LOW TEMPERATURE MOSSBAUER THERMOMETRY

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The basis of a Mössbauer low temperature thermometer has been discussed by Kalvius et al. The temperature is determined from the relative intensities of the various hyperfine lines as these are affected by the temperature dependent Boltzmann populations of the hyperfine levels in the resonant nuclei. One can perform either source experiments or those that make use of the nuclear polarization in the absorber. The second method is more advisable because the radioactive heating is much smaller.

Among the various Mössbauer transitions suggested for the absorber thermometer the 21.6 keV transition in $^{151}$Eu has acceptable characteristics for the temperature range from 25 to 250 mK. The relative intensity of a particular transition in the absorber nuclei being proportional to the square of the Clebsch-Gordan coefficient is modified at low temperature by the Boltzmann factor $P(m_{g})$, where $m_{g}$ is the magnetic quantum number for the ground state of this particular transition. Therefore in order to be a favorable candidate for a low temperature absorber thermometer the total splitting of the ground state, $g_{n}I_{n}H_{n}$, must be comparable to the absorber temperature in energy. The Eu-transition in our example has a large nuclear magnetic moment of the ground state ($3.463 \mu_{n}$), and with a hyperfine field $H_{n}=330$ kOe in EuS at very low temperature the total ground state splitting is 84 mK. The sensitivity on temperature of the spectral pattern of the EuS absorber at low temperature is illustrated in the upper part of Fig. 1. The symmetry of the pure magnetic pattern in EuS which consists of 18 hyperfine lines is destroyed by the influence of the Boltzmann term $P(m_{g})$.

The present work is concerned with a fundamental difficulty in absorber thermometry which arises from the fact that the line intensity in a Mössbauer spectrum is also dependent on the
absorber thickness, the dependence on that is not a linear one. We demonstrate that if this thickness effect is not analyzed properly, the experimental results will yield erroneous temperature values, destroying the absolute nature of the Mössbauer thermometer.

In order to describe the thickness effect it is convenient to define the effective thickness for the individual transitions $T_A(m_g, m_e)$, i.e. from state $|m_g>$ to $|m_e>$, by the product of the effective absorber thickness $T_A = n_A \sigma f$, the square of the Clebsch-Gordan coefficient, and the Boltzman factor $P(m_g)$. The precise spectral shape in a Mössbauer transmission experiment is given by the so called transmission integral which cannot be solved analytically. There the term $T_A(m_g, m_e)$

![Graph](image1.png)

**Fig. 1**: Upper part: The magnetic hyperfine spectra of $^{151}$Eu in EuS at (a) 10, (b) 60, (c) 80, and (d) 4200 mK calculated in the "thin" approximation.

Lower part: The spectra for EuS at 50 mK and for absorber thickness $T_A$ equal (a) 1, (b) 4, and (c) 6.
is part of the exponential function, resulting in a saturation effect of the resonant absorption in a thick absorber and consequently modifying the whole spectrum in a complicated way.

In the lower part of Fig. 1 we have calculated the spectrum for EuS at 50 mK for various absorber thicknesses by solving the precise transmission integral numerically. Comparison in Fig. 1 demonstrates that increasing thickness would have nearly the same effect on the EuS spectra as increasing temperature.

In the analysis of Mössbauer transmission spectra the "sum of Lorentzians" or "thin" approximation is generally applied where one replaces the exponential term in the transmission integral by the first order expansion term; but that is only valid in the limit T_A → 0. Consequently in actual experiments the EuS absorber thermometer would predict an apparently higher temperature if the spectrum is analyzed using the "thin" approximation.

In order to obtain an estimation of the error we have computer fitted the curve simulated with the exact transmission integral by using the "thin" approximation. This procedure was repeated for various temperatures and thicknesses. This enabled us to produce the plot in Fig. 2 where we have shown the percentage error in the temperature deduced from the "sum of Lorentzians" analysis as a function of the absorber thickness T_A. The percentage increase is defined relative to the true temperature. We observe from Fig. 2 that the percentage error is large, but on the other hand the spread in the error for a given T_A value and for various values of the temperature from 25 to 250 mK is rather small.

This interesting result of the insensitivity of the error in temperature makes the curve rather useful. In spite of the larger error one is not constrained to do curve fitting with the exact transmission integral which is in any way expensive in computer time. For a uniform EuS absorber with known number of resonant nuclei per cm², n_A, the temperature can be determined applying the simple "thin" approximation analysis together with
our correction plot in Fig. 2 with an accuracy of better than ± 2%. Thus an absolute Mössbauer thermometer becomes more feasible.

![Temperature correction plot](image)

**Fig. 2:** General temperature correction plot useful for the temperature determination in $^{151}$Eu from the "thin" approximation.

References: