^{55} in Dilute MnFe Alloys

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Abstract

Nuclear magnetic relaxation times (T_1 and T_2) were measured in dilute MnFe alloys. The relaxation processes are effected by the Mn-impurity and related by the functions with impurity concentrations.

§ 1. Introduction

Nuclear magnetic relaxations in ferromagnetic metals were investigated by Weger *et al.*[1] and Streever[2]. The experimental apparatuses of their measurements were designed to study the relaxation processes which could be investigated directly by use of NMR pulse techniques. According to Weger the relaxation process can be understood in terms of two mechanisms: (i) a non-exponential relaxation observed at low rf-power levels which is due to thermal fluctuations of the domain walls, (ii) an exponential relaxation observed at high rf-power levels which is due to an interaction of the conduction electrons with the nuclei via spin waves.

In NMR experiments of dilute Mn^{55} in iron, we have obtained the relation between the relaxation time and the concentration of the Mn-impurity.

It is the purpose of this paper to discuss the relations between T_1, T_2 obtained in this experiment and the concentration of Mn-impurity.

§ 2. Experimental results and discussions

Six samples (0.5, 1.0, 1.5, 2.0, 3.0, and 5.0 at% Mn in Fe) were prepared as follows.

i) The dilute alloys were prepared in an induction furnace.

ii) Alloys were powdered by a grinder.

iii) The samples were separated from the mixtures by a magnet.

iv) Annealing conditions :

at% Mn	temperature	annealing time
0.5	600°C	1 day
1.0	600	1
1.5	500	3
2.0	500	3
3.0	600	1
5.0	600	1

The zero-field NMR spectra and the relaxation times of dilute Mn^{55} nuclei were obtained by the stimulated echo technique.[3] The experiments were carried out at 77° K. The observed relaxation processes were mainly the exponential type which was due to the conduction electrons via spin waves in domain. The relations between T_1, T_2 and the concentration of Mn-impurity were shown in Fig. 1 and Fig. 2. The feature of the relaxation time ratio vs the impurity concentration was linear. The observed values of T_1 and T_2 are listed in Table I.

The observed resonance lines were very sharp, and the resonance frequencies did not depend on the concentration of Mn-impurity (less than 5.0 at%) and 240 MHz at 77° K.

Table I. The observed relaxation times T_1 and T_2 at 77° K.

C (at%)	T_1 (μ sec)	T_2 (μ sec)
0.5	140	90
1.0	113	65
1.5	95	60
2.0	83	49
3.0	70	39
5.0	49	26

As shown in Fig. 1, the relaxation time T_1 decreases as the Mn-impurity increases. The empirical equation is expressed as follows;

$$1/T_1 - 1/T_{10} = K_1 C, \tag{1}$$

where C is the impurity concentration, K_1 the proportional constant and T_{10} the extraporated value to $C = 0$. This means that the relaxation time decreases as the interaction between the nuclei and impurity moments via conduction electrons. By Weger, the relaxation time ratio is proportional to the area of Fermi surface.

The theories of ferromagnetic dilute alloys have been studied by Friedel[4]

and Kanamori.[5] The presence of an impurity atom in an other metal causes a change in the amplitude of the band wave functions in the vicinity of the impurity atom. In the case of Mn in Fe the repulsive potential due to the impurity is weak, and the screening is done, mainly, by down-spin electrons, resulting in the increase of magnetization of 1 μ_B per Mn. Since the Fermi surface increases by the repulsive potential due to the impurity, the contribution of conduction electrons to the relaxation process will increase as the impurity increases.

The relaxation time T_2 varied as like T_1 as shown in Fig. 2. Weger *et al.* measured T_2 as well as T_1 in pure metals, and Streever discussed the nuclear magnetic relaxation in dilute ferromagnetic alloys. Their conclusion is that T_2 is determined by the nuclear spin-spin interaction via a Ruderman-Kittel indirect coupling of nuclei by conduction electrons. Therfore, we considered the origins of the impurity concentration dependences of T_2 to be like those of T_1.

The empirical equation of T_2 is given as

$$1/T_2 - 1/T_{20} = K_2C \qquad (2)$$

where C is the impurity concentration, K_2 the proportional constant, and T_{20} the extraporated value to $C = 0$. The solid lines in Fig. 1 b and Fig. 2 b are calculated by Eq. (1) and Eq. (2), respectively. The extrapolated relaxation times (T_{10} and T_{20}) may be mainly effected by the host atom. The observed relaxation values were same order as those in domain wall by Streever, in spite of the exponential behaviors. The proportional coefficiencies (K_1 and K_2) mean the interactions between the nuclei and conduction electrons in the alloys, but have never been discussed in detail.

These values are as follws:

T_{10} (μ sec)	T_{20} (μ sec)	K_1 (at% sec)$^{-1}$	K_2 (at% sec)$^{-1}$
170	110	0.29×10^4	0.58×10^4

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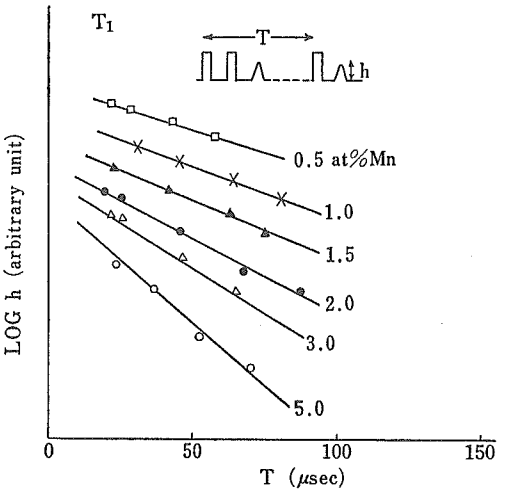

Fig. 1 a The stimulated echo decays vs the pulse intervals at 77°K

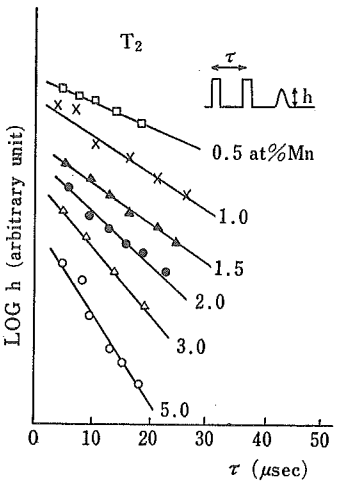

Fig. 2 a The echo decays vs the pulse intervals at 77°K

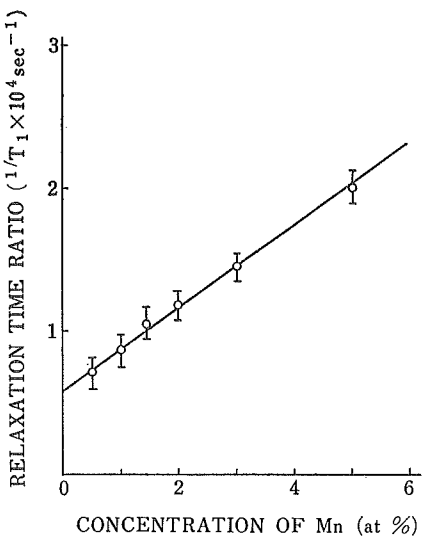

Fig. 1 b The relaxation time ratio ($1/T_1$) vs Mn-concentration at 77°K

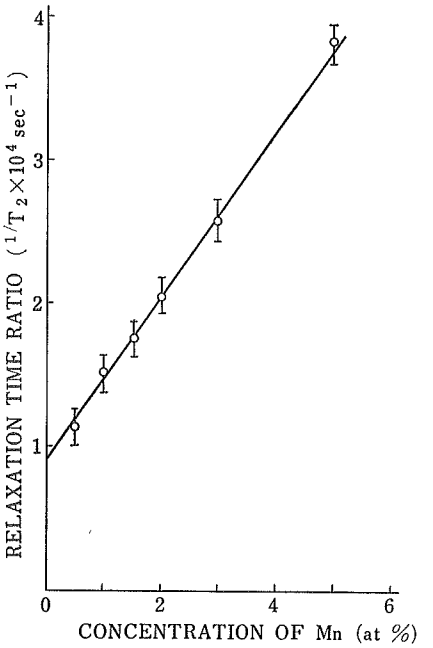

Fig. 2 b The relaxation time ratio ($1/T_2$) vs Mn-concentration at 77°K