

The Mössbauer Effect

Introduction

The purpose of this experiment is to measure the effect of resonance absorption on the transmission of gamma rays through an absorber, calculate the lifetime of the 14.4 KeV gamma of Fe_{57} , and estimate the total scattering cross section for the gamma rays. You will measure the effects of nuclear hyperfine splitting (Zeeman Effect), quadrupole splitting, and electric monopole (isomer) shift in Fe_{57} by taking velocity spectra using Iron and Stainless Steel foil absorbers. Quantify the effect of absorber thickness in your analysis.

Before starting you should have a qualitative understanding of resonant absorption and scattering, and be familiar with the Briet-Wigner formula for the elastic scattering cross section. You should also understand the Co_{57} decay mechanism, and be familiar with the Optical Theorem.¹

Be sure to read pages 137-149, 181-279, 265-279, and 479-487 in Melissinos and be familiar with the papers contained in this folder. The scope of the discussion that follows is limited to use of the equipment only. Use the references to learn the relevant physics and data analysis techniques.

Understand the operation of the proportional counter and related electronics equipment. Study nuclear counting techniques and applications discussed in the LeCroy, Canberra, and Ortec equipment catalogs.

Be aware of the safety issues relating to High Voltage, and radioactive sources. Refer to the UCI Radiation Safety Manual.

Since the process of taking data is for the most part automatic once the equipment is set-up, be prepared to do some extensive data analysis in your lab report.

SYSTEM OVERVIEW

The Mossbauer analyzer is comprised of a number of individual instruments, each of which must be properly adjusted in order to successfully collect data. Here is the equipment list and a brief description of each device: (refer to diagram)

Radioactive Source - millicurie intensity Co_{57} diffused into a dense non-ferrous substrate e.g. Palladium, Platinum, etc.

Absorber – thin Iron or Stainless Steel foil mounted in a stationary holder, adjustable height.

Proportional Counter - similar to a Geiger counter, used to detect gamma rays. Generates charge pulses of a size proportional to the energy of the incident gamma rays - do not touch the beryllium window. Used with high voltage power supply set nominally to 1800 volts.

Pre-Amp - conditions the pulses from the proportional counter so that they (the pulses) can be applied to the input of the spectroscopy amp. Usually set to X10 gain.

Spectroscopy Amp - boosts the amplitude of the pulses as required for input to the pulse height analyzer. Also shapes the pulses to improve signal to noise ratio.

Multi-Channel Analyzer (MCA) - a board in the desktop computer that receives analog pulses from the proportional counter and spectroscopy amplifier. The MCA board contains a Pulse Height Analyzer (PHA) for producing a gamma energy histogram, a Single Channel Analyzer (SCA) with upper and lower discriminators that generates a logic pulse whenever an analog pulse falls within the energy window, and a Multi-Channel Scaler (MCS) that generates a histogram of counts versus time. Since the motor changes velocity linearly with time, the horizontal scale can be calibrated in units of velocity.

Pulse Height Analyzer (PHA) – a unit which produces an energy spectrum by quantifying the height of pulses from a particle detector, counting the number of pulses at each height, and recording each number in the bin or channel that corresponds to that pulse height. The Y axis of the resulting histogram represents number of counts, and the X axis is proportional to energy.

Discriminators – pulse height comparators on the MCA card with upper and lower threshold adjustments, used to select pulses with amplitudes either above or below the pre-set limits.

Single Channel Analyzer (SCA) , part of the MCA card, produces a logic pulse whenever the gamma energy falls within the energy window defined by the PHA discriminator thresholds.

Linear Motor - a specially built air bearing motor that translates the axial position of a shaft with a mount for a Co_{57} source. This Mossbauer drive motor is driven by a servo motor controller and a power amplifier. A linear positional sensor provides analog feedback to close the PID loop in the motor controller. A terminal program running on the desktop computer is used to communicate with the motor controller through the serial port. The motor is programmatically commanded to reciprocate in a triangular velocity profile. The motor controller also generates a pulse once each cycle in order to trigger a sweep of the Multi-Channel Scaler.

PROCEDURAL NOTES

Safety

There are a number of things you must know about the equipment in order to do the experiment successfully (without damaging the equipment or yourself). This experiment requires some handling of radioactive sources. The radioactive material is encapsulated to prevent leakage and allow for safe handling. Guidelines for safe handling: Do not damage the seals. Spend as little time as possible near the source. Shield the source with lead sheeting to reduce exposure. Use radiation monitor to measure the flux at your work station. Consult the UCI Radiation Safety Manual for safe limits. >500 hours at 1.5 meters may exceed UCI total exposure limit.

High voltage is required to bias the proportional counter. This voltage can be lethal. The high voltage cables and connectors are designed to be safe to use. However it is very important to turn off the high voltage supply before making any changes to the

connections. Do not exceed 1800 volts. The front window of the proportional counter is very thin and is easily punctured – DO NOT allow anything to touch the window. The linear motor must be treated carefully. Do not apply power to the motor without 40 pounds of air pressure for the air bearings.

PROCEDURE

Step 1. Calibrate the proportional counter, i.e. find the 14.4 KeV line, using the oscilloscope and pulse height analyzer adjust the Spectroscopy Amp and set the SCA window.

Step 2. Characterize the linear motor by moving a known number of steps, and measure the corresponding displacement in millimeters using the digital micrometer. Within the motor control program, set displacement and acceleration (default settings will work). Use the HP counter to measure the translation period, and calculate maximum velocity.

Step 3. Configure the Multi-Channel Scaler operating parameters; input signal, trigger source, bin width, pass length, SCA window, calibrate x-axis in mm/sec,

Step 4. Acquire transmission spectra over a couple of days. Repeat with different absorbers, e.g. iron, stainless steel, iron oxide, etc.

Apparatus Set-Up and Adjustment

Proportional Counter / Detector

Position the detector so that the center of the window is aligned with the axis of motion of the source, and so that the detector window lies completely within the shadow cast by the absorber. Line up the center of the absorber with the source, and make sure that it does not impede the motion of the source. Make sure all the components are well anchored to the table. Wobbles and vibrations will adversely affect velocity resolution. Be careful with the proportional counter. Do not touch the window as it is made of very thin poisonous metal, and contains a vacuum. The operating voltage range of the tube

is 1000-2000 volts. Do not exceed this range as that can destroy the detector. +1800 volts is recommended.

The height (in volts) of any given pulse from the proportional counter (and its position in a pulse height spectrum) is proportional to the energy of the particle and the gain of the proportional counter. The gain of the proportional counter is determined by 1. the high voltage bias, 2. the pre-amp gain, and 3. the spectroscopy amp gain. Vary these parameters in order to change the pulse height (and thus the energy sensitivity) of the proportional counter. Please note: Too much gain is worse than not enough gain. Set the gain of the spectroscopy amp to ~30, and set the time constant to 12 uSec. The SCA requires positive, unipolar signals. First observe pulses from the 'Pos' output of the spectroscopy amp on an oscilloscope, and try to identify the amplitude of the 14.4 KeV gamma pulses. 0 volts < 14.4 gamma < 10 volts is an absolute requirement. Be sure there is no periodicity to the pulses (oscillations).

While identifying the 14.4 KeV peak, it can be helpful to record a spectrum on the Quantum 8 pulse height analyzer. Use the partial shielding technique described in Melissinos, and compare the spectrum with another source such as Am₂₄₁ in order to help identify the 14.4 KeV peak. Use the Table of Nuclides to determine the gamma energies for any particular source.

Multi-Channel Scaler

Once you have identified the 14.4 KeV peak in the energy spectrum, connect a BNC cable from the 'Pos' output of the spectroscopy amp to the Single Channel Analyzer 'SCA In' connector on the MCS multi-plug cable. Connect the cable from 'Out 1' of the motor controller to 'Start In' on the multi-plug cable. Connect 'Chn Adv Out' to 'Chn Adv In' on the same cable. Refer to the MCS-32 manual for a description of the connectors and their functions.

From the desktop, launch the MCS-32 application software. Under the 'Acquire' menu, select 'Input Control', and then 'SCA Input'. Select 'Run SCA Sweep'. This will accumulate the same type of energy spectrum that you obtained with the Quantum 8. Locate the 14.4 KeV peak, and set the Upper and Lower discriminator thresholds such

that only channels within the peak continue to increment. This sets the 'window' for the SCA and insures that only 14.4 KeV gamma rays will be counted in your absorption spectrum.

Once you've set the SCA window, stop counting, and select the 'Acquire' menu again. Set the MCS 'Pass Control' parameters initially for 'Pass Length' of 2000 channels, and 'Bin Width' of 300 uS. To accumulate more quickly, you can set the bin width longer and use fewer channels, at the cost of resolution. Ultimately, you will adjust these parameters in accordance with the speed and period of the linear motor and for optimal resolution.

Mossbauer Drive / Linear Motor

A few important characteristics of the electro-mechanical driver must be determined. Motion of the motor is controlled using the terminal emulator program Hyper-Terminal. Launch Hyper-Terminal from the desktop, then load and run the file named "Mossbauer". This short program file has a sequential list of commands that produce reciprocating motion with constant +/-acceleration. The program also generates a synchronizing TTL pulse at the point of maximum velocity in the direction of the absorber. This pulse is used to start each MCS sweep (MCS sweep begins on a positive to negative transition). The MCS time sweep is in this way correlated with the linear velocity sweep of the Mossbauer drive motor.

Commands sent to the motor controller from Hyper-Terminal must be in all caps, so turn on 'Caps Lock'. Type 'LS' to list program, 'XQ' to execute (run) program, and 'HX' to halt motion. Variables 'AXCEL' and 'DISPL' can be changed in order to vary acceleration and displacement, respectively (e.g. type AXCEL=1024 or DISPL=2000 on the command line). Both of these variables affect the range of velocity of the motor.

Consult the motor controller manual for more info on commands and syntax.

The motor controller uses units of 'steps' for displacement. The drive displacement can be measured in metric units using the digital micrometer by commanding an absolute move in X number of steps, and reading the change in millimeters on the micrometer.

Making a simple move is a two line command, e.g. PAX 500 <enter> BGX <enter>. This

tells the controller to begin a move in X to an absolute position of 500 steps. The conversion factor can be assumed initially to be 200 steps per millimeter.

Measure the period T of motion using the 'Out 1' pulse from the motor controller and the HP 5302 counter. In the 'Period B' mode, the HP counter will measure the time between consecutive pulses from the motor controller. Remember to re-measure the period T whenever you change 'DISPL' or 'AXCEL'.

MCS sweep is triggered at absolute position zero where velocity is maximum. The source moves from step zero to maximum displacement (DISPL) in $T / 4$. In order to calibrate the X-axis of the MCS in velocity first calculate average velocity, $V_{av} = (\text{DISPL} / \text{steps per mm}) / (T / 4)$. Since we have a linear velocity profile, $V_{max} = 2 * V_{av}$. In the MCS-32 program under the 'Calculate' menu, select 'Calibrate'. Enter data pairs for $t=0$, $t= T/4$, and $t= T/2$ using velocities $v = V_{max}$, $v = 0$, and $v = -V_{max}$ respectively in the linear mode, and MCS-32 will interpolate values for the entire period T.

This manual includes examples of similar experiments taken from "The Art of Experimental Physics", the M.I.T. junior lab manual, and a variety of journal articles. Read these to gather an understanding of the physics, and to help you to form ideas on how to proceed with your experiment. Consider trying other absorbers, such as magnetic recording tape, or floppy disc media.

UCI Mössbauer Effect

