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Magnetic phase transitions in itinerant electron system

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Résumé. — Les combinaisons diverses des transitions magnétiques du premier ordre et du deuxième ordre dans le système d'électrons itinérants sont représentées et la comparaison avec l'expérience est discutée.

Abstract. — Various combinations of the first-order and second-order magnetic phase transitions in itinerant electron systems are shown. The comparison with experiment is discussed.

It was pointed out many years ago by the present author that the first-order and second-order magnetic transitions from ferromagnetism to paramagnetism or *vice versa* with increasing temperature and also various combinations of these transitions can occur in the itinerant electron system [1]. In the case of weak ferromagnetism the magnetic free energy f can be expanded with respect to the magnetization M as

$$f = \frac{1}{2}(a_1 - \alpha) M^2 + \frac{1}{4} a_3 M^4 + \frac{1}{6} a_5 M^6, \quad (1)$$

where α is the molecular field coefficient. Here, the coefficients a_1 , a_3 and a_5 can be expressed as a function of temperature in terms of the density of states and the effect of spin fluctuations can be included [1]. Then, it was shown that the extended condition of ferromagnetism, even if the Stoner condition of ferromagnetism

$$a_1 < \alpha \quad (2)$$

is not satisfied, is given by

$$R \equiv a_1 - \frac{3}{16} a_3^2 a_5^{-1} < \alpha, \quad (3)$$

when $a_3 < 0$ and $a_5 > 0$. The first-order transition temperature T'_c was determined by $a_1 - \frac{3}{16} a_3^2 a_5^{-1} = \alpha$. The details of the transitions and their combinations were discussed for a few simple cases, where the paramagnetic Fermi level appears at a minimum of

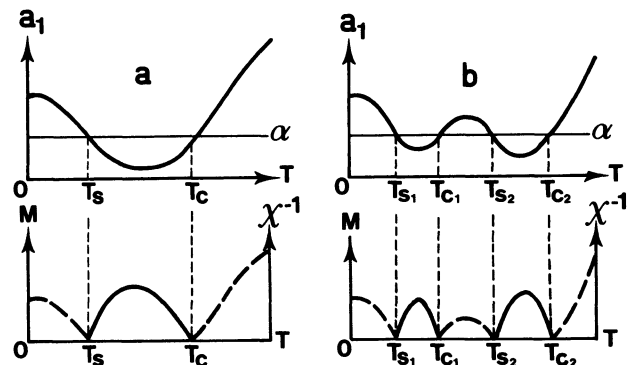
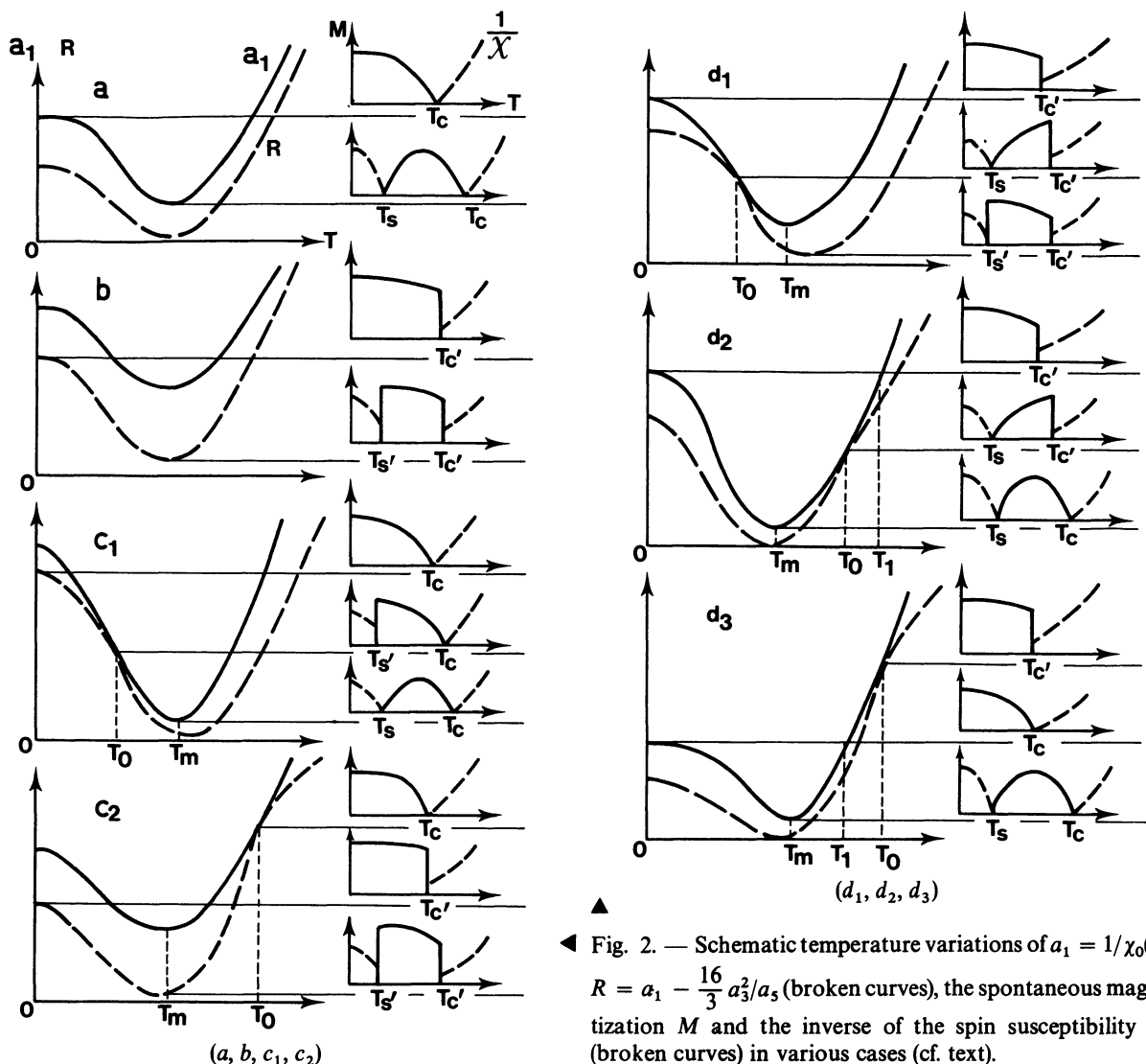


Fig. 1. — Schematic temperature variations of $a_1 = 1/\chi_0(T)$, the spontaneous magnetization M and the inverse of the spin susceptibility $1/\chi$ (broken curves), when $a_3 > 0$.

a symmetrical density of states so that the unenhanced spin susceptibility $\chi_0(T) = 1/a_1$ exhibits a maximum and $a_3 < 0$ at low temperature.

Recently, it has been discovered by very careful experiments that Y_2Ni_7 compound exhibits a spontaneous magnetization only between the temperature $T_s = 7$ K and the Curie temperature $T_c = 58$ K and this property has been named as the thermal magnetism [2]. It seems very difficult to distinguish whether these transitions are first-order or second-order transition experimentally, because of the inhomogeneity, defects and impurities in the samples. The explanation for this behaviour of M is very easy in the itinerant electron model, as discussed before [1]. We assume that $\chi_0(T)$ exhibits a maximum, a_3 is always positive and the value of α is smaller than the value of a_1 at 0 K and larger than the minimum of a_1 , as shown in figure 1a. Then, the Stoner

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▲ Fig. 2. — Schematic temperature variations of $a_1 = 1/\chi_0(T)$, $R = a_1 - \frac{16}{3} a_3^2/a_5$ (broken curves), the spontaneous magnetization M and the inverse of the spin susceptibility $1/\chi$ (broken curves) in various cases (cf. text).

condition of ferromagnetism is satisfied and M appears between T_s and T_c , where $a_1 = \alpha$. The transitions at T_s and T_c are second-order. If $1/\chi_0(T)$ exhibits a much more complicated temperature variation than that with one maximum, as shown schematically in figure 1b, we will have a series of the second-order transitions, as long as $a_3 > 0$.

The expressions of a_1 and a_3 are given as [1] :

$$a_1 = \chi_0(T)^{-1} = \chi_0(0)^{-1} \left\{ 1 + \frac{1}{6} (\pi k_B T)^2 \left[(N_1/N_0)^2 - (N_2/N_0) \right] + \dots \right\}$$

and

$$a_3 \propto 3(N_1/N_0)^2 - (N_2/N_0) \quad \text{at } T = 0 \text{ K,}$$

where N_i is the i th derivative of the density of states at the paramagnetic Fermi level at 0 K. Therefore, it is clear that when $a_3 < 0$ at low temperature and then the spin susceptibility increases with increasing field, $\chi_0(T)$ always exhibits a maximum and a_3 will become positive at high temperature, as observed in

YCo_2 [3]. In this case the transition may be first-order as shown above. But it is also clear that even if $\chi_0(T)$ exhibits a maximum the value of a_3 at low temperature can be positive and the transition in this case will be second-order, as mentioned above.

Therefore, it will be worth while to look for and to summarize the character of the magnetic transition in more general cases where there exists a change of sign in the temperature variation of a_3 . This is the purpose of this paper.

For simplicity, we confine ourselves to the case of the weak ferromagnetism, i.e. M is small, and the expansion of f in equation (1) is used. Furthermore, we assume that $\chi_0(T) = 1/a_1$ exhibits only one maximum, a_5 is always positive and a_3 and a_5 always change monotonically with temperature. When $\chi_0(T)$ does not exhibit a maximum, a_3 is positive at low temperature and the transition will be mostly second-order and simple. The extension to other complicated cases is very easy. The value of α is assumed to change. It is important to remember that the condition for ferromagnetism is given by equation (2) if $a_3 > 0$

and by equation (3) if $a_3 < 0$, when the value of α is changed.

Depending on the sign of a_3 and its temperature variation, the following four cases are considered : (a) a_3 is always positive, (b) a_3 is always negative, (c) $a_3 < 0$ at $T < T_0$, $a_3 = 0$ at $T = T_0$ and $a_3 > 0$ at $T_0 < T$ and (d) $a_3 > 0$ at $T < T_0$, $a_3 = 0$ at $T = T_0$ and $a_3 < 0$ at $T_0 < T$. Furthermore, the case (c) is divided into two cases, where (c₁) $T_0 < T_m$ and (c₂) $T_m < T_0$, here T_m is the temperature, at which a_1 is minimum, and the case (d) is divided into three cases, where (d₁) $T_0 < T_m$, (d₂) $T_m < T_0 < T_1$ and (d₃) $T_1 < T_0$, here T_1 is the temperature, at which $\chi_0(T_1) = \chi_0(0)$.

The schematic temperature variations of $a_1 = 1/\chi_0(T)$ and R for the cases a, b, c₁, c₂, d₁, d₂ and d₃ are shown by the full and broken curves in figures 2a, 2b, 2c₁, 2c₂, 2d₁, 2d₂ and 2d₃, respectively. In the right-hand side of these figures, the ranges for the values of α are divided by thin horizontal straight lines and the corresponding temperature variations of M and the inverse of the spin susceptibility $1/\chi = 1/\chi_0(T) - \alpha$ are shown by the full and broken curves, respectively. The second-order transition temperatures are denoted by T_s and T_c and the first-order ones are denoted

by T'_s and T'_c . In some cases $1/\chi$ may show a minimum above T'_c .

From figure 2, one can see that there are six kinds of combinations of first-order and second-order magnetic transitions. Only two of them, except a simple second-order transition, have been observed in heavy rare earth-Co₂ compounds [4] and in Y₂Ni₇ [2]. In the itinerant electron model and in the combined model of localized moments and itinerant electrons such as compounds of rare earth and transition metals, the coefficients a_3 and a_5 , etc. can be negative and can easily change their sign as discussed elsewhere [5]. Therefore, the magnetic materials, to which these models are applicable, may show the combinations of the magnetic transitions shown in figure 2, by changing the concentration of alloys or compounds, by changing alloying elements or by applying the pressure.

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References

- [1] SHIMIZU, M., *Proc. Phys. Soc.* **86** (1965) 147; *Rep. Prog. Phys.* **44** (1981) 329.
- [2] GIGNOUX, D., LEMAIRE, R., MOLHO, P. and TASSET, F., *Proc. 1980 Conf. on Cond. Mat. Div. EPS, Antwerpen 1980 (Solid State Commun. to be published).*
- [3] BLOCH, D., EDWARDS, D. M., SHIMIZU, M. and VOIRON, J., *J. Phys. F* **5** (1975) 1217.
- [4] LEMAIRE, R., *Cobalt* **33** (1966) 201; GIVORD, F. and SHAH, J. S., *C. R. Hebd. Séan. Acad. Sci. Paris B* **274** (1972) 923.
- [5] SHIMIZU, M., *J. Physique* **43** (1982) 155.