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THE THICKNESS DISTORTION OF $^{57}$Fe BACKSCATTER MöSSBAUER SPECTRA: II.
Effects of Secondary Resonant Absorptions

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Abstract

The result given in a previous paper [1] for the effect of thickness distortion on backscatter $^{57}$Fe Mössbauer spectra is extended to include resonant absorptions of re-emitted 14.41 keV $\gamma$-rays.

Our backscatter geometry consists of an incident $\gamma$-ray beam normal to the surface of a thick specimen, and the collection of all radiations re-emitted into the $2\pi$ steradians over the specimen surface. We retain the notation of the previous paper [1]. The contribution from re-emitted radiations originating at each depth, $t$, and traveling back each distance to the specimen surface, $z$, is a product of three important factors:

$$f_A n_A \sigma_A(E) \, dt,$$

which is the probability that a 14.41 keV $\gamma$-ray will be absorbed in the depth interval $dt$,

$$P_{\mu z} = e^{-[\mu_1 + f_A n_A \sigma_A(E)]z},$$

which is the probability that an incident $\gamma$-ray will have propagated to the depth, $t$, given x-ray and nuclear scatterings over this distance, and

$$P_{\mu z} = e^{-[\mu_1 + f_A n_A \sigma_A(E)]z},$$
for the probability that a re-emitted γ-ray will propagate to the surface of the specimen*. The observed 14.41 keV backscatter spectrum obtained from all isotropically emitting $^{57}$Fe nuclei is:

$$I(s) = \frac{1}{1 + \alpha} \frac{1}{2} \int_{0}^{\infty} \int_{E}^{\infty} S(E+\epsilon+s) P_{\mu_{14}n_{A}\sigma_{A}}(E) P_{\mu_{14}\sigma}(z) \frac{1}{z^{2}} dE \, dz \, dt \quad (4)$$

Included in eqn. 4 is an energy distribution, $S(E+\epsilon+s)$, of the incident γ-rays. The geometrical integrations can be performed (see formulae 3.3514 and 6.2282 of ref. [2]) to give:

$$I(s) = \frac{f}{2(1 + \alpha)} \int_{-\infty}^{\infty} S(E+\epsilon+s) \frac{f_{A}n_{A}\sigma_{A}(E)}{2[\mu_{14} + f_{A}n_{A}\sigma_{A}(E)]} \, dE$$

$$- \frac{f}{2(1 + \alpha)} \int_{-\infty}^{\infty} S(E+\epsilon+s) \frac{f_{A}n_{A}\sigma_{A}(E)[\mu_{14} + f_{A}n_{A}\sigma_{A}(E)]}{8[\mu_{14} + f_{A}n_{A}\sigma_{A}(E)]^{2}}$$

$$\times \left\{ \frac{\mu_{14} + f_{A}n_{A}\sigma_{A}(E)}{2[\mu_{14} + f_{A}n_{A}\sigma_{A}(E)]} \right\} dE \quad (5)$$

Eqn. 5 is very similar to eqn. 2 of ref. [1], but because of the inclusion of secondary resonant absorptions in eqn. 3, the hypergeometric function, $_{2}F_{1}$, now becomes:

$$_{2}F_{1}(1,2;3;\frac{1}{2}) = 8 \ln 2 - 4$$

The two integrals in eqn. 5 can now be added together to give our final result:

$$I(s) = \frac{f(1 - \ln 2)}{2(1 + \alpha)} \int_{-\infty}^{\infty} \frac{S(E+\epsilon+s) f_{A}n_{A}\sigma_{A}(E)}{\mu_{14} + f_{A}n_{A}\sigma_{A}(E)} \, dE \quad (6)$$

The symmetry of incident and re-emitted γ-ray propagation leads to this very simple expression for the effect of thickness distortion on backscatter 14.41 keV Mössbauer spectra that was missed in ref. [1]. This exact analytic result is more tractable than its analog for transmission geometry experiments [3]. If the energy distribution of the

* For 6.3 keV x-ray re-emission this factor will be: $P_{\mu_{6}}(z) = e^{-\mu_{6}z}$ and the similarity between eqns. 2 and 3 is lost.
incident γ-rays is deconvolved, \( \sigma_A(E) \) may be recovered by a trivial algebraic manipulation.

The thickness distortion for backscatter 6.3 keV Mössbauer spectra requires the full scheme of ref. [1], with the modification of the formulae: \( 2\mu \rightarrow \mu_6 + \mu_{14} \). Fig. 2 of ref. [1] is overcorrected for the effects of thickness distortion. This is clear from the ratio of intensities of peaks nos. 1 and 3, which is greater than its theoretically predicted value of 3.

With magnetically textured absorber materials (i.e. absorbers with non-random magnetic domains), not all re-emitted γ-ray trajectories along the cone with slant height, \( z \), will be subject to the same secondary resonant absorptions. In this case, eqn. 3 is an oversimplification, and eqn. 6 will be an approximation. The importance of this effect could be determined experimentally by comparing backscatter 14.41 keV γ-ray spectra with backscatter 6.3 keV x-ray spectra, for which there will be no resonant absorption of the backscattered radiation. Effects of magnetic texture on the primary resonant absorption will of course be the same for both 6.3 and 14.41 keV spectra.

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