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MAGNETIC ORDERING IN AMORPHOUS (Fe$_{1-x}$Mn$_x$)$_{75}$P$_{15}$C$_{10}$ ALLOYS

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Amorphous alloys of the composition (Fe$_{1-x}$Mn$_x$)$_{75}$P$_{15}$C$_{10}$ are of considerable interest. Their magnetic properties show a transition from the ferromagnetic Fe$_{75}$P$_{15}$C$_{10}$ to the antiferromagnetic-like behaviour of Mn$_{75}$P$_{15}$C$_{10}$ [1,2]. Magnetization measurements on amorphous (Fe$_{1-x}$Mn$_x$)$_{75}$P$_{15}$C$_{10}$ have been reported in [1] for the whole concentration range from $x=0$ up to $x=1.0$. In this paper the alloys with Mn contents up to $x=0.3$, investigated here, are considered to be ferromagnetic. But a rapid decrease of average magnetic moment per (Fe,Mn) atom as well as of Curie temperature has been observed with increasing Mn concentration. Also a nonsaturating behaviour of magnetization has been found with field up to 0.85 T. Magnetization measurements on our sample with $x=0.3$ confirmed the strong dependence of the magnetization curve from the applied field [3,4]. These anomalous magnetic properties lead to the suggestion that the antiferromagnetic interactions introduced by Mn atoms cause deviations from a pure ferromagnetic structure also at low Mn concentrations up to $x=0.3$. The aim of this paper is to prove this assumption by Mössbauer experiments.

Amorphous samples with $x=0$, 0.1, 0.2, and 0.3 were prepared by rapid quenching from the melt using a fast rotating copper wheel.

Figure 1 shows Mössbauer spectra of all four samples at temperatures for which the temperature dependence of magnetization is in the saturation range (room temperature for $x=0$, 80 K for $x=0.1$ and 0.2, 8 K for $x=0.3$). The spectra show a decreasing magnetic splitting and increasing smearing out of the line structure with increasing Mn content.

From these spectra the distribution function $p(H)$ giving the probability to find an effective magnetic field of value $H$ on an iron nucleus were determined by the Window method [5]. With increasing Mn concentration these distribution functions become broader and shift toward lower $H$ values. The contribution of very low fields increases. In Table 1 the values $\bar{H} = \int H p(H) dH$ are given together with the magnetic saturation moments $\mu_S$ per
(Fe,Mn) atom determined in [1] for 0.85 T external field. The second lower value for \( x = 0.3 \) is the result of an interpolation in magnetization data of our sample to a field of 0.85 T.

Table 1: Magnetic moments and average magnetic hyperfine fields

<table>
<thead>
<tr>
<th>( x )</th>
<th>( H [\text{kOe}] )</th>
<th>( u_B / u_B )</th>
<th>( u_B / u_0 )</th>
<th>( \bar{H}/H_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>230</td>
<td>2.07</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>0.1</td>
<td>215</td>
<td>1.62</td>
<td>0.81</td>
<td>0.93</td>
</tr>
<tr>
<td>0.2</td>
<td>170</td>
<td>1.15</td>
<td>0.57</td>
<td>0.74</td>
</tr>
<tr>
<td>0.3</td>
<td>125</td>
<td>0.70</td>
<td>0.35</td>
<td>0.54</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(\( u_0 = u_B (x=0) \), \( H_0 = \bar{H}(x=0) \))

A comparison of \( u_B / u_0 \) with \( \bar{H}/H_0 \) shows a much steeper decrease of \( u_B / u_0 \) with increasing \( x \). This leads to the conclusion that the decrease of \( u_B \) is due to an increasing deviation from the ferromagnetic orientation of the magnetic moments instead of a decrease of the individual Fe and Mn moments.

The effective field at the nucleus in many alloy systems can be properly described by the empirical relation

\[
H = A/u_B + B/u_0
\]

A decrease of the individual moments \( u_B \) leads to a decrease of both parts of \( H \). In this case we expect about the same behaviour of \( u_B / u_0 \) and \( H/H_0 \). The observed weaker decrease of \( H/H_0 \) can be explained assuming a nearly constant \( u_B \) and a decrease of only \( u_0 \) by increasing disorder in the alignment of magnetic moments. Therefore we suppose that there are ferromagnetic-like regions in conjunction with parasitic antiferromagnetism also in the alloys with relatively low Mn content investigated here.

Figure 2 shows the temperature dependence of the magnetic splitting of the Mössbauer spectra for \( x = 0.3 \). These spectra consist only of one broad peak. Therefore the full width in half maximum of this peak (FWHM) is presented together with \( H \) as a measure of the magnetic splitting.

The magnetic splitting increases only very slowly up to about 60 K. This is in sharp contrast to the temperature dependence of magnetization measured in large external fields \([1,3,4]\) were at 80 K the saturation range is already approached. We explain this discrepancy by the assumption of superparamagnetic behaviour of large ferromagnetic clusters. The steep increase of \( H \) and FWHM at about 30 K may be connected with the magnetic ordering of the antiferromagnetic regions which are important for the magnetic coupling. This temperature behaviour confirms the assumed model of parasitic antiferromagnetism. The temperature dependence of magnetization measured at 100 Oe \([4]\) shows the same behaviour as for micromagnetic Fe\(_{70}\)Al\(_{30}\) alloys \([6]\) which gives a further confirmation of our model.

References: