

Gamma Ray Spectroscopy

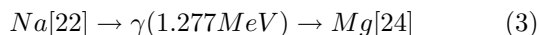
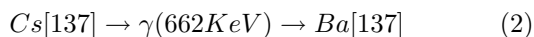
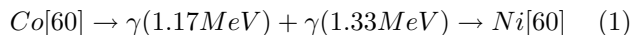
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Gamma ray spectroscopy is a powerful technique for quantifying the spectrum of emitted gamma rays from a radioactive source. These characteristics are depicted by such definitive marks as photo peaks, backscatter peaks, and Compton edges. This allows one to determine the exact radioactive element that has emitted the gamma rays. We were able to prove the accuracy of this method with three known samples, Cobalt-60, Sodium-22, and Cesium-137.

Many radioactive sources produce gamma rays. Therefore it is extremely important to have a sound method of determining the exact radioactive element that has emitted the radiation. Gamma rays are produced when nuclei of a radioactive element of higher energy decay to nuclei of lower energy. Each radioactive element that decays this way emits gamma rays that are of specific energy and are specific to that element. For example, Cs-137 emits gamma rays with a different energy than Co-60. By measuring the energies of emitted gamma rays and comparing them to known decay schemes, one is able to link these detected gamma rays to that element, and thus determine it.

Before beginning our experimentation we familiarized ourselves of the decay schemes of Co-60, Na-22, and Cs-137 shown below in Equations 1, 2, and 3 [1]. We are unconcerned with the beta decay in these decay schemes because it does not affect the gamma spectroscopy experiment.



Samples of Co-60, Na-22, and Cs-137 were provided to us by the University of Rochester Department of Physics and Astronomy. The Cobalt 60 and Sodium 22 samples were 1 μ Ci while the radioactivity of the Cesium 137 was labeled as 5 μ Ci. Laboratory records are scant, but it appears that both the Cs-137 and Na-22 samples are from December 1959. The Co-60 sample was clearly labeled and made in June 2004.

Additionally, our apparatus was provided by the University of Rochester Department of Physics and Astronomy. First, gamma rays pass through scintillator and fluorescence occurs. These emitted photons are captured by the photomultiplier tube (PMT) which was produced by ADIT, model number b50b01. The photomultiplier tube produces photoelectrons from the gamma rays. These

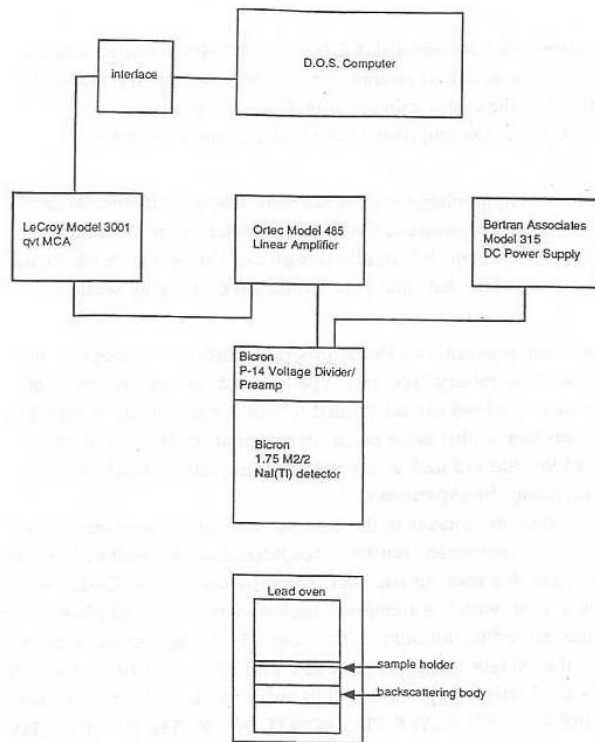


FIG. 1: Shown above is the schematic of our apparatus used for gamma ray spectroscopy [2].

electrons are converted to a voltage pulse that is proportional to the energy deposited by the gamma ray. The voltage output of the PMT is fed into an Ortec linear amplifier (model number 485) set at a coarse gain of 2 and a fine gain of 3, the minimum possible gain. The amplified voltages are then fed into a LeCroy multichannel analyzer (MCA) 1028 channels, each of which corresponds to a different but evenly partitioned voltage range. The output of the MCA analyzer is compiled by a personal computer running DOS. The collection program used was a Pascal program called by Nucspec.exe. See Figure 1 for a schematic of the apparatus [2].

When gamma rays pass through the NaI crystal that is doped with thallium in the scintillator, one of three processes can occur. The gamma ray may undergo Compton scattering or it may produce a matter-antimatter pair.

Additionally, it is possible that the gamma ray-crystal interaction may result in the emittance of a photoelectric electron. These three processes produce excited electrons that transfer their energy to NaI crystal in the scintillator and excite the atoms in the lattice. These atoms decay to the ground state and emit photons whose energies are proportional to the energy of that deposited by the gamma ray. The PMT then uses these photons to produce photoelectrons via the photoelectric effect which are then focused and amplified by a system of dynodes. These charges are converted to voltage pulses and yielded to an amplifier. This entire process is linear, making the voltage output proportional to the energy deposited by the gamma ray. The purpose of the amplifier is to proportionally intensify the signal so that it can be easily understood by the multi-channel analyzer [2].

Next, the signal is fed into a Multi-Channel Analyzer. The MCA has 1028 channels that correspond to a continuum of voltages in an equally partitioned fashion. For every voltage inputted from the amplifier, the MCA sends a signal to the computer that registers a count for the channel that that specific voltage corresponds to. The computer program then records each count for each channel and keeps a real time tally of these counts. After an allotted time, the data file can be recalled and lists each channel and the corresponding number of counts accumulated over the collection time [2].

Collections were taken for Co-60, Na-22, and Cs-137, each with a Pb background and an Al background with the intention of comparing the back scatter of the two materials. Each collection time was exactly twenty-five minutes and at the conclusion of that time the data was saved to a floppy disk and transferred to another PC. This was done in order to make use of twenty first century computing technology that was not available in the MC-DOS Environment.

In order to understand the relationship between the channel number and voltage, we compared our data to the known characteristics of our sources. It was very important to be sure that our range of focus included important points such as photo peaks and backscatter peaks. In order to do this, we began by using the most active source, Cs-137. Initially we set the amplifier gain to recommended settings per laboratory manual; coarse gain 16, fine gain 5 [2]. After a collection time of 5 minutes we saved the collected data to a floppy disk as a data file and graphed this data in Microsoft Excel. Initially we observed a peak that seemed to be the photo peak of Cs-137. After many more collections with Cs-137 and the other samples, we determined that this peak was not the photo peak. Rather, it was the much lower energy of a backscatter peak. It was determined that the energy continuum represented by the channels was not nearly broad enough to detect the photo peak of Cs-137, let alone the photo peaks of the other sources.

Through much trial and error it was finally determined

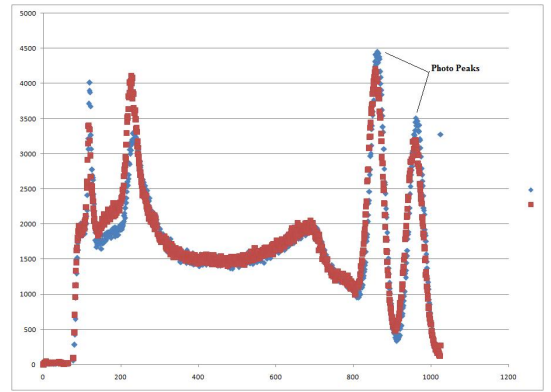


FIG. 2: This graph shows the uncalibrated spectrum for Co-60. This was the basis for finding the relation between energy and channel number.

that the optimum settings for our amplifier were coarse gain, 2 and fine gain, 3. These are the lowest possible gain values. However, this was the only way to insure that our energy continuum would include the photo peaks of all sources. Next, we established a background count by collecting data for the 25 minutes with no sources or backscatter body present. This allowed us to see problematic channels which was imperative, given the age of our equipment. Next, we repeated this process for all three sources with each backscatter body. At this point we had gathered all necessary data.

After gathering our data it was necessary to determine the energy that corresponds to each channel number. This can be done because it is known there is linear relationship between the energy deposited by the gamma ray and the final outputted channel number. We chose the two photo peaks of Co-60 in order to perform this calibration. Co-60 was chosen because it emits two gamma rays corresponding to the two well-defined photo peaks in our set of data. See Fig 2. The photo peaks of Co-60 were observed to be at channel 860 and 961 which corresponded to the energies of 1.17 MeV and 1.33 MeV respectively. Derived from the point slope formula the below equation was used to calculate the energy corresponding to each channel.

$$Energy = \frac{1.33MeV - 1.17MeV}{961 - 860} * Channel - 192.24 \quad (4)$$

The energy per channel that was calculated from the experimental results of the Cobalt is solely a characteristic of our experimental set up. Therefore, we can determine the relation between energy and channel number for all our trials. We were able to check this linear fitting of channels to energy by comparing the known gamma ray energies of Cesium and Sodium to the photo peaks observed in our experimental data. We compared the predicted channel number of Cs-137's photo peak with that

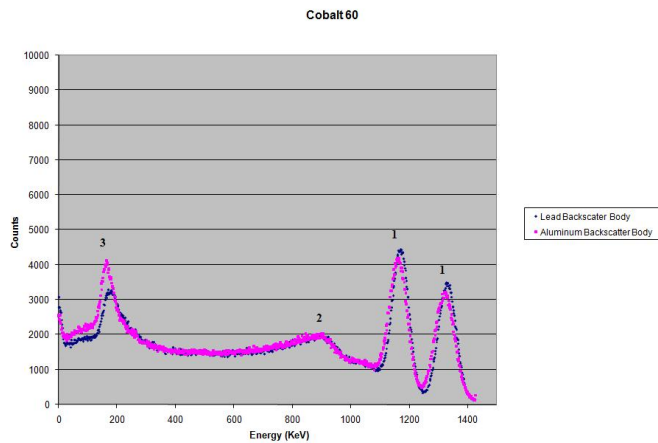


FIG. 3: Energy Spectrum for Co-60

of the experimentally measured result, channel 536. This model fit our Cesium and Sodium data with an absolute error of 3 channels for both cases. This very close matching with Cesium as well as Sodium gives justification to our pairing of channels to energies. A good Cesium result was important since Cesium was the most active source we had available and had the highest, sharpest photo peak. Additionally, the photo peak of Cesium is the most distant from the photo peaks of Cobalt which were used to calibrate our data. See Equation 5 below for in order to understand how we predicted the photo peak channel number.

$$662KeV = (1.584 \frac{KeV}{Ch}) * PhotoPeakCh - 192.24 \quad (5)$$

Therefore, if our model did not fit the data well we would expect a large error in the experimental value of the Cesium photo peak. See Figures 3, 4, and 5 for the final energy spectrums of Co-60, Na-22, and Cs-137.

It interesting to compare the theoretical values of the backscatter peak and Compton edge energies of Co-60, Cs-137, and Na-22 to the peaks corresponding to these features in the observed data. The theoretical energy of a Compton edge produced by a gamma ray of known energy is given by the below equation where E = the energy of the incident gamma ray, m = mass of an electron, and \check{E} is the energy of the Compton Edge [2].

$$\check{E} = \frac{E}{1 + \frac{mc^2}{2E}} \quad (6)$$

Likewise, the theoretical energy of the backscatter peak produced by a gamma ray of known energy with a known backscatter body is given by the below equation where E = the energy of the incident gamma ray, m = mass of an electron, and \check{E} is the energy of the backscatter peak [2].

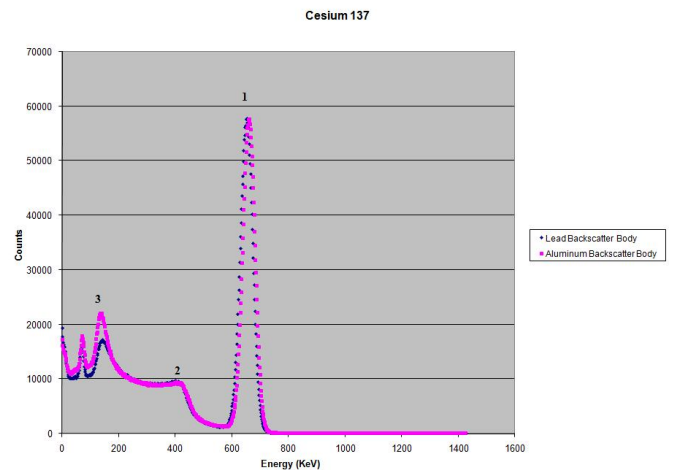


FIG. 4: Energy Spectrum for Cesium-137

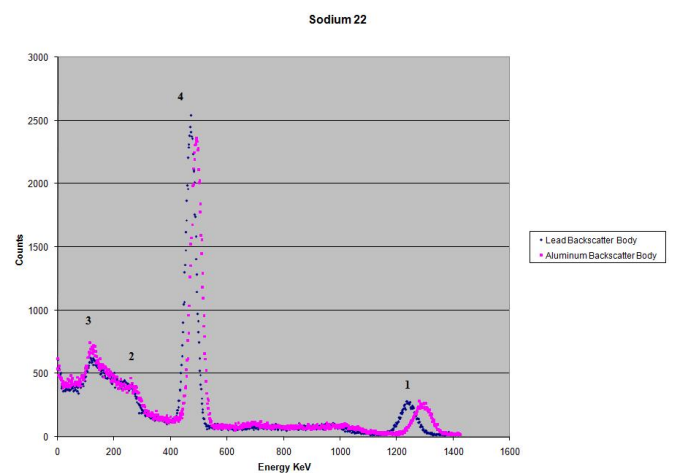


FIG. 5: Energy Spectrum of Sodium-22

[equation]

$$\check{E} = \frac{E}{2 + \frac{mc^2}{E}} \quad (7)$$

The table given in Figure 6 compares the theoretical and measured energies of the backscatter peak and the Compton edge along with the known and measured values of the photo peaks.

It is important to note that the backscatter peak with lead as the backscatter body is lower than that of the aluminum backscatter for all samples. Therefore, it sensible to use lead rather than aluminum as a shield for gamma radiation.

There was some difficulty in fitting the data to this linear model. There was obvious noise including completely saturated channels in our data from imperfections in the photomultiplier tube and the amplifier. However, these noisy data points were of no consequence in the determination of the spectrum of each sample and were

Cobalt 60			
	Theoretical	Measured	Percent Error
Backscatter Peak	.213 MeV	.173 MeV	19
Compton Edge	.96 MeV	.897 MeV	6.6
Cesium 137			
Backscatter Peak	.185 MeV	.141 MeV	24
Compton Edge	.477 MeV	.410 MeV	14
Sodium 22			
Backscatter Peak	.213 MeV	.120 MeV	44
Compton Edge	1.06 MeV	.260 MeV	75
e^+e^- annihilation	.512 MeV	.483 MeV	5.7

FIG. 6: This table summarizes the theoretical and measured for the Compton edge and the backscatter peaks for all samples.

omitted in our final figures for clarity. It is clear that the photopeaks from the Al and Pb collections for Na-22 differed in energy. We believe this may be the result of accidentally moving the source when the backscatter body was switched. Therefore we averaged the two values when analyzing the Na-22 data. Also, when fitting our data to the linear model, in the lowest channels we noticed our zero energy corresponded to channel 121. This suggests that the problem stems from our apparatus, specifically

our multi-channel analyzer rather than our model, given the relatively low error in the prediction of the Cesium and Sodium photo peaks and other spectrum characteristics. We believe that these channels below number 121 are not significant because they have counts that are virtually zero, further supporting our theory that the MCA is problematic.

Due to the limited time we had available to collect data only one collection was possible for each sample. It would be of interest to repeat this procedure multiple times in order to refine our model and solidify our results. It is our hope that after a significant number of trials more conclusions could be drawn regarding the behavior of the spectrum at the lower channel numbers. Additionally, one could further compare the difference between the lead and aluminum backscatter bodies after more collections have been taken refining our data.

Finally, we have successfully observed the photo peaks, Compton edges, and backscatter peaks of Cs-137, Na-22 and Co-60. It is our conclusion that gamma spectroscopy could be used to determine the identity of an unknown gamma source with sufficient accuracy.

This work was supported by the University of Rochester.

[1] L. Slack and K. Way, *Radiation from Radioactive Atoms* (United States Atomic Energy Commission, Washington D.C., 1959)

[2] University of Rochester Department of Physics and Astronomy, *Gamma-Spectroscopy* (Rochester, NY)