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DYNAMICAL ASPECTS OF THE MORIN TRANSITION IN HEMATITE AS REVEALED THROUGH A MÖSSBAUER MAGNETIC DIFFRACTION SPECTROSCOPY

B. Furubayashi and I. Sakamoto
Electrotechnical Laboratory, Tanashi, Tokyo, Japan

1. Introduction.- The problem concerning dynamical processes occuring and entities dominating during the MMD has acquired a central importance in physics. However, lacking adequate experimental means, direct experimental access to the most relevant variables has been severely restricted. The elaborate pioneering work by Balko and Hoy /1/ utilizing a SEDM method /2/ has shown for the first time that there certainly exists a relatively slow critical relaxation (~10^{-7} second) associated with the Morin transition.

Among several distinctive features of MMD /3/, the present work provides an example of its new application as a means to measure directly the averaged low frequency scattering function. The novel point is a combination therewith of the SEDM. At first glance, this may seem inappropriate, because we have no general relaxation theory of dynamical MMD in such a nonequilibrium situation as encountered in the SEDM yet. But if one has at hand a thick "perfect" single crystalline sample /4/ and restrict oneself to the second order degeneracy condition /5/ and sufficiently slow relaxation rates, it was found that the lowest order perturbation theory /6/ can be applied mutatis mutandis.

One of the most attractive features of this method is that, by specifying a definite Bragg reflection, the obtained relaxation rates is essentially just a space-time Fourier component of an electronic spin fluctuation correlation function averaged transmitting Mössbauer component. This is quite helpful, as critical spin fluctuations are in many cases of interest strongly anisotropic; this can be used in advantage in inferring which physical mechanism be responsible for the observed phenomena.

2. Experimental.- In brief, the employed Mössbauer diffractometer consists of a Ni-cooled cryostat (40.3 K) assembled with a goniometer in such a way as to allow for the incorporation of SEDM apparatus. An 100 mCi$^{57}$Co (Rh) source was used throughout. A single crystalline enriched α-Fe$_2$O$_3$ sample /4/ has a surface parallel to (111) plane. It is of high quality such that the dynamical diffraction theory for a thick "perfect" crystal /3/ applies with sufficient accuracy.

3. Results.- By a similar reasoning as in reference /1/, we adhered to the same sixth line (3/2-1/2), and measured the temperature dependence of SEDM spectra under a symmetric (555) Bragg reflection (θ=28°) near the Morin point ($T_M$=254.0 K). Examples are shown in figure 1, where the experimentally assigned relaxation rates $<\gamma(q,\omega)>$ are also given.

To further confirm that the observed relaxation is not spurious, the same sort of experiments were repeated, this time with a modified absorber motion scheme, namely with a constant velocity scanned slowly enough to avoid a troublesome transient irregular movement possibly originating from an absorber fly-back. The observed spectra are, however,
cative of no positive relaxation effect. Thus, although in our second series of experiments, the grains of the sample irradiated by the source are not necessarily the same as in the first, it cannot be excluded that the relaxation observed in the first might only be apparent one possibly resulting from the above-envisioned irregular absorber motion. 

Fig. 1: The temperature dependence of SEDM spectra measured near the Morin point. Solid lines indicate the best-fit theoretical line shapes with their assigned relaxation rates (MHz).

4. Discussions. - We have developed a theory of $\gamma(q,\omega)$ suggested by a remarkable paper by Chow and Keffer. The most essential element of ours is the assumption that the critical spin fluctuation (flipping) motion along the trigonal $\langle 111 \rangle$ axis is much more rapid than and decoupled dynamically from that in the basal $(111)$ plane. The former is dominated by critical magnetic double-Sine-Gordon solitons. Secondly, we assume the latter be described by a three-dimensional isotropic (weak-) ferromagnet, of which metastable inhomogeneous states have lately been shown to be well in accord with an instanton model. An important consequence of this in our context is that the instanton, a semi-macroscopic local metastable singular spin configuration having finite degrees of freedom, gives rise to a natural length to the instanton scale $h$ because of its quantum fluctuation in an otherwise scale-invariant $h^2$ distribution $\rho_0(\lambda) \propto \lambda^{-3}$.

$$\rho_q(\lambda) \propto \lambda^{-1} (\xi h)^2.$$ (1)

This has a zero at $\lambda = 1$ and an extremum at $\lambda = e^2$; the latter we normalize to $1.4 \mu m$ at $20^0C$ with a data /10/ and a theory /11/. The critical soliton may thus be envisioned to nucleate whenever it can avail itself of a proper-sized surface instanton.

These ideas really work well and give a closed analytic expression for $\gamma(q,\omega)$ even for a metastable phase by using an analytic continuation technique, but too lengthy to be presented here. Results are shown in figure 2 together with the experimental values. It is worthy of note that in the metastable phase (in our case $T>T_M$), $\langle \gamma(q,\omega) \rangle$ has an imaginary part, i.e., the relaxation shift which is strongly temperature dependent and far exceed the real part (relaxation width); this may be viewed as the second order Doppler (thermal) shift due to the liberated latent heat. The latent heat and the $q = 0$ thermal shift calculated from a free energy expression derived in the same spirit are also in agreement with the experiments /12/.

Fig. 2: The critical temperature dependence of relaxation rates $\langle \gamma(q,\omega) \rangle$ according to our model as compared with experimental values.

5. Conclusions. - We have undertaken to construct a new MMD spectrometer to obtain a similar dynamical information as in the inelastic neutron scattering, but with a much superior energy resolution and a far less expense, and applied it to study a critical spin relaxation phenomena in the Morin transition, although some experimental uncertainties are unsettled yet. This seems to be ideally suited to investigate a slow critical nucleation mode characteristic of a FOPT, as the latter to the soft mode. Simultaneously, we have developed a new theoretical model emphasizing the instanton-soliton aspect of the problem, and compared it with our experiments.
References