XMaS the UK-CRG	**Experiment title:** Search for an antiferromagnetic phase in gadolinum metal.	**Experiment number:** 28-01-46
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Report:

Measurements of the AC susceptibility of gadolinium have always pointed to ferromagnetism below a Curie temperature of 293 K. In the 1960's, Cable et *al.* also concluded (using neutrons [1]) that near 293K gadolinium is essentially ferromagnetic. The moments in this phase point along the c-axis. When the temperature is lowered below 225K (=$T_{spin\ reorientation}$) they begin to tilt towards the $\mathbf{a_1}$ direction. The angle subtended by the moments and the c-axis increases with decreasing temperature, reaching a maximum of approximately 65^o at 180K, before decreasing again as the temperature is lowered still further. This view of the magnetism of gadolinium has recently been challenged by Micheal Coey and his group at Trinity College, Dublin [2]. They have pointed out that the samples used in previous susceptibility measurements had large demagnetisation factors (due to their dimensions). This may have obscured features which would indicate states other than ferromagnetic below T_c (by saturation of the susceptibility reading at χ=1/N). They have carried out their own measurements on long thin samples (dimensions: 0.2×0.4×4 mm^3) with small demagnetisation factors. These have revealed evidence of new features in χ(T) which suggest the presence of an antiferromagnetic phase between 'T_c' and T_{sr}. Some of their data are displayed in Figure 1. For fields applied parallel to the c-axis there is no sign of of any divergence in χ near T_c (as would be expected from a ferromagnet). For fields applied in the basal plane a peak in χ is present; a result similar to that observed in other rare earth elemnts in which a helical spiral structure is known to exist.

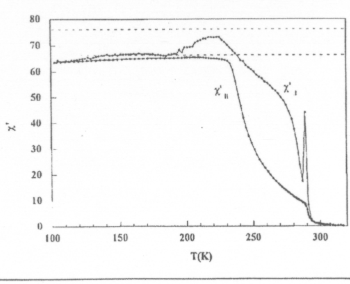

Figure 1.
Non-divergent behaviour in the real part of the susceptibility of gadolinium metal near T_c.

Following these results we have conducted a search for resonant magnetic diffraction peaks that would arise from such an antiferromagnetic phase. An energy of 7.929 keV was chosen for the search, based upon the resonance observed near the Gd L_{II} (7.930 keV) edge by M.M.R. Costa et *al*. in $GdNi_2B_2C$ [3]. In order to reduce background from charge scattering, a horizontal scattering geometry was adopted and a charge peak with a scattering angle 2θ of close to ninety degrees, namely the $(\bar{1}05)$, was chosen to base the search around. Extensive searches in reciprocal space were conducted within the volume shown in figure 2.

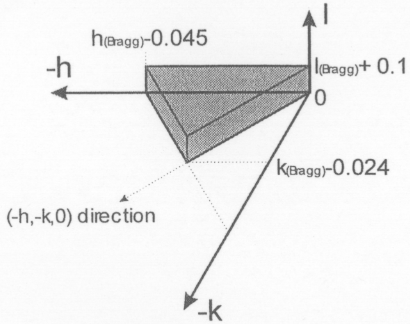

Figure 2.
Volume over which search for magnetic diffraction peaks was carried out.

The search was conducted in the form of a large number of scans along the **c*** direction. Each scan was slightly displaced in $\mathbf{b_1}$ and $\mathbf{b_2}$ by an amount defined by the size of the resolution ellipsoid. In addition, long scans were made along the **c*** axis, in search of peaks arising from longitudinal modulations. None of these searches provided evidence of magnetic diffraction peaks. Given the strength of the resonances previously reported (hundreds of counts per second on peak at the L_{II} edge [3]) and the resolution of the experiment, it is reasonable to conclude that modulations with **q**-values within the search volume are not present in gadolinium.

While conducting a scan in energy with **q** fixed to the position of the $(\bar{1}05)$ charge peak at 260K, an anomalous peak was observed which may be magnetic in origin. Scans were made at various angles of phi and it was found that the peak remained fixed in position, thus ruling out the possibility of multiple scattering. In order to investigate the peak's temperature dependence, the scans in energy were repeated at various temperatures. Figure 6.4 shows scans made at 240K (left) and 290K (middle) and the resulting subtraction (right). The subtracted data show a clear peak at an energy which would be consistent with a quadrupolar magnetic scattering resonance. It is possible that the huge reduction in the charge scattering background obtained from the scattering geometry described above may have enabled the observation of (ferromagnetic) resonant magnetic diffraction. This has not previously been observed in any system and should be the subject of further investigation.

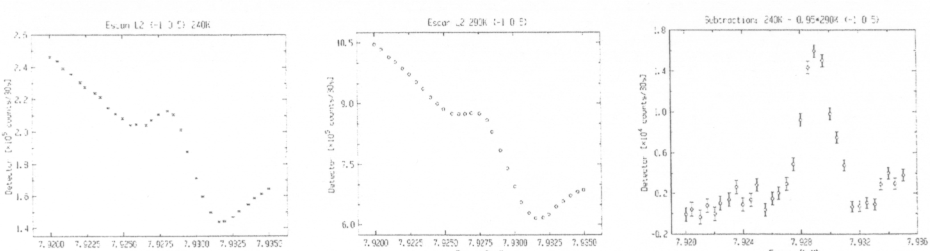

Figure 3. Evidence for ferromagnetic diffraction.

References.
[1] J.W. Cable and E.O. Wollan, *Phys. Rev.* **165** 733 (1968)
[2] J.M.D. Coey, V.Skumryev and K. Gallagher, *Nature* **401** 35 (1999)
[3] M.M.R. Costa *et-al., J. Phys. Cond. Mat.* **8** 2425 (1996)