Mössbauer study of spin-lattice relaxations of dilute Fe$^{3+}$ in MgO

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Outline

• Motivation / introduction

• Experimental details

• Results

• Discussion / conclusions
**$^{57}$Fe Mössbauer spectrum of $^{57}$Mn ion-implanted single crystal MgO**

![Mössbauer spectrum graph](image)

- **$^{57}$Mn (1.5 min)**
- **$^{57m}$Fe (98 ns)**
- **$^{57}$Fe (stable)**

Emission line: $14.4 \text{ keV}$

- $\beta^-$
- $\gamma$
Motivation

- Is the broadening consistent with Fe$^{3+}$ spin-lattice relaxations at elevated temperatures?

- Can the broadening be a measurement of the relaxation rate, $\tau^{-1}$?
  - Difficult to analyse, $B_{\text{ext}} = 0$ T
Decay of $^{57}$Mn (probe atom)

$^{57}$Mn (1.5 min) → $^{57m}$Fe (98 ns) → $^{57}$Fe (stable) via:

- $^\beta^-$ decay
- $^\gamma$ emission (14.4 keV)

10⁻⁴ at. % implanted dilute Fe.

Below spin-spin relaxation effects (~0.1 at. %).
Experimental setup

Incoming 60 keV $^{57}$Mn$^+$ beam
Intensity: $\sim 2 \times 10^8$ $^{57}$Mn$^+$/cm$^2$

Mössbauer drive with resonance detector

Implantation chamber

- On-line measurements
- High statistical spectrum
- Temperature range 77 – 700 K
Magnetic hf. splitting of $^{57}$Fe: Sextet

$^{57}\text{mFe}$
$I = 3/2$

$^{57}$Fe
$I = 1/2$

Source/sample: Mn/Fe implanted MgO

Case:
No external magnetic field. Ferromagnetic material.

For Fe$^{3+}$: $B_{hf} \sim 52$ T

Absorber/detector:
Single line resonance detector

Detector

$B_{hf} \neq 0, \quad V_z = 0$

Relative emission

Relative velocity
Magnetism in the Mössbauer spectrum

<table>
<thead>
<tr>
<th>Fe concentration</th>
<th>Magnetism</th>
<th>$B_e = 0$</th>
<th>$B_e \perp \gamma$</th>
<th>$B_e \parallel \gamma$</th>
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</thead>
<tbody>
<tr>
<td>High</td>
<td>Ferromagnetism</td>
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<td>$\uparrow \sim \uparrow$</td>
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<tr>
<td>Intermediate</td>
<td>Paramagnetism</td>
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<td>$\uparrow \sim \uparrow$</td>
<td>Fast spin-spin relaxations:</td>
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<tr>
<td>Low</td>
<td>Slow paramagnetism</td>
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<tr>
<td>$\uparrow \uparrow$</td>
<td>Spin-lattice relaxations:</td>
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</tbody>
</table>

$S_z = \pm 5/2, \pm 3/2, \pm 1/2$

Kramers split lines
**Case:**
No/low external magnetic field:

$$\rightarrow$$ Overlapping lines/"smearing":

The eigenstates are combined nuclear and electronic states.

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*Dilute Fe in a frozen sample.*

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**Case:**
Applied external magnetic field:

$$\rightarrow B_{\text{ext}} > \sim 0.3 \text{ T}$$

Kramers doublets $\propto |S_z|$ 

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**Case:**
No/low external magnetic field:

$$\rightarrow$$ Overlapping lines/"smearing”:
The eigenstates are combined nuclear and electronic states.
Paramagnetic sextet (spin-lattice relaxations)

\[ \tau^{-1} = 500 \text{ MHz (high)} \]

\[ \Delta l = \frac{E_0}{\tau^{-1}} \]

Total collapse of all spectral lines

Observed collapse of the relaxing sextet, due to change of the relaxation rate, \( \tau^{-1} \).
Results
Temperature ↑ : Broadening ↑
EPR (electron paramagnetic resonance) data:
Biasi and Portella, Magnetism and Magnetic Materials. 15, 737 (1980)

Sensitive region:
\( \tau^{-1} = 10 \text{ – } 100 \text{ MHz} \)
Sensitive region:
\( \tau^{-1} = 10 \text{ – } 100 \text{ MHz} \)

Temperature ↑  ⇒  Broadening ↑
ZnO

- This method (MB)
- Tribollet et al., 2008
Conclusions

- Observed slow spin-relaxation of Fe$^{3+}$ in MgO.
  - Negligible spin-spin relaxation ($<10^{-4}$ at. %).
  - Low Fe$^{3+}$ relaxation rates ($T < 200$ K).

- Broadening is consistent with Fe$^{3+}$ spin-lattice relaxation rates.
  - Comparable to EPR data.

- Possible to obtain relaxation rates without $B_{\text{ext}}$. 
Thank you for your attention