

Mossbauer Experiment

Required reading: MIT experiment writeup

Leo, pages 127 – 141,

pages 277 – 302 and 353 – 357

Siegbahn pages 1293 – 1304 (need not understand details of Debye-Waller factor but should get general idea)
pages 24 – 51 (need not understand details but should know main ways in which gamma-rays are absorbed and how absorption varies with energy and atomic number)

Introduction

When a system decays to a lower state by the emission of electromagnetic radiation (i.e. gamma rays) the energy of the emitted gamma ray is usually given as the difference in energy between the two states (E_0). This is a very good approximation, certainly good enough for nuclear spectroscopy which rarely requires energies to be known to better than $\sim 10^{-4}$. However, this is only an approximation because:

1. The uncertainty principle mandates that a state which has a finite lifetime has an uncertainty in its energy determined by the relation $\Delta E \Delta t = \hbar$. For electromagnetically decaying nuclear states $\Delta E/E_0$ is at most about 10^{-6} .
2. If the emitting nucleus is moving with a velocity v the Doppler effect causes the gamma-ray energy to be shifted by $(v/c)E_0 \cos\theta$, where θ is the angle between the motion of the source and the direction of the gamma ray. For an atom at room temperature $v/c \sim 10^{-6}$.
3. When a gamma ray is emitted conservation of momentum requires the emitting nucleus to recoil with an energy $E^2/2mc^2$ reducing the gamma ray energy by $E_0(E_0/2mc^2)$. A typical value for $E_0/2mc^2$ is 10^{-5} though it can be much smaller or much larger than this.

In all practical cases the recoil energy is much larger than the width of the states. [The fraction of the energy lost to the recoil gets smaller as the gamma ray energy gets smaller but the longer the gamma ray energy, the longer the lifetime of the emitting state and therefore the narrower the state.] However, if the emitting nucleus is attached to a lattice and the whole lattice recoils, m becomes the mass of the lattice which is $\approx 10^{23}$ the mass of an individual nucleus

and the recoil energy becomes negligibly small even when compared to the width of the state.

Radiation is absorbed in the same way that it is emitted and therefore all of the above holds for absorbing radiation as well. In particular, a nucleus won't absorb radiation from an identical emitting nucleus unless both the emitting and the absorbing nucleus are attached to a lattice. This was first accomplished by R. Mossbauer and the effect bears his name.

The nucleus in which the Mossbauer effect has been most studied, though it is not where it was first observed, is ^{57}Fe . The first excited state of ^{57}Fe is at 14.4 keV and has a lifetime of about 10^{-7} sec, giving it a width of about $6.6 \cdot 10^{-9}$ ev. In contrast, a free ^{57}Fe nucleus could carry away about $2 \cdot 10^{-3}$ ev. The decay of ^{57}Co forms ^{57}Fe in a state at 136 keV which, in turn, decays to the 14.4 keV state – see diagram on page 3 of MIT writeup. The recoil energy is low enough so that a substantial fraction of the absorbing and emitting nuclei remain attached to the lattice (Debye-Waller factor) so that resonance absorption is readily observed. This is done by varying the energy of the emitted gamma ray by varying the velocity of the emitter and measuring the absorption as a function of velocity. The resonance is sharp enough so that very small energy differences can be observed such as those due to the interaction of the nucleus with the surrounding electromagnetic field. The most dramatic of these is the Zeeman splitting of the 14.4 keV transition into a six line absorption pattern in magnetic iron.

Apparatus

Gamma rays from a ^{57}Co source pass through an absorber and are detected by a proportional counter. The output of the proportional counter is amplified and a single channel analyzer selects out the 14.4 keV peak in the spectrum. The output of the single channel analyzer is fed into a multichannel analyzer operated in the time mode, i.e. counts as a function of time is what is measured.

A drive motor moves the source and is controlled so that the velocity is a linear function of time. The sweep of the multichannel analyzer is synchronized with the sweep of the drive motor. Therefore, the spectrum that is generated is counts as a function of source velocity and resonance absorption manifests itself as dips in the spectrum.

Procedure

1. With the drive motor off put up the ^{57}Co source.
2. With no absorber set the single channel analyzer (SCA) on the 14.4 keV peak.
3. Put the multichannel analyzer in "mcrs" mode and the (positive) output of the SCA into the output of the multichannel. Turn on drive and adjust motor so that the sawtooth is (almost) a straight line. (Note that the analyzer must be in "acquire" mode).
4. Run enriched ^{57}Fe absorber long enough to get good 6 line pattern – about 2 hours. Dump and plot spectrum and put plot in notebook.
5. Run the following absorbers (you need not do them in any particular order): Stainless steel, natural iron, $\text{Na}_4^{57}\text{Fe}(\text{CN})_6\cdot 10\text{H}_2\text{O}$, Ferrous Sulphate, Potassium Ferrocyanide, Sodium Nitro-Prusside, Ferric Oxide. The times needed to get a good spectrum will vary but none will take longer than 24 hours. At the end of each run check that the SCA window covers the 14.4 keV line (using the scope is sufficient) and also take (and dump) a spectrum with the enriched absorber. Make sure that you record your findings in the notebook. If either the SCA wasn't right or the ^{57}Fe absorber pattern shifted significantly the spectrum should be repeated.

Data analysis

Use the known energies of the outermost iron dips to calibrate the analyzer (see Mossbauer Data Index). Determine the position of the other iron lines and of the stainless steel absorption. If you ran other samples determine the position of the absorption lines. Determine the widths of the absorption resonances.

Results

Interpret your results in terms of the interaction of the ^{57}Fe nucleus with its surrounding electric and magnetic fields.