Rheinische Friedrich-Wilhelms-Universität Bonn

Advanced Laboratory Course

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K221: Mößbauer Effect

Authors
Paarth Thakkar
Keito Watanabe

Tutor(s)
Dr. Jens Barth

Abstract

Contents

Chapter 1

Introduction

In this experiment, the phenomenon known as Mößbauer effect. is studied by means of transition spectroscopy. Using a ^{57}Co source, this effect is observed and the hyperfine structure of 14.4 keV transition in ^{57}Fe is measured.

From the Mößbauer spectrum of measured, we can see the isomeric shift and quadrupole and magnetic splitting of energy levels. Using this, one can determine the g-factor of the ground state and the first excited state can be determined.

Chapter 2

Theory

In the following section, we shall study the theoretical background of the Mößbauer effect in brief. A much more detailed discussion can be found in [1], mostly on which the following section is based.

2.1 Principles

Let's take two atoms. If one of the atom's nucleus emits a photon and goes from an excited to a ground state, one might assume that the other nucleus can absorb this photon because the excitation energy of both the nuclei is the same. But that is not the case, since energy is lost by the radiated photon because of the recoil of the nucleus, just like a gun recoils when a bullet is fired. In 1957, R. Mößbauer found that this energy reduction in the emitted photon can be reduced if the atom is part of the bigger crystalline structure. In such a situation, the recoil momentum is transferred to the crystal as a whole, which is much more massive than the atom itself and hence the recoil energy is negligible. The recoilless emission and absorption of γ-radiation by the nucleus of an atom is known as the Mößbauer effect [1]. This effect can be seen in Fig. 2.1.1.

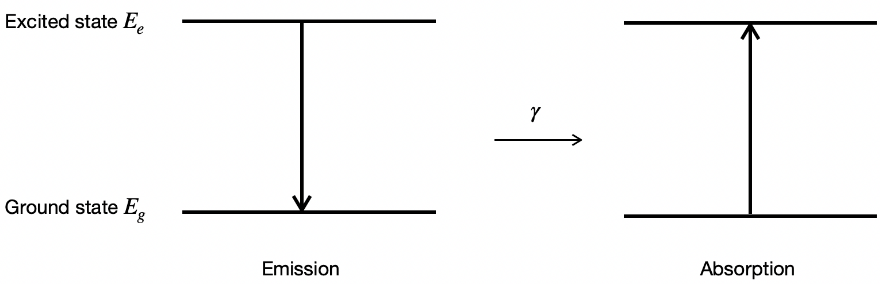


Figure 2.1.1: The recoilless emission and absorption of photon (Mößbauer effect).

2.1.1 Natural Linewidth

The uncertainty in energy in the case of recoilless emission is limited by its natural linewidth. From the Heisenberg's uncertainty principle, we know that

$$\Delta E \Delta t = \hbar, \tag{2.1.1}$$

where ΔE is the energy difference, Δt is the time difference and $\hbar$ is the reduced Planck's constant. In our case, if we have a nuclear level with a mean lifetime of τ_N, the energy uncertainty is given by

$$\Gamma = \hbar / \tau_N. \tag{2.1.2}$$

The frequency spectrum given by this emitted γ-ray is given by a Lorentz distribution,

$$I(\omega) = \frac{I_0}{1 + [2\hbar(\omega - \omega_0)/\Gamma]^2} \tag{2.1.3}$$

where $I(\omega)$ is the intensity of the radiation at frequency ω. The distribution (Fig. 2.1.2) is centered at ω_0 and has a halfwidth of $\Gamma/\hbar$. For ^{57}Fe used in this experiment, $\Gamma = 4.7 \times 10^{-9}$.

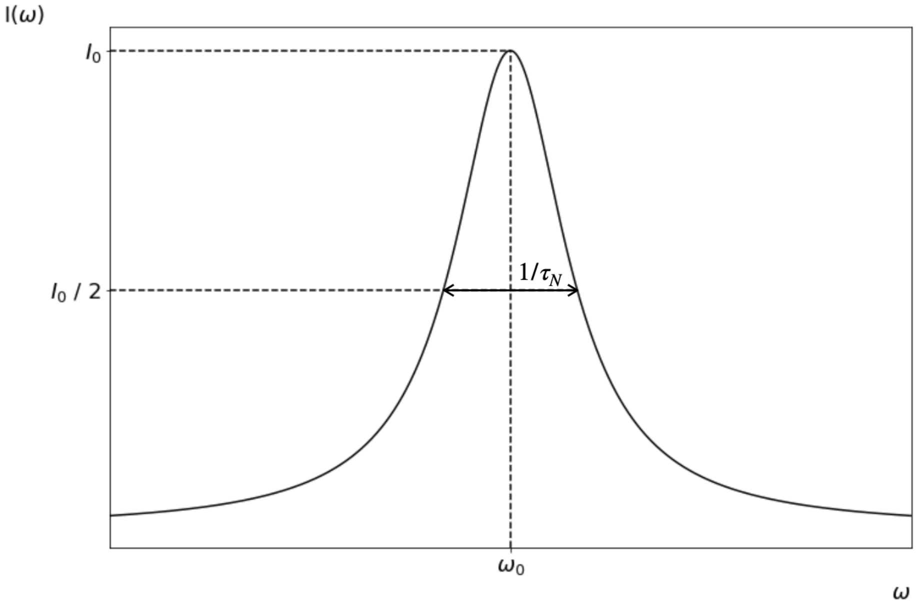


Figure 2.1.2: Intensity distribution of emitted γ-ray, centered at ω_0 with a halfwidth of $1/\tau_N$.

2.1.2 Recoil and Doppler Shift

As discussed in Section 2.1, the recoil of the nucleus when emitting a γ-ray leads to a reduced energy. This can be written as

$$E_{before} = E_e + \frac{p^2}{2M}, \tag{2.1.4}$$

where, p is the momentum and M is the mass of the nucleus. Energy after the emission can be written as

$$E_{after} = E_g + \frac{(p - \hbar k)^2}{2M}, \tag{2.1.5}$$

where $\hbar k$ is the momentum of the emitted γ-ray. The energy difference is

$$E_{before} - E_{after} \equiv \hbar\omega = \hbar\omega_0 + \hbar(k \cdot v) - \frac{\hbar^2 k^2}{2M}, \tag{2.1.6}$$

where the term $\hbar(k \cdot v)$ is the Doppler effect, which is responsible for shift and broadening of the spectra. At room temperature, the Doppler shift for ^{57}Fe is $\propto 10^{-2}$. The recoil energy $\hbar^2 k^2 \frac{}{2Mis} 2 \ \times 10^{-3}$ eV, both of which are orders of magnitude greater than the natural width. The absorption and emission frequency spectrum is shown in Fig. 2.1.3.

2.1.3 Debye-Waller Factor

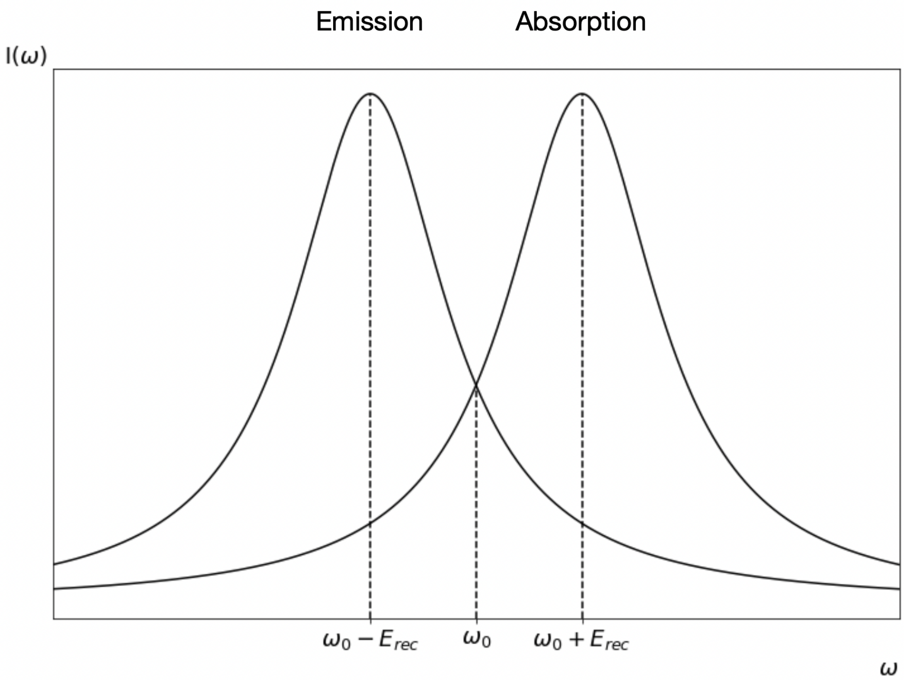


Figure 2.1.3: Emission and absorption spectrum of a monoatomic gas in thermal equilibrium. Both the spectra are shifted by the recoil energy and have been broadened due to Maxwell velocity distribution.

Chapter 3

Experimental Set-Up and Procedure

3.1 Experimental Set-Up

To measure the Moessbauer spectrum, we placed a Co-57 radioactive source onto a table with a moving absorber that has a maximum displacement of $25.1 \pm 0.2\,\mathrm{mm}$. A photodetector is placed behind the absorber that detects the number of photons that are not absorbed via this process. The speed of the absorber is controlled by a motor that uses the voltage as an input. See Fig. **??** for the Moessbauer source apparatus.

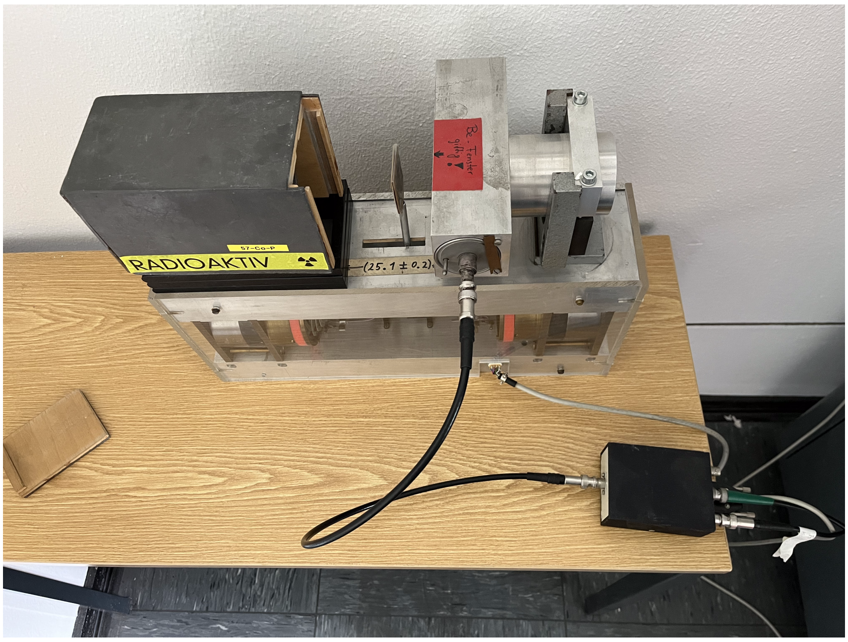
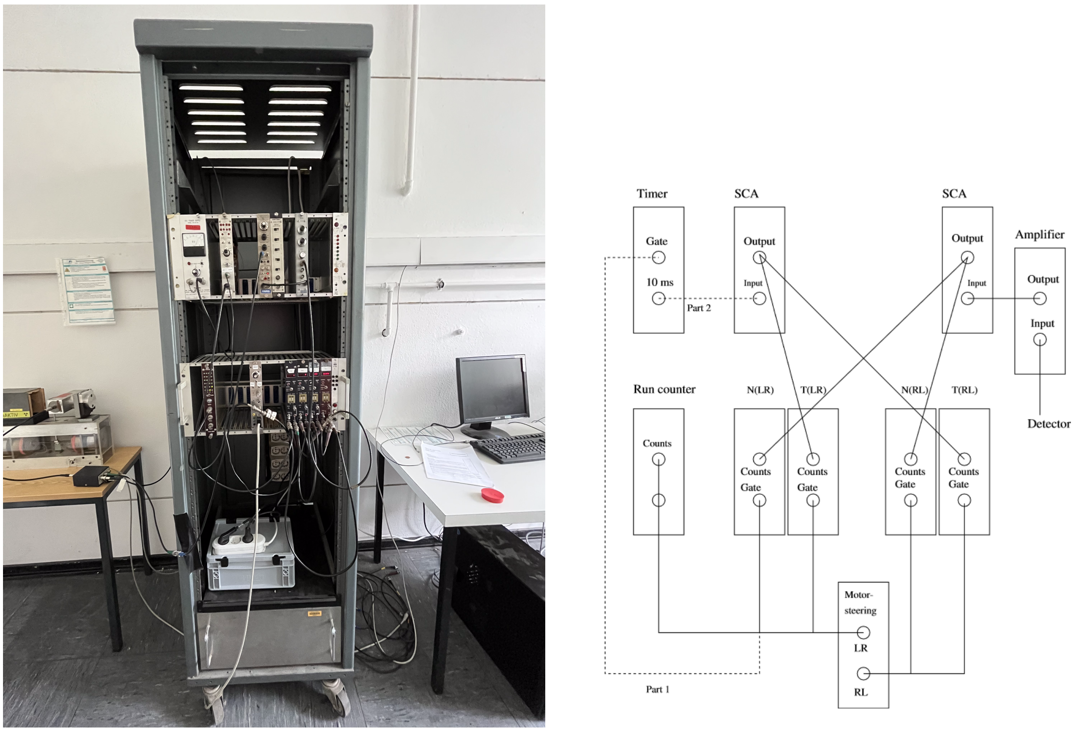


Figure 3.1.1: The set-up of the Moessbauer source. *Left*: The Co-57 source. *Middle*: The moving absorber. *Right*: The photodetector which is connected to the detector apparatus.

The photodetector is then connected to a single channel analyzer (SCA), which determines the number of counts detected in a given time range and maximal and minimal width to observe the counts. The SCA has 2 main parameters that should be modified: the Upper Level Discrimator (ULD) and the Lower Level Discrimator (LLD), which controls the binsize and the lower limit for photodetection respectively. The modes of the ULD can be set to measure with a higher resolution by detecting counts with 10 % of the binsize. The SCA was then connected to a display in which the number of counts obtained in a specific time interval was shown. The photodetecting apparatus consisted of two such setups to consider for measurements with positive and negative velocity of the absorber as the offset voltage between the two can allow the measurements in the LR and RL direction to differ. A separate run counter that tracks the number of turns that the absorber had is also contained in the apparatus. A timer that controls the time interval of measurement is also placed which is used for the calibration process. See Fig. 3.1.2 for the apparatus used for the photodetection as well as the schematic of the apparatus.



(a) (b)

Figure 3.1.2: (a) The photodetector apparatus used in this experiment. (b) The schematic of the apparatus. Obtained from Ref. [2].

3.2 Procedure

3.2.1 Calibration of SCA

Before we took any measurements, we determined the optimal values for the LLD in order to ensure that we are detecting counts from the 14.4 keV transition. In order to do so, we modified the LLD from 0 to 4 and determined the number of counts obtained at each value. The ULD and time interval was fixed to be 10 for all measurements. Once the data was obtained, we plotted the count rate N/T against the LLD values and compared our results to the Fe-57 γ-spectrum as seen in Fig. add reference here. Fig. **??** shows the obtained spectrum from our experiment.

We identified the 14.4 keV transition line as the third peak on Fig. .

Chapter 4

Results and Discussion

Chapter 5

Conclusion and Outlook

Chapter 6

Acknowledgements

We would like to take this moment and thank Dr. Barth, who was really helpful and patient with us. We were lucky to have him as our tutor. Next, we would like to thank...

Bibliography

[1] G. Schatz, G. Schatz, A. Weidinger, and J. Gardner, *Nuclear Condensed Matter Physics: Nuclear Methods and Applications*. Wiley, 1996, ISBN: 9780471954798. [Online]. Available: https://books.google.de/books?id=xMDvAAAAMAAJ.

[2] P. A. L. Course, *K221 mößbauer effect*, Jul. 2016.

Chapter 7

Appendix