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MAGNETIC PROPERTIES OF QUASICRYSTALS

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Abstract. The aperiodic T-Al73Mn21Si6 phase is magnetic with an effective moment 1.3 µB / Mn. Below 4.1 K a spin glass state is observed. The T-phase and the quasi-crystalline Al73Mn21Si6 phase exhibit similar magnetic properties. The crystalline phase, obtained by annealing the T-phase, is less magnetic than the T-phase.

Quasi-crystalline (qc) phases, first discovered in Al-Mn based alloys, are aperiodic crystals which present a five-fold symmetry diffraction pattern (see [1] for a survey). One can wonder whether the electronic properties of qc differ from those of crystalline phases with the same composition. To this purpose the Al80Mn20 T-phase is an interesting case as it is known to present a periodic order in one direction and a qc structure in the perpendicular plane [2]. In magnetism studies differences do appear between crystalline and 3 dim qc phases. Indeed the magnetisation of qc-Al73Mn21Si6 increases strongly as the temperature decreases while the crystalline phase obtained by annealing the qc phase has similarity in magnetic properties. It has been suggested that these non magnetic Mn, forming virtual bound states, would be responsible for the enhancement of the overall (s-p-d) density of states at the Fermi level detected by specific heat measurements [6]. In a previous paper [4], comparing the initial susceptibility and the saturation magnetisation, we could estimate the fraction of magnetic Mn to be about 15 at. %. We have also shown that the magnetic Mn freeze in a spin-glass state below Tg = 5.2 K. We discuss here the magnetic properties of the T-Al80Mn20 phase and of the crystalline phase obtained by annealing. The T-phase sample was provided by C. Janot and J. M. Dubois. Details can be found in [7]. The T-phase sample was provided by C. Janot and J. M. Dubois. Details can be found in [7].

The magnetisation of the T-Al80Mn20 alloy is found temperature dependent (Fig. 1) but does not follow a Curie-Weiss type law, \( M / H = \chi_0 + C / (T + \theta) \), in the whole temperature range. Good fits can only be obtained in restricted temperature ranges: see table I. Moreover as the three parameters \( (\theta, C, \chi_0) \) are not independent, the values given in table I should only be considered as indicative. The ac susceptibility exhibits a maximum at \( T_g = 4.1 \) K (Fig. 2). Below \( T_g \) the magnetisation is found to depend on the cooling process. The magnetisation measured when field cooling is temperature independent while the magnetisation measured when warming up the sample, after cooling in zero field, shows a broad maximum around \( T_g \) (Fig. 2). Thus the T-Al80Mn20 phase, like the qc-Al73Mn21Si6 studied previously [4], exhibits qualitatively the magnetisation irreversibilities characteristic of spin glasses. Both samples are actually very similar, having close \( T_g \) and similar Curie-Weiss parameters (Tab. I). Magnetic measurements have been reported for 3 dim qc Al80Mn20 [8] but some care should be taken in the data analysis since the samples of reference [8] contained fcc Al and likely a non negligible amount of T phase. However when comparing the present results and those of reference [8] it appears that the magnetic properties of the 3 dim qc Al80Mn20 phase and of the T-Al80Mn20 phase are similar. The
Table I. - Magnetic properties of quasi-crystalline and crystalline alloys. Susceptibility data were obtained either by ac susceptibility technique (in zero static field) or by magnetisation measurements in fields up to 10 kG. At high temperature $M$ increases linearly with $H$ up to 10 kG so $M (H = 10)$ provides a good determination of the initial susceptibility $\chi_i$. This is no longer true below 15 K where $M$ has to be measured in 2 kG to get $\chi_i$. The parameters deduced from Curie-Weiss fits, $\chi = \chi_0 + C/(T + \theta)$, depend on the fitted temperature range. The effective moment $p_{\text{eff}}$ was deduced from $C$ by assuming that all the Mn have the same moment, which is certainly wrong, but allows comparisons between different samples. The spin value $S$ was then deduced from $p_{\text{eff}}$ assuming $g = 2$.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Curie-Weiss fit parameters</th>
<th>fitted temp. range</th>
<th>$\chi(T = \infty)$ (emu/g)</th>
<th>$\chi(T = 4.2 K)$ (emu/g)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi$</td>
<td>0.31</td>
<td>3</td>
<td>0</td>
<td>$6-20 K$</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.35</td>
<td>2</td>
<td>$2 \times 10^{-6}$</td>
<td>$15-300 K$</td>
<td>$7 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.28</td>
<td>5</td>
<td>0</td>
<td>$8-30 K$</td>
<td>$2.6 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.35</td>
<td>2</td>
<td>$1.4 \times 10^{-6}$</td>
<td>$20-300 K$</td>
<td>$2.6 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.35</td>
<td>2</td>
<td>$1.4 \times 10^{-6}$</td>
<td>$20-300 K$</td>
<td>$2.6 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.16</td>
<td>7</td>
<td>$1.6 \times 10^{-6}$</td>
<td>$6-20 K$</td>
<td>$2.6 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.16</td>
<td>7</td>
<td>$1.6 \times 10^{-6}$</td>
<td>$10-80 K$</td>
<td>$2.6 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

annealed $\alpha$-$\text{Al}_{80}\text{Mn}_{20}$ phase is different. It is still found partly magnetic (Fig. 1) but at 4.2 K its magnetisation is 4 times smaller than that of the T phase. The susceptibility increases continuously by a factor 3 between 4.2 K and 1.5 K. These results are somewhat surprising as the crystalline $\text{Al}_{80}\text{Mn}_{20}$ phase was reported in [8] as non magnetic with a temperature independent susceptibility.

The origin of the magnetism of Al-Mn and Al-Mn-Si qc phases remains unclear. Since the crystalline phases are either non magnetic, or at least much less magnetic than the aperiodic phases, local environments of Mn atoms could play an important role. Namely an increasing number of first Mn neighbours could trigger the apparition of a local magnetic moment. In this model isolated Mn would remain non magnetic. This suggests either a key role of the defects, present up to now in all real AlMn qc, or intrinsic different Mn local environments in the crystalline and qc phases. Although recent EXAFS [10] and diffraction [11] works seem to reveal some differences their link with magnetism is far from being clear. An alternative explanation for the apparition of magnetism in the qc phases, is that the s-p density of states of the Aluminium matrix would be smaller in theqc phases than in the periodic ones [12].

Acknowledgements

We are very grateful to C. Janot (ILL-Grenoble) and J. M. Dubois (Ecole des Mines, Nancy) for providing the T-phase sample.

[9] The annealing conditions used in [8] are close to ours. The annealing time is slightly longer in our case.