

ESRF

**Experiment title:**

Investigation of higher-order terms in the resonance scattering cross section

**Experiment number:**

HE-603

**Beamline:**

ID20

**Date of experiment:**

from: 24/3/99 to: 30/3/99

**Date of report:**

12/2/00

**Shifts:**

18

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21 FEB. 2000

**Report:**

The object of this experiment was to examine the cross section for magnetic resonance scattering from an incommensurate cycloid structure using the M edge of uranium. The electric dipole part (E1 contribution) of the resonance cross section is made up of three terms:

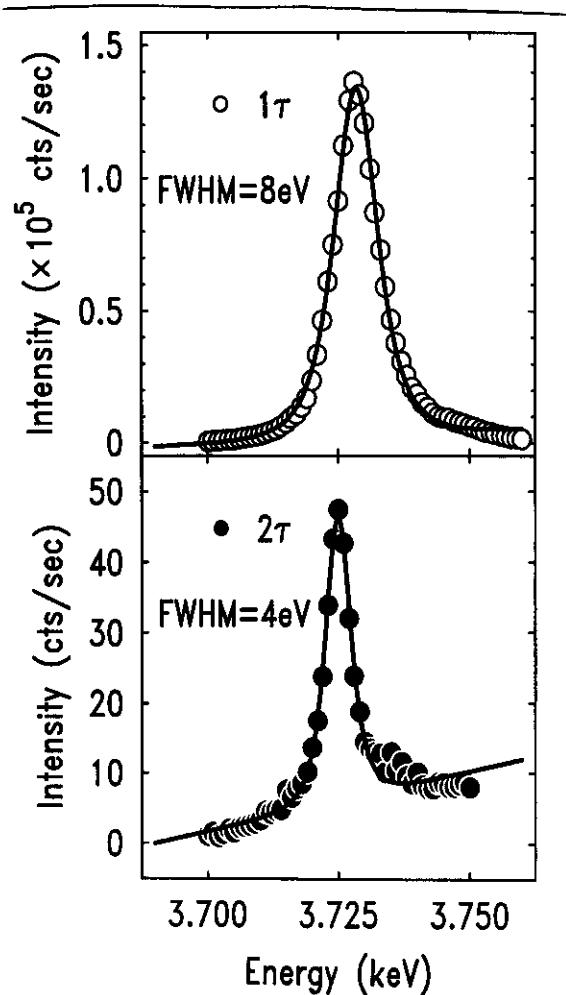
$$f_{nE1}^{XRES} = (\hat{\epsilon}' \cdot \hat{\epsilon}) F^{(0)} - i((\hat{\epsilon}' \times \hat{\epsilon}) \cdot \hat{z}_n) F^{(1)} + (\hat{\epsilon}' \cdot \hat{z}_n)(\hat{\epsilon} \cdot \hat{z}_n) F^{(2)} \quad (1)$$

where  $\hat{\epsilon}'$ ,  $\hat{\epsilon}$  are unit vectors representing the final and incident photon polarisation,  $\hat{z}_n$  is a unit vector in the direction of the magnetic moment  $\mu_n$  on the n-th atom, and  $F^{(j)}$  contain matrix elements which relate initial to final states and the overlap of the wavefunctions of those states. In standard atomic resonance notation these terms also contain a denominator that depends on the energy difference of the photon to the resonance energy in units of the half-width of the relaxation process. It is this latter term that gives rise to the Lorentzian nature of the resonance scattering with a peak at the resonant energy. The first term in Eq. (1) above is not sensitive to the magnetism – it relates to the contribution to the anomalous scattering, i. e. to  $f'$ . The second term, linear in  $\mu$ , is proportional to  $F^{(1)} \propto [F_{11} - F_{1-1}]$  and is the standard term that we observe when we look at the antiferromagnetic reflections at wavevector  $\tau$  of an antiferromagnetic modulation. However, the third term is *quadratic* in  $\mu$  so that it appears at  $2\tau$  and has an amplitude proportional to  $F^{(2)} \propto [2F_{10} - (F_{11} + F_{1-1})]$ . It is important to stress that this scattering at  $2\tau$  is intrinsic to the resonant process. There may be other effects, normally structural, because of a magneto-elastic wave following the magnetic modulation, that appear at  $2\tau$ , but they will be in addition to the intrinsic  $2\tau$  modulation.

These terms were examined in UPtGe because of the cycloidal nature of the structure. We show in the Figures below two of the principle results from the experiment. A long paper is now in preparation for Physical Review B; this includes both the neutron and ID20 results. The result is that  $F^{(1)}/F^{(2)} \sim 60$ , which has to be compared to a ratio of  $\sim 3$  in holmium. No theory exists for this ratio.

**Figure 1**

Intensity as a function of incident photon energy of the 1st- and 2nd-order satellites,  $200$  and  $0^{2+}00$ , respectively. Notice the different energy widths of the two reflections. This difference in energy is due to the different terms  $F^{(1)}$  and  $F^{(2)}$  as discussed above.



**Figure 2**

Upper panels: absorption as a function of energy as derived from the fluorescence data obtained from the crystal.

Lower panels: resonant enhancements at the U  $M_4$ , Ge K, and Pt  $L_3$  edge as a function of energy across the edges. Note that polarisation analysis was used for the Ge and Pt edges so to compare relative intensities, those at the Ge and Pt should be increased by  $\sim 20$  to account for the reflectivity of the analyser Al(333).

