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1. Theory & Preparation

1.1 Mössbauer effect

The process of **resonant absorption** in nuclear physics describes the phenomenon of subsequent de- and excitation of two equal atoms to the same energy levels via one γ-quant. Consider for example an excited state of ^{57}Fe, that emits a photon with energy (roughly) 14.4 keV during its transition to the ground state.

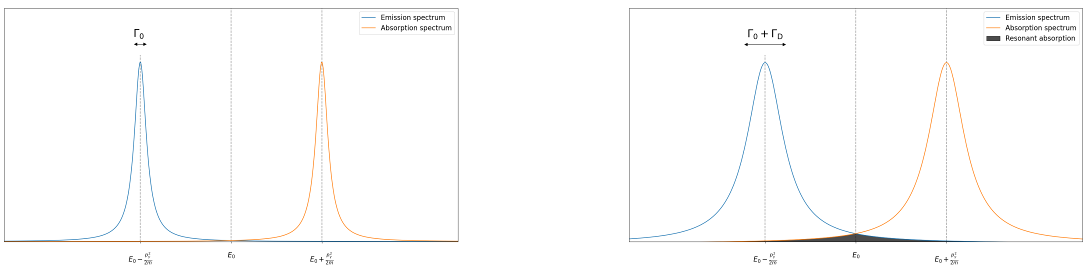
$$^{57}\mathrm{Fe}^* \longrightarrow {}^{57}\mathrm{Fe} + \gamma$$

In principle, one could use this emitted photon to excite another ^{57}Fe atom to the higher energy state. The photon is absorbed resonantly by the second atom during this process.

In reality, resonant absorption such as the Na-D-line only occurs under certain circumstances. Due to conservation laws the energy E_γ of the emitted photon does not exactly equal the transition energy E_0, but is instead shifted downward by the nuclear recoil energy. A similar analysis finds that the energy for absorption of the same atom is shifted upwards.

$$\underbrace{E_\gamma = E_0 - \frac{p_\gamma^2}{2m}}_{\text{Emission}} \qquad\qquad \underbrace{E_\gamma = E_0 + \frac{p_\gamma^2}{2m}}_{\text{Absorption}} \tag{1.1}$$

With the photon impulse p_γ and atom mass m. If the line width introduced by natural broadening or other effects does not exceed the energy gap, resonant absorption cannot occur (see **??**). It is also notable that the energy gap between emission and absorption spectrum can be increased by additional effects. This will be further discussed in **??**.



(a) Natural broadening **(b) Natural + Doppler broadening**

Figure 1.1: (a) The natural linewidth Γ_0 is not sufficient for a sizeable overlap of both spectra. Resonance absorption is not possible. **(b)** The line width of both spectra can be increase by other effects such as Doppler broadening. In such cases the spectra with linewidth $\Gamma_0 + \Gamma_\mathrm{D}$ can overlap and resonant absorption is possible.

As it turns out, the above rules stating when resonant absorption can and cannot occur are not strictly true. Experiments in the 1960s conducted by R. Mössbauer ([**?**]) showed that resonant absorption in a crystal lattice happens much more readily than one would expect based on the previous discussion. The difference is the tight binding of the atoms in the crystal lattice. Instead of the individual atom recoiling, different phonons can be created (or destroyed) by the emission and absorption. In a sense, the entire crystal absorbs the recoil energy, effectively substituting the atom mass m in equation **??** by the mass M of the entire crystal. Because $m \ll M$, the energy gap between emission and absorption spectrum drastically decreases. This phenomenon of recoilless nuclear resonant absorption is named **Mössbauer effect**.

1.2 Mössbauer spectroscopy

To measure the the natural linewidth of ^{57}Fe with roughly 5 neV common measurement methods will fail. Even with high-resolution interferometers, some orders of magnitude are still missing to resolve such lines by direct measurement of the spectrum. Therefore we take the Mössbauer effect into consideration. It is possible to measure the resonant absorption by the transition rate of the photons. The detector does not need to be energy sensitive, it is sufficient to detect the quanta in this case. The magnitude of the transition displays the overlap of the probabilities for emission and absorption (see **??**) of the natural lines. By varying the distance of the emission and absorption peaks we can make a statement about the line profile.

If the gamma radiation source is in motion a **Doppler shift** occurs and the photon energy changes. Therefor we can slightly modify the photon energy by changing the velocity of the source (see **??**).

$$\Delta E_\gamma = \pm \frac{v}{c} \cdot E \tag{1.2}$$

With the measured transmission spectrum as a function of the velocity of the source one can make qualitative as well as quantitative statements about the element. Furthermore it is possible to observe three types of nuclear interaction: isometric shift, quadrupole splitting and hyperfine magnetic splitting. The FWHM of the transmission curve corresponds to the double natural linewidth of the transition.

2. Experiment & Evaluation

2.1 Setup

The experiment consists of several components. A schematic setup can be seen in **??**. An interferometer monitors the velocity at which the Mössbauer driving unit (MVT) as well as γ-source are moving relative to the lab frame. A target can be placed in the beam path of the high-energy photons. The transmitted number of photons is then counted by a 512 channel multi-channel-scaler (MCS). The various other components of the setup (MDU, DFG, etc.) are used for calibration as well as data acquisition (DAQ) purposes.