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Critical Scattering of Neutrons by Nickel

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Critical scattering of neutrons by nickel has been studied by time of flight technique. Complete measurements have been made at T_C and above T_C. The two more important results are

a) the existence of a rather important inelasticity at T_C, giving to parameter Λ the value

$$\frac{2m}{\hbar}\Lambda_{T_C}\sim 10\ .$$

b) a term in K^4 in the spatial dependence of the cross section. This last point is an important difference with the case of iron.

Critical scattering of neutrons by magnetic substances at transition point T_C has been observed a few years ago[1] and has been attributed[2)3] to the strong fluctuations of the magnetic density at T_C. The treatment of this phenomenon is similar to that of scattering of X-rays at critical point of a liquid. The differential cross section for neutrons is the Fourier transform of the space time correlation function $\langle M(0,\ 0),\ M(r,\ t)\rangle$ where $M(r,\ t)$ is the magnetisation density at point r and time t. Explicit calculation[4] gives for small angle scattering $T>T_C$.

$$\frac{d^2\sigma}{d\Omega d\omega}=\frac{k'}{k}\left(1.91\frac{e}{\hbar e}\right)\frac{1}{\pi}\ \frac{k_BTV}{V/\chi+AK^2}\ \frac{\Lambda K^2}{\omega^2+\Lambda^2K^4} \tag{1}$$

where K is the momentum change in the scattering process, $\hbar\omega$ the energy change, k is the initial momentum of neutron and k' his final value, χ is the susceptibility of the material of volume V. The other symbols have their usual meanings. The evolution in time of magnetisation density has been described by a diffusion equation with a coefficient Λ which is expected to be zero at T_C. The denominator of the first factor is the beginning of an expansion in K^2.[5] In the case of iron detailed experiments[6)7)8] have given a confirmation of the validity of formula (1).

We have made a similar experiment in the case of nickel. Small angle scattering is measured for neutrons of 4.75Å. The scattered spectrum is measured by time of flight technique[8]. Special care has been taken to have good angular definition (the detector has a size of $4\times4\ \mathrm{cm}^2$ at a distance of 4 meters from the sample). Air scattering has been eliminated by having vacuum between sample and detector. The experiment is made simultaneously at two angles.

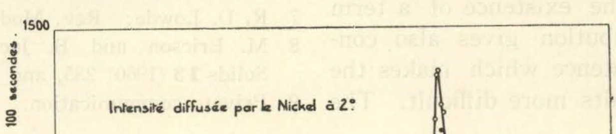

Fig. 1.

Fig. 1. shows the intensity of neutrons scattered at 2° as a function of temperature. Careful measurement around Curie point gives $T_C=351°5\pm0°5$. The existence of a large and well known incoherent cross section $(5.9\pm0.2)b$ of nickel makes unnecessary a measurement of the incident spectrum. The spectrum scattered at room temperature above 4° is independent of angle, as expected, and provides a good reference for shape of the spectrum, and absolute cross section determination. No correction is necessary for capture.

Results

a) Scattering at Curie point

The scattering at Curie point is not elastic. The spectra measured at 2°, 3°, 4°, 5° have a width increasing with scattering angle. This seems to imply that A does not go to zero at T_C. The different spectra give $\mu_{Tc}=2m/\hbar\, A_{TC}\sim 10$.

The angular distribution at T_C, even if we take account of the inelasticity, implies the existence of term BK^4 in the denominator of formula (1). This term is important; we found $B/A=200\text{Å}^2$. We have no evidence for a term in K^6. The existence of term in K^4 means the existence of a long range magnetic interaction in nickel. Such thing was not found in iron.

b) *Scattering above* T_C

If we try to make a determination of A by comparison of the area[8] of the spectrum scattered at temperatures T and T_C, we find values which decrease with the angle at which the experiment is made. This is another evidence for the existence of a term BK^4. Angular distribution gives also confirmation of this existence which makes the analysis of the results more difficult. The fact that the inelasticity is rather strong, makes impossible a separation of the analysis of the spatial part and energy part of the cross section as we have done in the case of iron. Only calculations with an electronic computer are possible. Such calculations are being done. Here we can give only qualitative results obtained by a very crude analysis. The values obtained for A are following:

T	K^2_1	χ(per gram)	A	$\mu_T-\mu_{Tc}$
362	0.310	$1.43\cdot10^{-3}$	$2.62\cdot10^{-12}$	7
379	1.2	0.35	2.67	20
404.5	2.9	0.15	2.57	45

The values of the susceptibility have been obtained by Allain[9]. The corresponding value of A for iron[8] was $1.18\cdot10^{-12}$. The value of B seems to be independant of temperature in the above range.

The values of $\mu_T-\mu_{T_c}$ are independent of angle giving confirmation of the diffusion process. These values are about 15 times higher than for iron for the same $(T-T_C)$.

Note added in proof: There is now evidence that at Curie point the width is varying as K^4 and not as K^2.

References

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4 See for instance P. G. De Gennes: *Theory of neutron scattering by magnetic crystals* (to be published).

5 In the notation of Van Hove $V/A\chi$ is K_1^2.

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