

MOSSBAUER SPECTROSCOPY

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I. INTRODUCTION

The Mossbauer Effect consists of the "recoilless" emission of gamma ray photons from certain radioactive nuclei, and the selective reabsorption of those photons by other nearby nuclei. The process is exquisitely sensitive to small differences between the structure of the emitting and the absorbing nuclei. Mossbauer spectroscopy is the science of using this phenomenon to explore the nuclear and atomic structure of materials. In this experiment you will explore three phenomena:

- (i) the shift in nuclear energy levels induced by the static charge of nearby atomic electrons (the "isomer shift").
- (ii) the energy level splitting in a nucleus due to the magnetic fields induced by the nearby atomic electrons ("nuclear Zeeman splitting").
- (iii) the shift in nuclear energy levels induced by a strong electric field gradient due to nearby electrons ("quadrupole splitting").

Different materials exhibit these effects to differing degrees. You will explore four different materials in this experiment.

II. BACKGROUND READING

The following references may provide useful background for the experiment and should be perused:

<u>Reference</u>	<u>Sections</u>	<u>Pages</u>	<u>Topics</u>
Melissinos ¹	9.3	385 - 399	Mossbauer experiment
	6.2, 6.3	218 - 232	Atomic Zeeman splitting
	6.4	236 - 238	Natural line width
	8.3.3	327 - 328	Proportional Counters
	App D.	485 - 488	Radiation safety
Wertheim ²			Mossbauer effect monograph
Krane ³		74, 362, 605, 645 ff	Introduction to theory

Melissinos describes the basics of recoilless emission and resonant absorption, while Wertheim discusses the theory of the Mossbauer effect in more detail. Krane's book has the information scattered about, but is easier to follow than Wertheim. Below we give a brief overview of the theory, though you will need to read the reference books for a more complete picture.

III. THEORY OVERVIEW

1. *The Mossbauer Effect*

The Mossbauer⁺ effect involves the resonant absorption of photons emitted by nuclei which undergo recoilless transitions. Because the line widths of these transitions are very small compared to their energies, the process of resonant absorption is highly sensitive to small changes in photon energies. The resolution of the Mossbauer effect is typically on the order of one part in 10^{12} making it a powerful tool in nuclear spectroscopy and condensed matter physics. From Mossbauer spectra it is possible to determine a number of nuclear and condensed matter properties. In this experiment the condensed matter properties to be determined are the isomer shift, the nuclear electric quadrupole interaction, and the magnetic level-splitting interaction in ferromagnetic materials. The nuclear properties are the spins of the ground and excited nuclear states and the ratio of their magnetic moments.

2. *Resonant Absorption*

When a photon is emitted in a transition between two energy levels, the frequency of the photon has a natural line width resulting from the finite lifetime of the excited state. If this photon is incident on a similar system in its ground state, there is some probability that it will be re-absorbed, raising that system to the excited state. This is what is meant by resonant absorption of photons.

In a transition, however, not all of the energy goes into the photon. Because momentum is conserved some of the energy is lost to recoil of the emitter. Likewise, when the photon is absorbed, the absorber will recoil. The distributions of the emission and absorption energies are therefore separated by twice the recoil energy. The probability of resonant absorption is proportional to the overlap of these distributions.

In the case of atomic transitions, recoil energies are small compared with natural line widths. For this reason, there is a high probability of resonant absorption in atomic transitions. In the case of nuclear transitions, however, photon energies are much higher and recoil energies are much larger than the natural line width. Therefore, there is little or no overlap of transition energy probabilities. As a result, resonant absorption is not very probable for nuclear transitions.

3. *Recoilless Emission*

When determining the recoil energy of a nucleus which is part of a solid, the interaction with the rest of the solid lattice structure must also be considered. By increasing the effective mass of the recoiling system, the recoil energy is decreased. The nucleus transmits energy to the lattice by exciting vibrational states through the creation of phonons. If no phonons are produced (quantum mechanics allows this), then all of the energy of the transition goes into the emitted photon. This is what is meant by recoilless emission.

+ Discovered by Rudolf Mössbauer in 1958. We will omit the umlaut in the name.

The fraction of zero-phonon emission, given by the Debye-Waller factor, is a function of the Debye characteristic temperature, the γ -ray energy and the temperatures of the emitter and absorber. Because vibrational excitation is a quantized process there is some (not small) probability that a given transition will transfer *no* energy to the lattice: *recoilless* emission.

4. Doppler Shift

When an emitter has a motion relative to the absorber, the energy of the photons is Doppler shifted. For non-relativistic velocities, $\Delta E = h\Delta\nu = \beta h\nu_0$ where $\beta = v/c$, and ν_0 is the frequency of the photon emitted from an atom at rest. This is the first-order Doppler shift and is valid for $v \ll c$. According to this relation, the change in photon energy is proportional to the relative velocity.

By varying the relative velocity of the emitter, it is possible to sweep photon energies over a range of values. In Mossbauer spectroscopy, absorption rate is measured as a function of source velocity. Using the Doppler formula we can convert velocity to energy shift. Analysis of observed absorption peaks reveals details about nuclear energy levels.

5. Observable Interactions

Since the energy levels of the nucleus are dependent on a number of external factors, it is possible to obtain information about the atomic and molecular structure of materials from their Mossbauer spectra. Depending on the nature of the interaction, there may be a resulting split or shift of nuclear energy levels. In this experiment the isomer shift, the magnetic splitting, and the electric quadrupole coupling can be observed. The next three sections give a descriptive overview of each, but a more complete understanding will require consulting the references given.

6. Isomer Shift

The energy levels of a nucleus are determined mostly by the strong interaction which binds the nucleons together. To a very slight degree, the overlap of the electronic wavefunction with the nucleus will also, via a Coulomb interaction, affect the levels of the states. In different materials containing a given type of nucleus, but with differing *electronic* properties, can therefore have small but measurably different *nuclear* energy levels. The so-called isomer shift involves a change in nuclear energy levels resulting from electron charge densities at the nucleus which differ for the emitting and absorbing materials.

Consider an idealized atom consisting of a "point" nucleus with a Coulomb field. Solving the Schrödinger equation gives a ground state energy and some atomic (electronic) wavefunctions, $\psi_e(r)$, but we don't care about the details. Now we ask, how does the ground state energy level change when we consider the nucleus as an extended object of radius R and uniform charge density? In first-order perturbation theory this is

done by letting the nuclear "perturbing Hamiltonian" , H' , act upon the unperturbed ground state electron wavefunction, ψ_e , according to:

$$\delta E_e = \langle \psi_e | H' | \psi_e \rangle \equiv \int \psi_e^*(r) H'(r) \psi_e(r) d^3r \quad (1)$$

This gives the first-order energy shift for the ground state energy, δE_e . Roughly speaking, we compute the energy of interaction between an extended Coulomb potential due to the nucleus with the electron cloud. The perturbing Hamiltonian is the difference between the point-like Coulomb potential that yielded the unperturbed wavefunctions, V_o , and the potential due to the nucleus modeled as a small uniformly-charged sphere, V .

$$H' = e(V - V_o) \quad (2)$$

where in MKS units

$$V_o = \frac{1}{4\pi\epsilon_0} \frac{Ze}{r} \quad (3)$$

and

$$V(r < R) = \frac{Ze}{4\pi\epsilon_0} \frac{1}{R} \left(\frac{3}{2} - \frac{1}{2} \left(\frac{r}{R} \right)^2 \right) \quad (4)$$

Exercise 1: Show that the preceding equation is true.

The Hamiltonian contains no derivatives, so it doesn't really do anything to the wavefunction when it operates. The wavefunction of the electrons, $\psi_e(r)$, is taken to be constant over the range of the tiny nucleus, and is therefore taken out of the integral and replaced with $|\psi_e(0)|^2$, the probability density of the electrons at the origin. Doing the integral leads to

$$\delta E_e = \frac{1}{10\epsilon_0} Ze^2 R_n^2 |\psi_e(0)|^2 \quad (5)$$

Exercise 2: Show that the preceding equation is true.

A subscript n has been added R to indicate that this is the radius of the n^{th} state of the nucleus. Thus we see that given a state, n , the so-called isomer shift depends upon the square of the "size" of the nucleus and upon the electron charge density at the location of the nucleus. R_n is not the same for all states. The shift of the energy levels for a given nuclear species depends upon the difference in electron densities between different materials. For a single material, the energy difference, ΔE , between a ground state (0) and an excited state (1) would be

$$\Delta E = \frac{1}{10\epsilon_0} Ze^2 |\psi_e(0)|^2 (R_1^2 - R_0^2) \quad (6)$$

We must realize that $|\psi_e(r)|^2$, or indeed, $|\psi_e(0)|^2$, depends not only on a single atom's electrons, but also on the electrons of nearby atoms in the lattice of the given material.

Now if the emitter of a gamma ray and the absorber of that same gamma ray in the Mossbauer measurement have different electronic charge densities at the position of the nucleus, then we get a small *shift* in the *difference* of the energy levels:

$$\Delta E_{isomer} = \Delta E_{absorb} - \Delta E_{source} = \frac{1}{10\epsilon_0} Ze^2 (R_1^2 - R_0^2) \left[|\psi_e^{absorb}(0)|^2 - |\psi_e^{source}(0)|^2 \right] \quad (7)$$

This is called the isomer shift, and it causes the centroid of the Mossbauer spectrum to be displaced from zero relative velocity between emitter and absorber. Depending on whether the excited state has a larger or a smaller radius than the ground state, the isomer shift will be either positive or negative.

7. Magnetic Level-Splitting (Nuclear Zeeman Effect)

Whenever a system with a magnetic dipole moment vector, μ , is placed in a magnetic field H there is a torque which tries to align the moment with the field. There is an energy associated with the degree of alignment that goes as

$$E_M = -\vec{\mu} \cdot \vec{H} \quad (8)$$

In quantum mechanics we have objects with both angular momentum, L , and finite magnetic moments; the vectors must point along the same direction since a given spinning object can have only one meaningful symmetry axis, on the average. However, quantum mechanics shows that the projection of L along some external direction, such as the H direction, can have only a fixed number of projections given by $(2L+1)$, with a magnetic quantum number m_L which specifies which state the system is in. Thus, when the quantum system tries to align itself with the magnetic field, it can only achieve this specific set of states, with a set of discrete energies to match.

The magnetic moment of an atomic (electronic) or nuclear system is measured in units of "magnetons", where one magneton is the magnetic moment of a unit of charge when it has one unit of angular momentum. The value of the magneton is

$$\mu = \frac{e\hbar}{2m}, \quad (9)$$

Exercise 3: Starting from the simple case of a massive charge in a circular orbit, show why this equation provides the most "natural" definition of a unit of magnetic moment.

where the mass is the electron mass for atomic (electron) systems (μ_B is the "Bohr magneton"), or in nuclear systems the proton mass (μ_N is the "nuclear magneton"). It has units of Joules (or MeV) per Tesla in the MKS system.

Any real system, however, can have a structure that makes its actual magnetic moment different than a single unit of either Bohr or nuclear magneton. The structural information is captured in the form of a unitless "g-factor" which can be calculated, in principle, for each given situation. In nuclear physics, total angular momentum (orbital plus intrinsic spin of nucleons) is traditionally designated by the letter I , to distinguish it from the total angular momentum J of the electronic wavefunction. Thus we have the interaction energy for a quantized nuclear system in the form:

$$E_M = -\vec{\mu} \cdot \vec{H} = -g\mu_N H m_I \quad (10)$$

This energy is a "perturbation" on the energy of the system in the presence of the magnetic field, H . Given the index of the state m_I , we can calculate the corresponding energy shift E_M . Transitions can then occur between these sub-levels. The magnetic field can result from the atom's own electrons or in interaction with other atoms in the solid, and is called the internal field. The structure of the spectrum depends largely on the magnetic nature of the material, whether it is dia-, para-, ferro- or antiferro-magnetic. Consult Melissinos, Chapter 6, for more information on how the Zeeman Effect allows us to examine the transitions between these split energy levels. The chapter is written for atomic (electronic) systems, but the same physics applies at the nuclear level. The Mossbauer Effect allows one to "sweep" across absorber nuclei with a range of well-defined gamma ray energies to map out the spectrum of line-splittings in the absorber.

For some materials used in this experiment a magnetic field is present at the Fe^{57} nucleus, so the $I=1/2$ ground state is split into two levels, while the $I=3/2$ excited state is split into 4 levels. With the electric dipole selection rule that m_I should change by 0 or ± 1 in the absorption process, there are a total of six possible "lines" corresponding to six different transitions.

Exercise 4: Make a drawing of energy levels to show how this makes sense.

The source you will be using was prepared such that the gamma rays are *not* themselves split into several energies. Thus, you will be sweeping a single Doppler-shifted energy across the split energy levels of the absorbing nuclei.

8. Electric Quadrupole Splitting

The charge or current distribution of a nucleus need not be spherically symmetric. As discussed above there may be a net magnetic dipole moment, for example. There can also be a net electric quadrupole moment, Q , which means that the distribution of electric charge is either prolate ($Q > 0$, "cigar-shaped") or oblate ($Q < 0$, "flattened"). The mean position of the charge remains at the origin, but it is deformed. In atomic or nuclear systems such permanent deformations are caused by tensor forces. The direction of a quadrupole moment is along the angular momentum vector, which must have one unit of \hbar or greater. It is easy to show (ask your instructor) that an electric quadrupole moment tries to align itself in the direction of the *gradient* of an external electric field (not the field itself). In a given material there can be an electric field gradient (EFG) due to the atomic electrons, the overall structure of the material, or both. As in the case of the magnetic splitting there is a perturbation energy associated with this interaction which shifts the energy levels of some nuclear states. Roughly speaking, its magnitude is the quadrupole moment of the nucleus "times" the electric field gradient. But since the electric field is a vector quantity, its gradient is a 3-by-3 matrix of components with each of three field components acted upon by the gradient operator in each of three directions. Similarly, the quadrupole moment of the nucleus is in general a nine component tensor object. Fortunately, many systems have spatial symmetries which make many components vanish.

The quadrupole moment, Q , for a nuclear electric charge distribution $\rho(r)$ is given by³

$$eQ = \int \rho(r) r^2 (3 \cos^2 \theta - 1) d^3r \quad (11)$$

where the polar angle is with respect to the nuclear spin direction. One sees from this equation that Q has units of area, and in fact tabulated values for Q are in units of *barns*, where 1 barn = 10^{-24} cm² (See the *Table of Isotopes*⁴ for the value of Q for the excited state of Fe⁵⁷). We do not need to do this integral: we will just look up the values for states of interest to us. For systems with suitable cylindrical symmetry the interaction energy, E_Q , is given by³

$$E_Q = \frac{1}{4} eQ' \left(\frac{3}{2} \cos^2 \theta - \frac{1}{2} \right) \left(\frac{\partial^2 V_{ext}}{\partial z^2} \right)_{z=0} \quad (12)$$

where this time the angle is between the symmetry axis of the external electric field and the symmetry axis of the nuclear spin, and Q' is the quadrupole moment recomputed along the z axis. In this equation V_{ext} is the electric *potential*, the gradient of which is the electric field, and the second derivative of which is the electric field gradient. The derivative factor $\left(\frac{\partial^2 V_{ext}}{\partial z^2} \right)_{z=0}$ is sometimes written as " q ", not to be confused with Q , the quadrupole moment of the nucleus, or q which sometimes represents the charge of the nucleus.

In quantum mechanics the spin may only take certain discrete directions with respect to the electric field, and the proper calculation³ then leads to the equation we can actually use in this experiment:

$$E_Q = eQ \frac{3m_l^2 - I(I+1)}{4I(2I-1)} \left(\frac{\partial^2 V_{ext}}{\partial z^2} \right)_{z=0} \quad (13)$$

The ground state of Fe^{57} has angular momentum $I = 1/2$, and thus has a vanishing quadrupole energy shift. The excited state has $I = 3/2$, however, and so will have four states with quantum number m_l that take the values $-3/2$, $-1/2$, $+1/2$, and $+3/2$. From the equation you can see that the four states will split into only two different energies.

*Exercise 5: Compute the numerical factor in this equation for the $I=3/2$ states. What is the energy **difference** between the two levels?*

Where might the electric field gradient necessary to have this effect come from? If the arrangement of electric charge external to the iron nucleus is such that there is an axis along which the electric field changes. In this experiment, you will use sodium nitroprusside, also known as sodium nitroferricyanide, and often abbreviated “SNP” by Mossbauer spectroscopists. Figure 1 illustrates the arrangement of atoms in this molecule, and it is quite plausible that the asymmetric arrangement of nitrogen, carbon, and oxygen atoms on either side of the iron atom could lead to an electric field gradient.

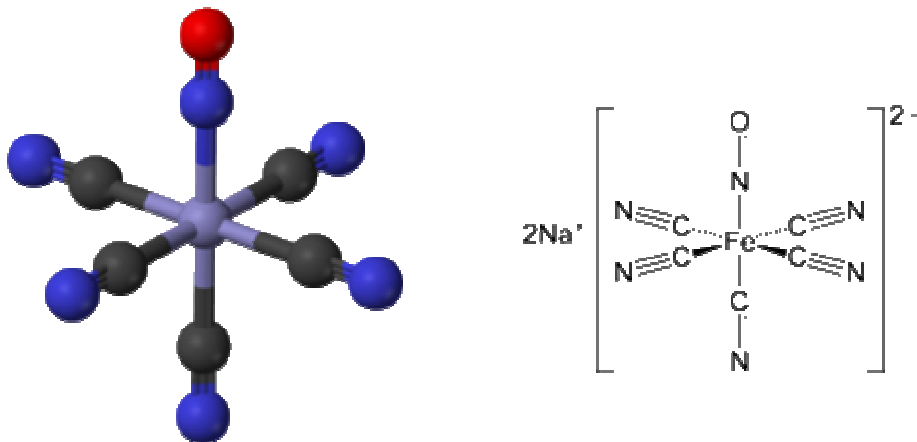


Figure 1: Two representations of the molecular structure of Sodium Nitroprusside or “SNP”. (image source: Wikipedia)

Exercise 6: Look up this material in a suitable reference source. What is its main claim to usefulness?

IV. EXPERIMENTAL APPARATUS

This section will describe briefly the apparatus which is used in this experiment. Data are gathered using a constant-acceleration, transmission-geometry Mossbauer spectrometer and are stored in a small computer transfer via diskette to an analysis program such as Excel.

The γ -ray source is attached to a vibrating mechanism driven so as to cause a triangular velocity waveform. That is, the velocities are swept through a specified range, increasing and then decreasing linearly with time. The velocity range is selected with a dial control, with maximum velocity up to 20 mm/s. The γ -rays which pass through the sample are detected by a proportional counter. Signals from the counter pass through a pre-amp and a linear amplifier before reaching a single-channel analyzer (SCA), which generates a pulse if the signal falls within a selected range. The output from the SCA is fed into the computer which sorts the event. The computer accumulates data in 512 data bins, each corresponding to a specific source velocity. Phase is maintained between the computer and driving electronics so as to produce one pass through all bins for each velocity cycle. This produces a spectrum with *two* zero-velocity positions, with the maximum speed at the end bins, and zero velocity at the center. (The average velocity must be zero, of course). On the screen of the computer the two halves of the spectrum are folded together and binned rather coarsely, but the data you will get in your data files has the full 512 channel resolution.

The source used in this experiment is Co^{57} which decays with a half-life of 270 days to the 136.4 keV excited state of Fe^{57} by electron capture. See Figure 9.13 in Melissinos for details. Gamma-ray transitions then occur very quickly to the 14.37 keV state and directly to the ground state. The emission of the 14.37 keV γ -ray has a significant recoilless fraction, and is the one used in this experiment. The emitted photon energies are unsplit, *i.e.* they have only one precise energy. This is because this source was prepared by ion implantation of the cobalt into a copper substrate, in which none of the perturbing interactions are present. The ground state of the Fe^{57} has spin 1/2, and the excited state has spin 3/2.

The samples used for absorbers are stainless steel (which exhibits only the isomer effect), soft iron (which shows only the Zeeman splitting), sodium nitroprusside “SNP” ($\text{Na}_2\text{Fe}(\text{CN})_5\text{NO} \cdot 2\text{H}_2\text{O}$) (which shows the quadrupole splitting), and hematite ($\alpha\text{-Fe}_2\text{O}_3$) (which shows all the effects). Note that hematite is a very common mineral oxide of iron and is one of form of iron ore. Each absorber contains the naturally-occurring abundance of the Fe^{57} isotope of iron, which is about 2%.

The details of running the software and the computer are given in Appendix A.

V. EXPERIMENTAL PROCEDURE

The following general results are to be obtained for this experiment:

1. Determine the linewidth of the source (in mm/s), and the relative source-absorber isomer shift, using a stainless steel absorber.
2. Determine the energy spacing of the nuclear Zeeman effect using the pure iron absorber, and the iron vs. stainless steel isomer shift. Obtain values for the isomer shift, the strength of the magnetic field strength at the nucleus, the g-factor ratio.
3. Determine the quadrupole splitting of the sodium nitroprusside "SNP" absorber and its isomer shift relative to stainless steel. Get a value for the electric field gradient at the nucleus.
4. The magnetic and quadrupole splittings of the hematite absorber and the isomer shift relative to stainless steel. All effects are present. See if you can detect the presence of both magnetic and electric quadrupole splittings. The latter causes the $m=3/2$ states to move up slightly, and the $m=1/2$ states to move down slightly in energy. This gets reflected in the position of the peaks.

More detailed steps to get the results:

- 1) Look at the pulse-height spectrum from the proportional counter on the oscilloscope. Observe how the dominant pulse-heights change depending on the absorber present in the path of the gamma rays.
- 2) Change the "E" setting on the single-channel analyzer in small steps and measure the count rate as a function of "E". This will trace out the pulse height spectrum of the gamma rays seen by the pulse-height analyzer. After obtaining this curve, decide on wise value to use for E and for ΔE at which to run the experiment.
- 3) Velocity calibration. We will *assume* that the velocity calibration of the system is as given in this write-up. Where does this calibration come from? From the measurement we are about to do! Thus, in this experiment we will be using the result of earlier runs of this experiment to give us the needed calibration. There is no independent way to do it with the equipment we have. The velocity calibration is given in Appendix B.
- 4) Stainless steel absorber. The structure of this metal does not result in either the quadrupole or the magnetic Zeeman splitting of the Mossbauer line. It will only result in an isomer shift: the shift in energy level of the Fe^{57} 14.4 keV line due to the atomic electrons in stainless steel versus the atomic electrons in copper (recall that our source is Fe^{57} ion-implanted into a copper substrate. Measure the isomer shift in mm/sec. Convert the result into an energy difference.

5) Soft iron absorber. This material has a strong magnetic field at the location of the nucleus, and this induces a level-shifting of the different magnetic substates involved in the Mossbauer absorption process. It is like the atomic Zeeman effect, but at the nuclear level. Measure the absorption spectrum for soft iron. There should be six lines corresponding to the six possible transitions. Use the data to obtain values for the magnetic field strength at the nucleus using g -factors looked up in a handbook⁴, the measured ratio of the g -factors of the excited state and the ground state, and the value of the isomer shift in soft iron compared to copper. These three numbers are algebraically over-determined by the six numbers you have measured. Devise a way to make best use of your data to extract these numbers.

Exercise 7: If you have or are taking the Nuclear and Particle physics course, use the single-particle shell model to estimate the g -factors for the ground and excited states.

6) Sodium nitroprusside “SNP” absorber. This material has electronic structure which induces a strong electric field gradient at the nucleus. This field gradient is "felt" by the quadrupole moment of the nucleus. Obtain data for the absorption on this material. The splitting is proportional to the product of Q , the quadrupole moment of the nucleus and the electric field gradient. Look up⁴ the value for the quadrupole moment and obtain a value for the electric field gradient.

7) Hematite absorber. This material exhibits all three effects discussed previously. The excited state magnetic levels are modified by the quadrupole interaction: The $m = \pm 3/2$ levels shift up in energy and the $m = \pm 1/2$ levels move down in energy. Measure the absorption spectrum on hematite and compare to the others you have measured. Get new values for all of the parameters studied separately above: H at the nucleus, q , and the isomer shift with respect to copper.

Even more detailed instructions for running the equipment:

1) *Set up.* The set-up consists of three main procedures, namely connecting the pieces of the experiment, powering up, and setting the single channel analyzer.

a) Connections (Usually already made)

1. Connect the OUT connector from the PC to the connector labeled J1 on the back of the driving electronics.
2. Connect the outlets labeled J2 and J3 to the vibrator with the appropriate connectors.
3. Connect the proportional counter to the pre-amp input.
4. Connect the high voltage power supply to the proportional counter using the red cable that has been provided. (Keep fingers off the HV connection at the counter).
5. Connect the pre-amp output to the linear amplifier input.
6. Connect the output of the linear amplifier to the input of the single-channel analyzer.
7. Connect the output of the SCA to the scalar and thence to the IN connector on the computer.

b) Power-Up Instructions (Usually already done)

1. Turn on the power switch of the driving electronics. Then turn the DRIVE SIGNAL switch from the standby position. Check the VEL(ocity) output on the front panel with an oscilloscope to verify that it is a saw-tooth waveform. This can be done only when the computer is in data collect mode.
2. Make sure that the VEL RANGE switch on the front panel is in the 0-20 position at all times. Note correct calibration of velocity scale on last page of this handout.
3. Make sure there is power for the single channel analyzer, the linear amplifier, the pre-amp and the high-voltage supply.
4. Set the high voltage to about 2800 volts (if counter is rated at 3kV.)
5. Set the coarse gain on the linear amplifier to approximately 1/4.
6. Turn on the high voltage. (Do **not** turn HV off at the end of session. Just put in the beam-blocker if you are not taking data overnight.)

c) Setting the Single-Channel Analyzer

1. With a Co^{57} source in place, check the output of the linear amplifier on an oscilloscope. A number of peaks should appear corresponding to photon energies. To identify the 14 keV pulses, put a piece of 1/8" Lucite between the source and the counter. This should eliminate the 6keV pulses. A 1/32" thick piece of copper should eliminate the 14 keV pulses. (Question: Where do the 6 keV gamma's come from?)
2. Note pulse height on the oscilloscope screen which fairly well isolate the 14 keV pulses. The signal should be DC coupled.
3. Set the E and ΔE controls (which are calibrated in volts) so that E and $E+\Delta E$ encompass the range of the 14 keV pulses. A ΔE of 0.5 to 1.0 volts is appropriate.

4. Measure the count rate as a function of E , for values of E from 0 to $10 - \Delta E$ in steps equal to your choice of ΔE . Plot the count rate vs. E and identify the positions for maximum count of the 14 keV line. This is the value of E to be used in data acquisition. Things may drift from day to day, so the optimum value of E should be checked, at least by varying E and watching the counter, before each run.

2. Preparing a Sample

To prepare a sample for analysis on the Mossbauer spectrometer you must insert the sample absorber between the gamma ray source and the proportional counter. This can be done by taping the sample (a thin foil mounted on a small plastic disk) over the opening in the lead collimator nearest to the source. Make sure that the vibrator, collimator and proportional counter are aligned so that gamma rays that pass through the sample will reach the counter.

The next step is to set the velocity range for the oscillator using the dial control. To determine the sweep velocity needed to cover the entire spectrum, consult the sample spectra for each of the absorbers. Be sure to check both ends of the spectrum to determine the required magnitude of the velocity sweep. Add an extra ten percent for possible calibration error and to be sure the ends are out of the resonance region.

References

- 1) A. C. Melissinos & J. Napolitano, *Experiments in Modern Physics*, 2nd Ed. Academic Press, New York, 2003.
- 2) G. K. Wertheim, *Mossbauer Effect: Principles and Applications*.
- 3) K. S. Krane, *Introductory Nuclear Physics*, John Wiley & Sons, New York, 1988.
- 4) R. B. Firestone, V. S. Shirley *et al*, *Table Of Isotopes*, 8th Edition, John Wiley & Sons, Inc., New York, 1996.
- 5) P. R. Bevington and D. K. Robinson *Data Reduction and Error Analysis for the Physical Sciences* 3rd Ed., McGraw Hill Book Company, New York, 2003.

Appendix A:

LOADING AND RUNNING THE PROGRAM

Some of the information in this appendix may be obsolete. If you annotate these notes and give them to the instructor, these pages will be updated for the benefit of future students.

A.1. Loading the Program The program to handle data acquisition and display for the Mossbauer spectroscopy experiment is kept on the disk. The following steps will tell you how to load the program.

If the PC is off:

1. Turn the PC on, and wait for the system to load. This should take about a minute.
2. If the PC is on and not running the Mossbauer program, type "mosbauer" (note spelling).
3. If the PC is stuck (crashed) do a "warm boot": CTL-ALT-DEL. pressed simultaneously.

A.2. Running the Program The program is not thoroughly debugged. If it asks for your name, the date, or whether it should run diagnostics, ignore these requests. The program consists of four main operations, and the functions of each of the operations are outlined below. These are the the four options presented at the main menu.

1. Reset All Bins to Zero
2. Gather & Display Data
3. Dump Results
4. Exit to Operating System

A.2.1. Reset All Bins to Zero

This operation is done whenever you want to restart the experiment. It clears all data from memory and allows you to set the name of the sample and the date. Your previous spectrum will (hopefully) be safely stored on disk.

A.2.2. Gather & Display Data

This operation allows you to choose the display format for the data and to set display parameters. There are three display formats, linear histogram, logarithmic histogram and tabular. There are five display parameters which control the scale of the

display axes. Each of the display parameters are described in the section called "Set Display Parameters."

These are the five Gather & Display Data Options:

1. Set Display Parameters
2. Linear Histogram
3. Logarithmic Histogram
4. Tabular Display
5. Return to Main Menu

NOTE: Data is being accumulated only while the linear or logarithmic histogram or tabular display is running. To exit any of these displays and return to the Display Options Menu, strike any key.

Each of these display options is described in detail in the following sections.

Set Display Parameters

The display is controlled by five display parameters. When you select option # 1 from the display options menu, you can set any of the display parameters. They are as follows:

Unfold Spectrum (YES/NO) (Default=NO) - Normally, only 256 bins are used for display, although data is gathered in 512 bins. This is done because the spectrometer sweeps each velocity twice on every pass, causing the spectrum to be reflected across **the center bin**.

If you select UNFOLD SPECTRUM=NO, the display will show each bin combined with its reflection bin. (For example, bins #1 and #512 will be added, bins #2 and #511, and so on.) For this reason, only 256 bins are available for display. With this display parameter setting, you will see a single copy of the absorption spectrum.

If you select UNFOLD SPECTRUM=YES, there will be 512 bins available for display, and two mirror images of the absorption spectrum will be apparent.

Show Average Counts per Bin (YES/NO) (Default=YES) - When data is displayed, there are usually not enough display columns to show the count of each individual bin. Each display column represents the sum of several bins. (Between 1 and 7 bins are included in each column, depending on the display range.) The counts for the columns are shown on the vertical axis.

If you select SHOW AVERAGE COUNTS PER BIN=NO, the vertical axis scale will indicate the total number of counts for each column, which is the sum of the bin counts for each bin in that column. If you change the display range, the number of bins per column will change, and the vertical axis scale will change accordingly.

If you select SHOW AVERAGE COUNTS PER BIN=YES, the vertical axis scale will indicate the average number of counts per bin, which is the sum of the bin counts for each bin in a column divided by the number of bins per column. If you change the display range, the scale on the vertical axis will be unchanged, because it indicates the average number of counts per bin, and is independent of the number of bins per display column.

Include Vertical Origin (YES/NO) (Default=NO) - When a spectrum is being accumulated, the depth of an absorption peak is usually only about one third of the number of counts in a bin. For this reason, you may not want to include the origin of the vertical scale in the display, but rather, focus your attention on the top part of the spectrum.

If you specify INCLUDE VERTICAL ORIGIN=NO, the upper and lower limits of the vertical axis will be determined by maximum and minimum bin counts for the range of bins being displayed. This will enlarge the vertical scale, focusing on the absorption peaks.

If you specify INCLUDE VERTICAL ORIGIN=YES, the upper limit of the vertical axis will be determined by the maximum bin count for the range of bins being displayed, and the lower limit will be zero or one. This will shrink the vertical scale, but will show the size of the absorption peaks relative to the total number of counts per bin.

First Bin to Display (Default=1) - Selects the first bin to be displayed. This parameter is the lower limit of the horizontal display axis.

Last Bin to Display (Default=256) - Selects the last bin to be displayed. This parameter is the upper limit of the horizontal display axis.

NOTE: Any of these parameters can be changed at any time during the accumulation of a spectrum without loss of data. Also notice that data is accumulated for all 512 bins regardless of the display parameter settings. These parameters serve only to set the range of the display window.

A.2.2.2. Linear Histogram

The linear histogram is a data acquisition function which displays the number of events per bin (vertical axis) against bin number (horizontal axis). The display is updated constantly as data is acquired.

The settings of the display parameters are shown at the top of the screen. The sample name, number of bins per display column, and total number of counts (for all bins) are also shown.

To stop gathering data and return to the Display Options Menu, strike any key.

A.2.2.3. Logarithmic Histogram

The logarithmic histogram is a data acquisition function which displays the number of events per bin on a logarithmic scale (vertical axis) against bin number (horizontal axis). The display is updated constantly as data is acquired.

The settings of the display parameters are shown at the top of the screen. The sample name, number of bins per display column, and total number of counts (for all bins) are also shown.

To stop gathering data and return to the Display Options Menu, strike any key.

A.2.2.4. Tabular Display

The tabular display is a data acquisition function which displays bin count by bin number in a numeric representation. The display is updated constantly as data is being acquired.

The settings of the display parameters are shown at the top of the screen. The sample name, number of bins per display entry, and total number of counts (for all bins) are also shown.

To stop gathering data and return to the Display Options Menu, strike any key.

A.2.2.5. Return to Main Menu

This option takes you back to the main menu, where you can select one of the Mossbauer Experiment Options.

A.2.3. Dump Results

This option allows you to copy the accumulated data to a diskette file or printer. This operation has no effect on the data, and can be repeated. When the results are copied, each bin count is added to the count in its reflection bin. For this reason, only 256 bin counts will be output.

NOTE: The program normally writes your data to disk periodically, so that if the computer crashes you still have almost all of it saved.

A.2.3.1. Send Results to Printer

(This feature does not work. You can copy a file to the printer from DOS if you want.)

A.2.3.2. Send Results to File

NOTE: The program normally writes your data to disk periodically, so that if the computer crashes you still have almost all of it saved.

You can also recall results previously stored on disks in order to use the graphing capabilities of the program. Just follow the instructions on the screen.

CAUTION: If you specify a filename which already exists, the old file will be lost.

A2.4. Load data from disk

See above. This is the opposite of the Dump Results function. This function works, but you cannot take more data to add to the data already accumulated. It is mainly for displaying previous results on the screen.

A2.4. Exit to Operating System

This operation will leave the program and return to the operating system.

Appendix B:**CALIBRATION OF VELOCITY DIAL
FOR MOSSBAUER EXPERIMENT
DRIVER CIRCUIT**

<u>Dial Setting (mm/s)</u>	<u>Maximum Velocity (mm/s)</u>
2.0	1.23
4.0	3.47
6.0	5.71
8.0	7.94
10.0	10.18
12.0	12.41
13.0	13.53

USE ONLY THESE SETTINGS.

ZERO VELOCITY IS AT CHANNEL 129.8