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DIFFUSION AND SPIN WAVES IN THIN FILMS

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Résumé. — L'influence de la diffusion sur les ondes de spin a été étudiée sur un système de deux réseaux monoatomicques à une dimension s'entre-pénétrant par diffusion. Les résultats nous laissent entrevoir à quoi peut-on s'attendre si l'on tient compte de la diffusion.

Abstract. — The influence of diffusion on the behaviour of spin waves in thin films has been investigated on a system of two linear monoatomic chains penetrating each other by diffusion. The results give some information on what may be expected if we take diffusion into account.

I. Introduction and Model Assumptions. — In order to get the first insight into the changes of spin waves caused by diffusion we investigate in this paper a simple model of a thin film consisting of two monoatomic ferromagnetic linear chains diffusing in each other.

The effect of mutual penetrating of the two monoatomic linear chains will be demonstrated here for systems of 20, 40 and 60 atoms as shown in figure 1. Here figure 1a, b, d correspond to diffusion symmetric in both directions (equal diffusion constants), figure 1c, e represent an asymmetric case (unequal diffusion constants).

The interaction of the atoms A and B, represented in figure 1 as « [ ] » and « ● » respectively, is assumed to be of the Heisenberg type with the nearest neighbors interaction complemented by a special anisotropy term \( \hat{H}_{\text{ani}} \) responsible for the magnetic anisotropy due to diffusion.

\( \hat{H}_{\text{ani}} \) depends on the nature of the atoms A and B and its choice admits, therefore, some flexibility. In this paper we assumed simply that \( \hat{H}_{\text{ani}} = \sum k_j^2 S_j^2 \) (\( j \) labels the atoms, \( S_j \) is the z-component of the j-th spin) which means that we attribute an uniaxial anisotropy to the diffused atoms. We tentatively used the following scheme: If A appears in the situation ... BBABB... we take \( k_d = 1/100 \ A_2 \), for B in the position ...AABAA... we take \( k_d = 1/100 \ A_1 \). Moreover, for atoms laying at the ends of the chain or at the interface between some periodic arrangements of atoms we take \( 1/10 \ A_1 \) or \( 1/10 \ A_2 \) respectively. Other possibilities which we also should take into account (e.g. positions of the type AAB, BBA) have been omitted for simplicity. Operating with the anisotropy term we must consider spins with \( S \geq 1 \) due to \( S_j^2 \) in \( \hat{H}_{\text{ani}} \).

Using the usual diagonalisation procedure (see e.g. Tjiblikov [1]) we obtain for the spin wave amplitude \( U_j^k \) and the energy eigenvalues \( \varepsilon_k \) the following homogeneous system of linear equations:

\[
\varepsilon_k U_j^k = \sum_j \left[ (A_{jj'} S_{jj'} - 2 \delta_{jj'} k_d S_j) U_j^{j'} - \sqrt{S_j S_{jj'} A_{jj'}} U_j^{j'} \right].
\]

Fig. 1. — Arrangements of atoms A ( ) and B (●) at various stages of diffusion — a) 20 atoms, b) 40 atoms — 20 A + 20 B — symmetric case, c) 40 atoms — 20 A + 20 B — asymmetric case, d) 60 atoms, e) 40 atoms — 30 A + 10 B.

With \( A_{jj'} \) mean the exchange constants, \( S_j \) the spins. If our system is placed in a circularly polarised h. f. field \( h \equiv h_0(e^{i\omega t} - e^{-i\omega t}, \theta) \) treated as a small perturbation, we easily find that the probability \( P \) to create one magnon of the k-th mode per second is

\[
P \sim \left| \sum_j \sqrt{S_j} U_j^k \right|^2.
\]

II. Results. — In this paper we present a selection from some of our numerical results. Some other results concerning the analytical solution of this and some related problems will be published elsewhere [2].

In calculations leading to figure 2a, b, c, d we used \( A_0 = 4 \times 10^{-14} \) erg, \( A_1 = 2.83 \times 10^{-14} \) erg, \( A_2 = 3.5 \times 10^{-14} \) erg, \( S_1 = \frac{1}{2} \) and \( S_2 = 1 \). Figure 2e and figure 4 correspond to \( A_0 = 4 \times 10^{-14} \) erg, \( A_1 = 0.1 \times 10^{-14} \) erg, \( A_2 = 5 \times 10^{-14} \) erg, \( S_1 = 2 \) and \( S_2 = 1 \).

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Figure 2 shows the energy spectrum for various stages of diffusion as given in figure 1a-e demonstrating the transition from the spectrum of a double layer to a system of acoustical and optical branches for a regular chain with the sublattices of atoms A and B.

The point shown by the arrow in figure 2 remembers of a localised surface state, which confirms the figure 3 where the spin wave amplitude is plotted along the chain.

In figure 4 the transition probability $P$ (see (2)) for the possible modes numbered by 1, 2, ... is given for the atomic arrangements 1, 2, ... 7 of figure 1e.

Calculations without the anisotropy term give the main peak accompanied by the other ones with the amplitude of about $10^{-12}$ amplitude of the main peak.

Let us also remark, that the resonance peaks are very sensitive to small changes caused by diffusion as may be seen comparing figure 1e and figure 4.

III. Some Remarks and Conclusions. — Though some special cases may be solved analytically (see [2]) it seems that the most suitable way for such calculations is the numerical one. Apparent is the sensitivity to changes caused by only a few (say 3 or 5) atoms. The imposed «diffusion anisotropy» seems to play the same role as the use of the flageolet technique used by violinists.

It must be investigated what remains as characteristic if we use an averaging procedure going over to three-dimensional films.

Our «diffusion model» of magnetic anisotropy is, of course, very flexible due to many possible forms of $\mathbf{H}_{\text{anis}}$. The «diffusion anisotropy» plus the surface anisotropy is able to describe various situations treated usually by means of pinning, effective pinning etc., which will be shown in more detail in [2].

The «diffusion anisotropy» should be a function of concentration and its maximum should be somewhere inside of the specimen.

If it proved to be possible to prepare samples with diffusion prevailing strongly over other defects, spin waves might be used, at least in principle, for investigations of the process of diffusion.

Though the problem of the influence of diffusion on spin waves is in its very beginning we see that the presence of diffusion in real materials, which is almost unavoidable, must be taken into account.

Let us remark at the end that the physical part of this paper has been elaborated by L. Valenta and D. Vamanu and the numerical calculations have been performed by H. Havlasová.

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