Mössbauer Spectroscopy – Daniel Queen – Physics 173 – June 14, 2001

This lab manual is designed to give a general overview of the theory of Mössbauer spectroscopy along with a description of the experimental setup and data reduction techniques.

Theory

The Mössbauer effect is the recoilless emission of a gamma ray from a nucleus in the excited state and the subsequent absorption by a similar nucleus in an absorber material. In the case of a free atom, when a decay occurs from the first excited nuclear state to the ground state a gamma ray will be emitted. However, energy and momentum must be conserved so the atom recoils. This recoil has the effect of producing a photon with lower energy than the initial transition. This photon is then unable to excite the same nuclear state in an identical atom. When an atom is in a crystal lattice only certain vibrational modes (phonons) are allowed. Here when the excited nucleus decays, if no phonons are excited then the emitted photon will be at the energy of the nuclear transition. This photon can then be absorbed by an identical nucleus provided it is also in a solid; otherwise, the atom would be able to recoil. This creates a very local probe that can be used to investigate the environment around the atom.

In a solid, the atom sits in a potential well that is created by neighboring atoms. To explore this well we can excite the atom and get it to oscillate with what is known as an optical phonon. To explore different atomic environments we need photons with a range of energies so that the nucleus can absorb the photon and excite optical phonons. To do this we Doppler shift the energies of the gamma rays by moving the source back and forth with an electromechanical servo. By looking at the absorption spectrum we see which energy gamma rays are missing and hence what the energy environment of the atom is.

Experiment: Setup

A spread in gamma ray energies is obtained by providing a time varying Doppler shift. Here we mount our source to a voice coil that is driven by a triangle wave when in flyback mode. Our source is ^{57}Co and it emits gamma rays at 14.4keV and 6keV. We keep only the 14.4keV gamma rays and filter out the 6keV component. A source velocity of 1 cm/s corresponds to a change in energy of $4.8 \_ 10^{-7}$ eV as given by:

$$\Delta E_S = (v_0 / c)E_\gamma \cos\theta$$

where _ is the angle between the observer and the source.

The experimental equipment consists of a spectrometer, Michaelson interferometer, timing circuitry, velocity transducer, radioactive source, and a PC. The Mössbauer spectrometer (S-600) provides control for the velocity transducer along with data collection and interface with the PC. Velocities can be set with the thumbwheel located on the front panel. The Spectrometer monitors each channel for 320_sec for 512 channels or 160_sec for 1024 channels. The data is then fed into the computer through the S-600 PC board. Channels 1-47 each record the total number of oscillator pulses N_{OS}

in one monitoring step of a channel. Channel 48 and starting with channel 63 every sixteenth channel record the number of counts received from the interferometer N_D. The remaining channels collect the Mössbauer spectrum. The S-601A timing board has a crystal oscillator with a 100kHz signal that controls the overall timing for the system. The signals available are 50kHz for velocity data collection and both 6Hz and 24Hz for the velocity motor control. The Michealson interferometer monitors the motion of the velocity transducer by counting the number of fringes that appear during a given time. This will later be used to extract the velocity. The interferometer is monitored by the S-603.

Experiment: Data Collection

When collecting data, the PC controls the choice and output of timing signal that the S-600 receives therefore it is important to always press F1 (Acquire) prior to pressing RUN on the spectrometer. The following procedure should be used for collecting a Mössbauer spectrum. A detailed description of calibrating the spectrometer is outlined in the Software Instruction Manual. Initially, RUN should be off on the spectrometer and Acquire should be off on the computer.

1.) Press Ctrl+F2 to clear the data from the screen.
2.) To acquire a spectrum you need to be in MCS mode.
    A. Press Alt-M to select the Mode menu
    B. Select MCS and press Enter
    C. Select Passes
    D. Enter 0 for infinity
    E. Select Dwell
    F. Select External. This will use the 320_sec dwell time supplied by the crystal oscillator.
    G. Press ESC to exit the menu
3.) We will now set the number of channels to use. The manufacturer recommends using 512 channels.
    A. Press ALT-S for the setup menu
    B. Select Memory Group
    C. Select Half
    D. Select Division 1
4.) We are now ready to acquire spectrum data
    A. Press F1: make sure Acquire is on
    B. Press the green RUN button on the S-600. You should now see data being collected.
    C. The scale can be adjusted by using the up and down cursor keys
5.) To stop the data acquisition do the following
    A. Press the green RUN button on the S-600
    B. Press F1 to turn the Acquire off
6.) The data can be saved to a disk from the File menu (Alt+F)

A. Save data as an ASCII text file

Data Reduction

The data can be curve fit in a program such as Origin that supports Lorentzian curves. In the ASCII text file there are three columns of data but the first two are of most interest to us. As stated above Channels 1-47 contain N_{OS}, the number of oscillator pulses during a single channel reading. Channel 48 and starting with channel 63 every sixteenth channel contains the fringe count N_D corresponding to a velocity measurement. Again, the remaining channels contain the Mössbauer spectrum. To extract the velocity we need to find the distance the drive piston covers in a given amount of time. For every _/2 of motion for the piston constructive interference occurs and the detector receives two pulses. We can calculate the distance from the following relation:

$$\text{distance} = \frac{1}{2} N_D \cdot \frac{\lambda}{2}$$

where _=6328.198Å is the wavelength of the He-Ne laser. We can give a similar expression for the time knowing the number of oscillator pulses and the pulse frequency, which for us is 50kHz.
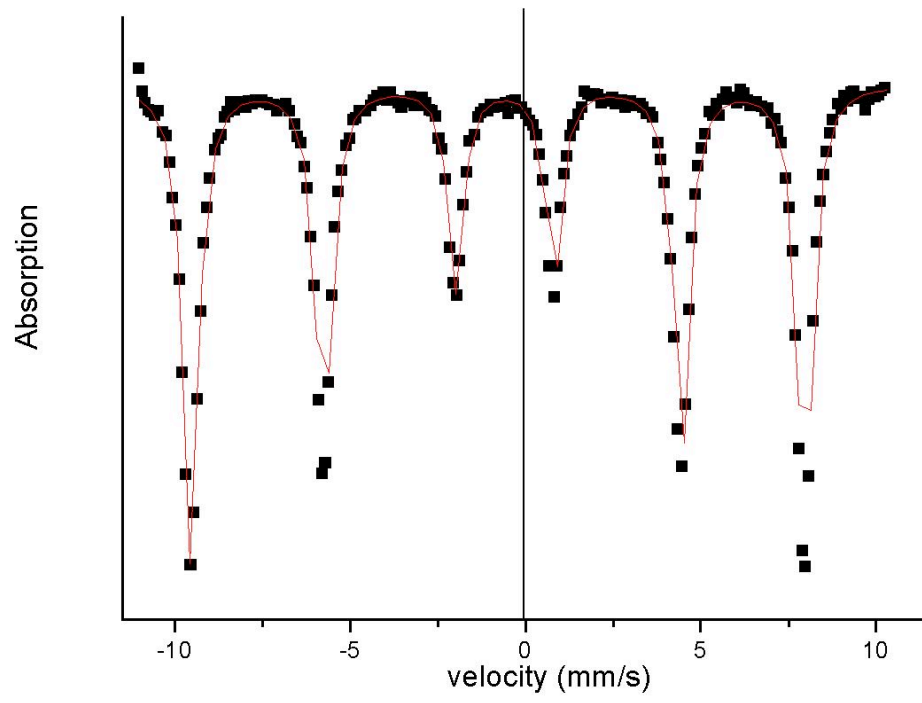
$$\text{time} = \frac{N_{OS}}{50 \text{kHz}}$$

Now, the velocity is just the ratio of the distance and the time. Taking the channel with minimum counts as the zero of velocity we can calibrate our curve. A plot of channel number vs. velocity will provide a conversion from channel number to velocity for use in our Mössbauer spectrum. A plot of counts vs. velocity of our Mössbauer spectrum allows us to fit the curve to get the full width at half maximum _ and the position of the peak center. These two parameters we can then use to extract information about the Isomer Shift, Quadrupole Splitting, and the Magnetic Hyperfine Structure. These effects I will leave for discussion in the references listed below.

References

Bancroft, G.M., *Mössbauer Spectroscopy*, Wiley, 1973.
May, L., *An Introduction to Mössbauer Spectroscopy*, Plenum Press, 1971.
Werthheim, G.K., *Mössbauer Effect*, Academic Press, 1964.

Fe Foil
0.0005"

Absorption

velocity (mm/s)

Stainless Steel Foil

Absorption

velocity (mm/s)