Nuclear Resonance Fluorescence from the 58 keV Level in $^{159}$Tb

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Received October 21, 1977

The half-life of the 58 keV level of $^{159}$Tb was determined by classical resonance absorption using the centrifuge technique and by Mössbauer spectroscopy measuring the natural line width and found to be $\tau_{1/2} = (58 \pm 10) \, \text{ps}$. Mössbauer spectra for Tb and Tb$_2$O$_3$ absorbers and for Dy$_2$O$_3$ and GdFe$_2$ sources were investigated for temperatures between 9 and 385 K. Results for hyperfine interactions and Debye Waller factors are given. The Debye Waller factors are compared with predictions obtained from other experimental results.

1. Introduction

Two investigations on the Mössbauer effect of the 58 keV level in $^{159}$Tb have been reported [1, 2]. From the observed line widths the half-life of the 58 keV level was determined to be $\tau_{1/2} = (96^{+37}_{-21}) \, \text{ps}$ [1] and $\tau_{1/2} = (105 \pm 15) \, \text{ps}$ [2], respectively. These results are in agreement with the result of a life time measurement using the method of delayed coincidences yielding a value of $\tau_{1/2} = (130 \pm 40) \, \text{ps}$ [3]. However, the results disagree with the result of a further measurement in which Coulomb excitation of the 58 keV level was observed. Taking into account the M1/E2 mixing ratio deduced from conversion coefficients, a half-life of $\tau_{1/2} = 53 \, \text{ps}$ [4] was obtained.

Since the knowledge of the natural line width is of great importance for the interpretation of Mössbauer spectra, the first part of the present investigation was performed in order to remeasure the life time of the 58 keV level using two independent methods. In the first measurement, the classical resonance absorption of the 58 keV radiation in a terbium absorber was observed by applying the ultracentrifuge technique. In the second measurement the Mössbauer effect was studied in different absorbers and at different temperatures. Extrapolation to zero absorber thickness yielded a value for the natural line width.

In the second part the investigation of Mössbauer spectra for Dy$_2$O$_3$ and GdFe$_2$ sources as well as for terbium metal and Tb$_2$O$_3$ absorbers will be reported. With the natural line width determined in the first part, hyperfine splittings and Debye Waller factors can now be deduced from these data.

2. Experiments

The 58 keV level in $^{159}$Tb is populated in the electron capture decay of $^{159}$Dy ($\tau_{1/2} = 144 \, \text{d}$) and also in the $\beta^-$ decay of $^{159}$Gd ($\tau_{1/2} = 18 \, \text{h}$). Due to the strongly emitted 363 keV radiation and the rather short half life of $^{159}$Gd, $^{159}$Dy is more suitable as a source for the 58 keV radiation. Therefore, most of the measurements were performed with Dy$_2$O$_3$ sources. Strong $^{159}$Dy sources with negligible contaminations were obtained by irradiation of Dy$_2$O$_3$ enriched to 20% $^{158}$Dy with thermal neutrons in the reactor at Karlsruhe*. $^{159}$Gd served as a source only in the investigation of GdFe$_2$. For this measurement, GdFe$_2$ was irradiated for 24 h in the reactor**.

* We thank the KFA Karlsruhe for several irradiations
** We thank Dr. Wiesinger, Technische Universität Wien for the preparation of the GdFe$_2$ sample
The absorbers consisted of foils containing 13.3 mg/cm², 41.1 mg/cm², and 207 mg/cm² of terbium and of disks obtained by mixing Tb₂O₃ powder with epoxy and containing 5.4 mg/cm², 16.2 mg/cm², 26.9 mg/cm², 43.1 mg/cm², and 91.1 mg/cm² of terbium.

The 58 keV radiation was observed with a germanium detector. The energy resolution of about 600 eV was sufficient for a complete separation of the 58 keV line from the intense Kα and Kβ lines of terbium. To improve the intensity of the 58 keV line relative to the strongly emitted K-lines, the source was shielded by 0.5–1 mm copper foils. Using a pile up rejector it became possible to perform the measurements with total counting rates up to 25,000 cts/s. In Figure 1 the spectrum of the γ radiation after having passed the 207 mg/cm² absorber is shown. The 58 keV line is separated completely from the intense K-lines.

Figure 2 shows the experimental arrangement for the observation of the classical resonance fluorescence. Due to the large conversion of the 58 keV transition, the cross section for resonant absorption rather than for resonant scattering was determined in a transmission experiment as a function of the source velocity. An ultracentrifuge was used to accomplish the high source velocities. Four sources each containing about 10 mCi of ¹⁵⁹Dy were attached at the tips of the rotor.