Mossbauer Effect

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I. Abstract

This experiment studied the Mossbauer Effect in stainless steel using the 14.4 keV emission of Cobalt-57. The source was mounted on a linear drive motor (shown in Figure 1), which was used to control the source velocity. After plotting the number rate of gamma rays (observed by a proportional tube) versus the source velocity and fitting the data to a lorentzian, the width at half maximum was determined to be .133±.009mm/s. This corresponds to a $\Delta E/E$ value of $4.4(10^{-13})\pm0.3(10^{-13})$, which agrees with the known value of $4.5(10^{-13})$ [(1)].

II. Introduction

Consider a nucleus in an excited state α (call it nucleus A) that undergoes de-excitation to state β by the emission of a gamma ray with energy E_γ. By conservation of momentum, the nucleus must recoil with non-relativistic energy equal to $E_\gamma^2/(2mc^2)$. Thus the total energy released by the transition from α to β must be $E_\gamma + E_\gamma^2/(2mc^2)$. Now, consider another nucleus in state β (call it nucleus B). In order for it to absorb the gamma ray emitted by nucleus A, by conservation of momentum, the energy absorbed in the transition from β to α must be equal to $E_\gamma - E_\gamma^2/(2mc^2)$. Thus, only when $E_\gamma + E_\gamma^2/(2mc^2) = E_\gamma - E_\gamma^2/(2mc^2)$ does one nucleus absorb the emitted gamma ray of the other. In free nuclei, the energy associated with the recoil of a nucleus is significant enough that the probability of this absorption is unlikely. However, if both nuclei are embedded in a crystal lattice, the recoil is shared with the entire lattice. This makes the mass associated with the recoil energy (the m in $E_\gamma^2/(2mc^2)$) large, which in turn makes the energy associated with the recoil small and the probability of absorption more likely. This effect, observed in certain crystal lattices, is called is Mossbauer Effect.(2)

Suppose the lattice moves with a velocity v, towards the incoming gamma ray, so that the total momentum of the lattice-gamma ray system is zero. If the emission (or absorption) of the gamma ray is recoilless, then the gamma ray has energy E_γ in the system and energy $E_\gamma' = \frac{1+\beta}{\sqrt{1-\beta^2}}$ in the laboratory, where $\beta = v/c$. for small velocities, $\Delta E/E = v/c$, where $\Delta E = E_\gamma' - E_\gamma$. The value for v/c corresponding to the 14.4keV line is known to be $4.5(10^{-13})$ (1).

III. Apparatus

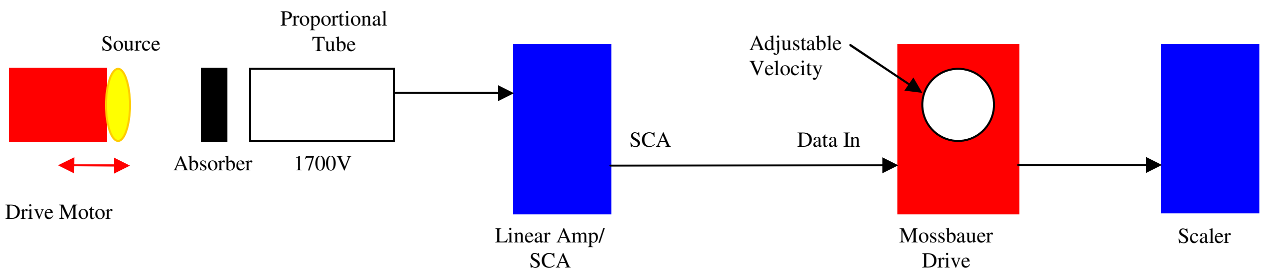

Figure 1: Experimental setup used to observe the Mossbauer Effect.

The experimental setup shown in Figure 1 was used. A Cobalt-57 source was mounted on a K-4 linear motor, which moved the source at a constant velocity. The velocity was controlled via the S-700A Mossbauer drive module. The low energy gamma rays emitted by the source were detected by a proportional tube filled with Kr gas. The output of the proportional tube was connected to a linear amplifier / single channel analyzer (SCA). The SCA used both a lower and upper level discriminator to create a gate.

IV. Procedure

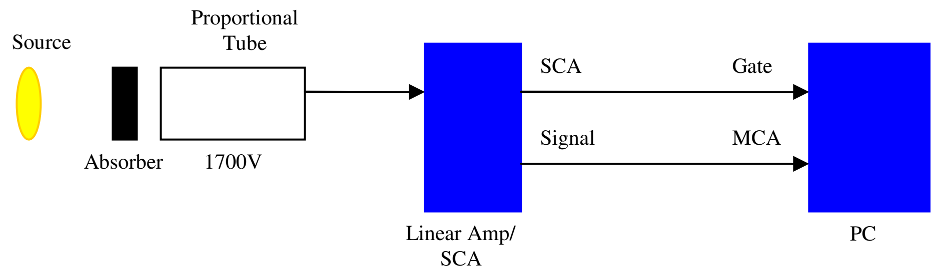

Figure 2: Setup used to determine and isolate the 14.4 keV line.

To observe the Mossbauer Effect in stainless steel using the 14.4 keV emission of the source, the 14.4 keV line was determined and then isolated with the discriminator of the SCA. The setup shown in Figure 2 was used. First the full spectrum (both discriminators of the SCA fully open) of the source without an absorber was observed and recorded via PC readout (see Figure 3). To determine which peak corresponded to the 14.4 keV line, a plexiglass absorber was used. It is known that the source emits gamma rays of 6 keV and 14.4 keV. The plexiglass attenuates the 6 keV peak. Thus, after observing and recording the spectrum with the plexiglass absorber in place (see Figure 3), it was determined that the peak directly after the attenuated peak (when compared to the spectrum without the plexiglass) was the 14.4 keV line. This peak was then isolated using the discriminators of the SCA.

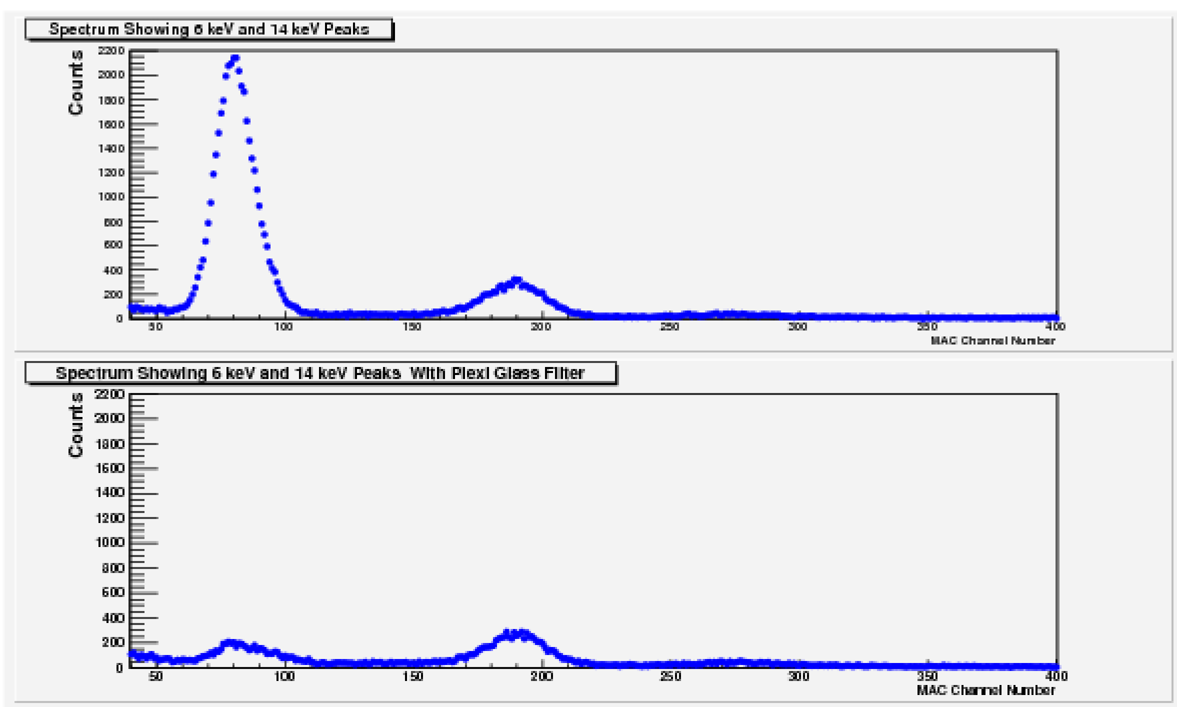

Figure 3: Spectrum used to find the 14.4 keV line. Recorded with and without plexiglass absorber.

The experimental setup shown in Figure 1 with a stainless steel absorber was used to observe the Mossbauer Effect. The number of gamma rays was recorded via the scaler for 240 seconds at various velocity settings on the drive motor.

V. Results

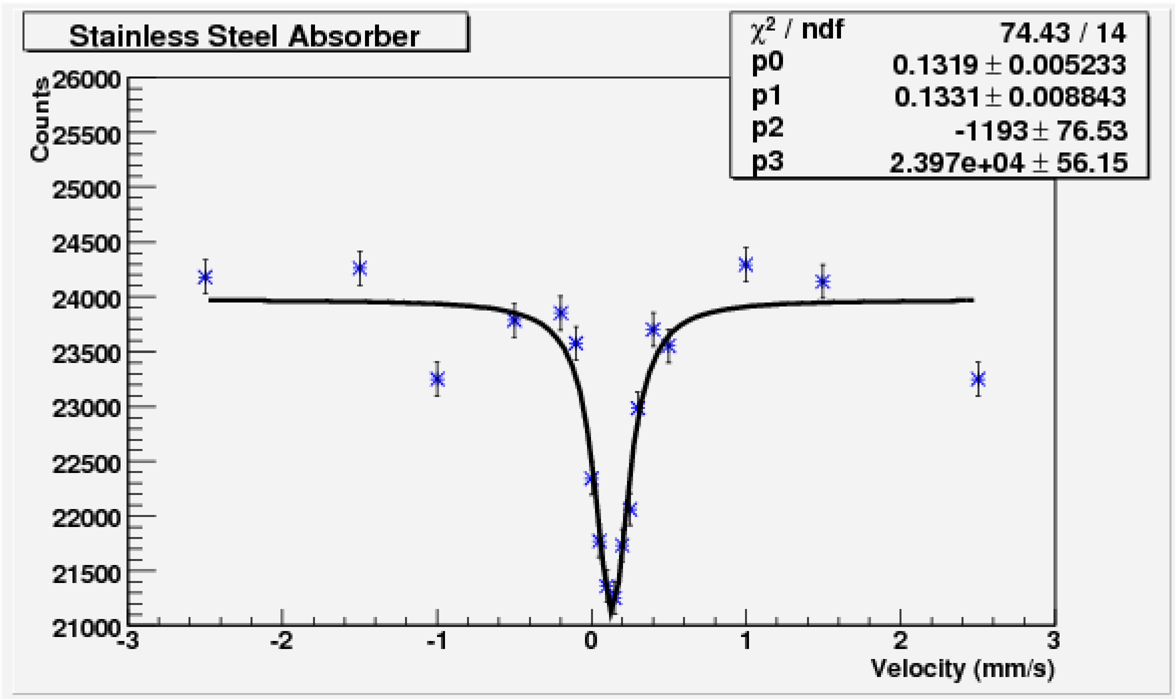

Figure 4: Mossbauer Effect in stainless steel fitted to a Lorentzian plus a constant background:

$$2.40\,(10^4) - 1.19\,(10^3)\frac{1}{\pi}\frac{.133}{(x-.131)^2+(.133)^2}$$

After fitting the data for the mossbauer effect in stainless steel (see Figure 4) to a Lorentzian, the width at half maximum was determined to be 0.133±0.009 mm/s. This is the value of v in the equation ΔE/E=v/c.

VI. Conclusion

Using the value v, determined to be 0.133±0.009mm/s, the value of ΔE/E=v/c was calculated to be $4.4(10^{-13})\pm0.3(10^{-13})$. This agrees with the known value of $4.5(10^{-13})$ [(1)].

VII. References

1. Melissinos, AdrianC. and Napolitano, Jim. *Experiments in Modern Physics, 2nd Edition*. Academic Press, 2003.

2. "Mossbauer Effect." *Wikipedia*. http://en.wikipedia.org/wiki/Mossbauer_effect.