

# Nuclear Spectroscopy with the PC

## I) Introduction:

This write-up describes the software and associated hardware that is used to turn a PC into a multi-channel analyzer (MCA). A MCA is an electronic instrument which analyzes pulses input into it and sorts them depending upon their respective voltages. As its name implies the MCA contains many channels. Each channel holds the count of the number of pulses which have a given voltage range. Thus the MCA generates a histogram of the number of pulses which fall in various voltage ranges. A typical use for the MCA is the measurement of the  $\gamma$  ray energy spectrum from a radioactive source such as Cs137.

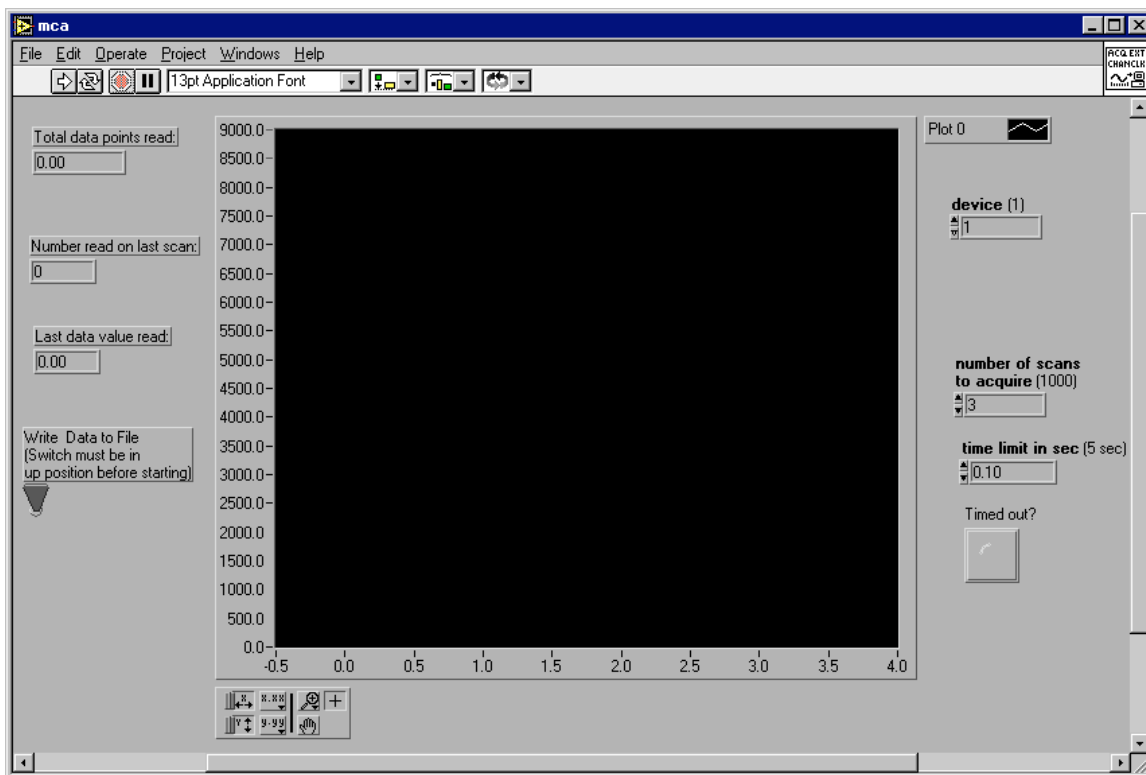
## II) Software:

The PC is turned into a MCA using a software package called LABVIEW. LABVIEW is a product of National Instruments and is commonly used in research environments to interface computers with data collecting hardware. For the LABVIEW applications in this class you will not need to know any of the details of how to program with this software system. However, a complete set of manuals is available for those of you who are curious.

For our purposes the LABVIEW software serves two functions. First, it controls the data board (PCI-1200) inside the PC that is used to record (digitize) the electronic signals from the NaI Spectroscopy Amplifier. Second, it allows us to manipulate the recorded data and, for example, display it as a histogram.

The program used to “turn” the PC into a MCA is called MCA! To run the program (C:\LabView), double click the MCA icon. The program was designed to sort “events” (actually input voltages from the spectroscopy amplifier) and display a count of them (actually a histogram) as a function of voltage. This histogram is updated as a function of time as more events are collected.

Once MCA is started the computer screen will look like this:



The above will display a histogram (once data collection has started) in which the vertical (y) axis gives the number of pulses (counts) in a bin (range) of voltages (x axis). As we collect data, the number of counts in a given bin will build up on the y axis.

### Starting and Stopping MCA:

To start the program first click on the *arrow* icon in the upper left hand corner of the display. Once the program starts to collect data an icon in the shape of a *stop* sign will appear in the upper left hand corner. To *stop* the program click on this *stop* sign icon.

### Writing data to a file:

After you have taken some data but **BEFORE** you click on the *stop* sign, you can record the number of counts in each bin in a data file. This is done by clicking the switch titled *Write Data to File*. After you click on this “switch”, the MCA will continue taking data for a few moments (it is designed to take data in loops of 100 events each). MCA then asks for the name of the file and writes the data to that file. This file can be opened and manipulated by other PC programs, e.g. Kaleidagraph.

### III) Hardware:

The hardware used for the nuclear spectroscopy experiments is described below:

#### 1) NaI Calorimeter

The NaI calorimeter consists of a scintillator, a photomultiplier tube (“phototube”), and a phototube base. The scintillator is a NaI crystal doped with Tl which converts  $\gamma$ -ray energy into many photons of light. The phototube converts the light quanta emitted by the scintillator into photoelectrons and amplifies the number of photoelectrons, giving a current pulse proportional to the amount of energy deposited in the NaI. The phototube base also distributes the necessary voltages (typically a 1000 V, total) to the phototube itself.

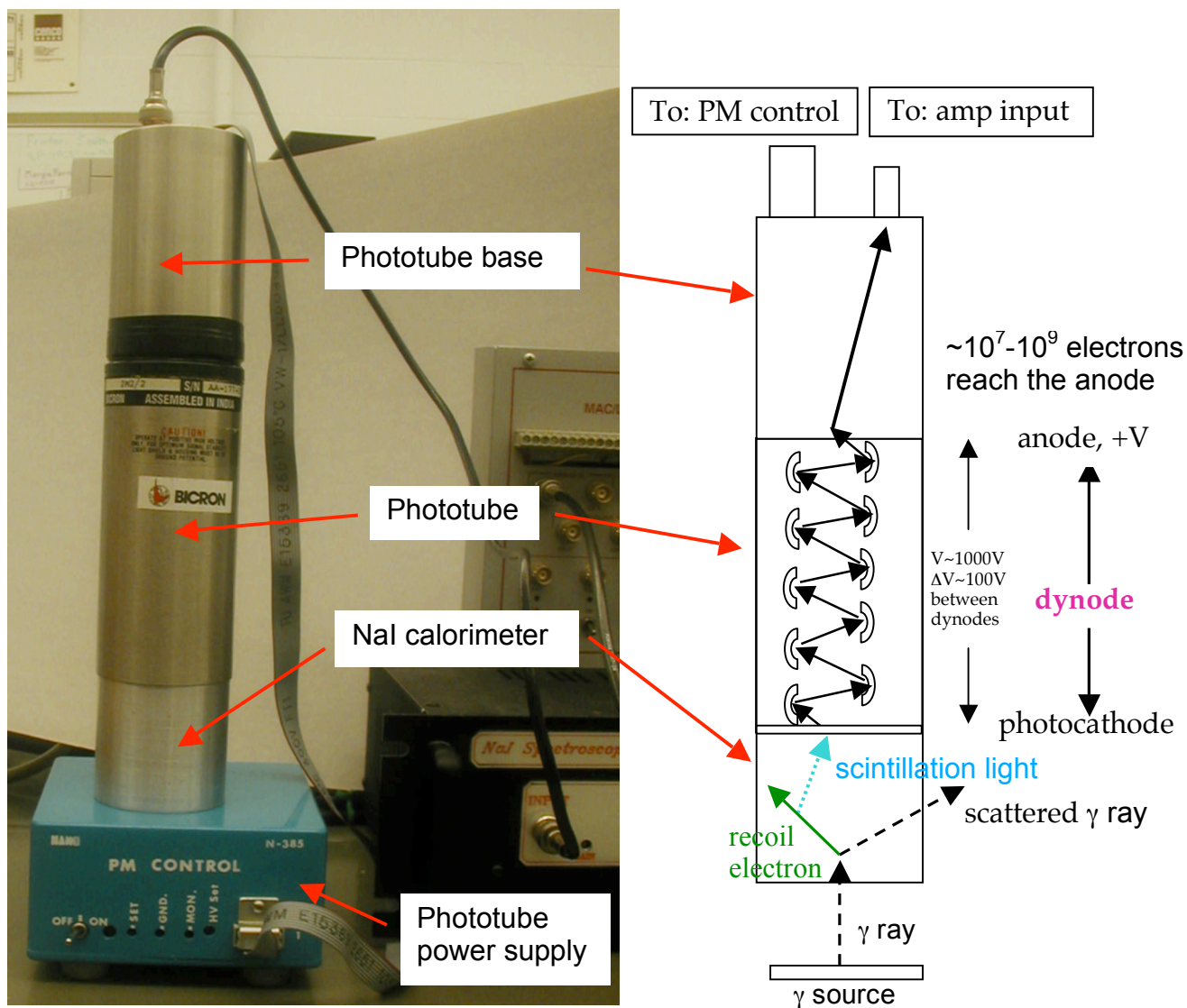
#### 2) PM Control

The blue box (“PM Control”) connected to the phototube base serves as the voltage controller for the phototube. Here's what's what on the box:

- a) ON/OFF switch: The light goes on when the power to the phototube is turned on!
- b) SET: This is a test point. You can read the “set voltage” (i.e. the voltage that the phototube is set to) with a voltmeter by putting one voltmeter probe here and the other probe in the GND test point. The calibration is such that a reading of 10 Volts corresponds to setting the phototube voltage to -2 kV.
- c) GND: This is the ground test point.
- d) MON: The voltage difference between this test point and GND is the voltage at the phototube (actually its scaled so that -2 kV at the phototube = 2 V on voltmeter).
- e) HV SET: This is a potentiometer that sets the phototube voltage. Turn clockwise to increase the voltage. You should always have a voltmeter reading the voltage difference between MON and GND when you adjust this potentiometer.

The SET and MON phototube voltages should agree with each other (after taking into account their different calibrations) to within a few volts for a working phototube. If they do not agree to within a few volts then there is a problem with either the phototube, phototube base, or both.

The picture below shows the NaI calorimeter, phototube, and PM Control together with the principle of the phototube:



### 3) NaI Spectroscopy Amplifier:

This box amplifies and filters the signals from the phototube and tells the computer that there is data available to be recorded. Here's what's what with this box:

- INPUT:** The INPUT connector takes the input signal from the phototube.
- ANALOG OUT:** This connector sends the amplified signal to the MAC/LC INTERFACE and ultimately to the computer.
- TRIG OUT:** The output from this connector tells the computer that an event is coming and it needs to “get ready to count”.
- GAIN:** This control (potentiometer) allows you to adjust the “volume”, that is, it allows you to set how much an incoming signal gets amplified. The gain is just the ratio between input and output voltages.
- THRESHOLDS:** Two very important dials are the upper level (labeled **UL**) and lower level (labeled **LL**) thresholds. The upper and lower level thresholds indicate the window of



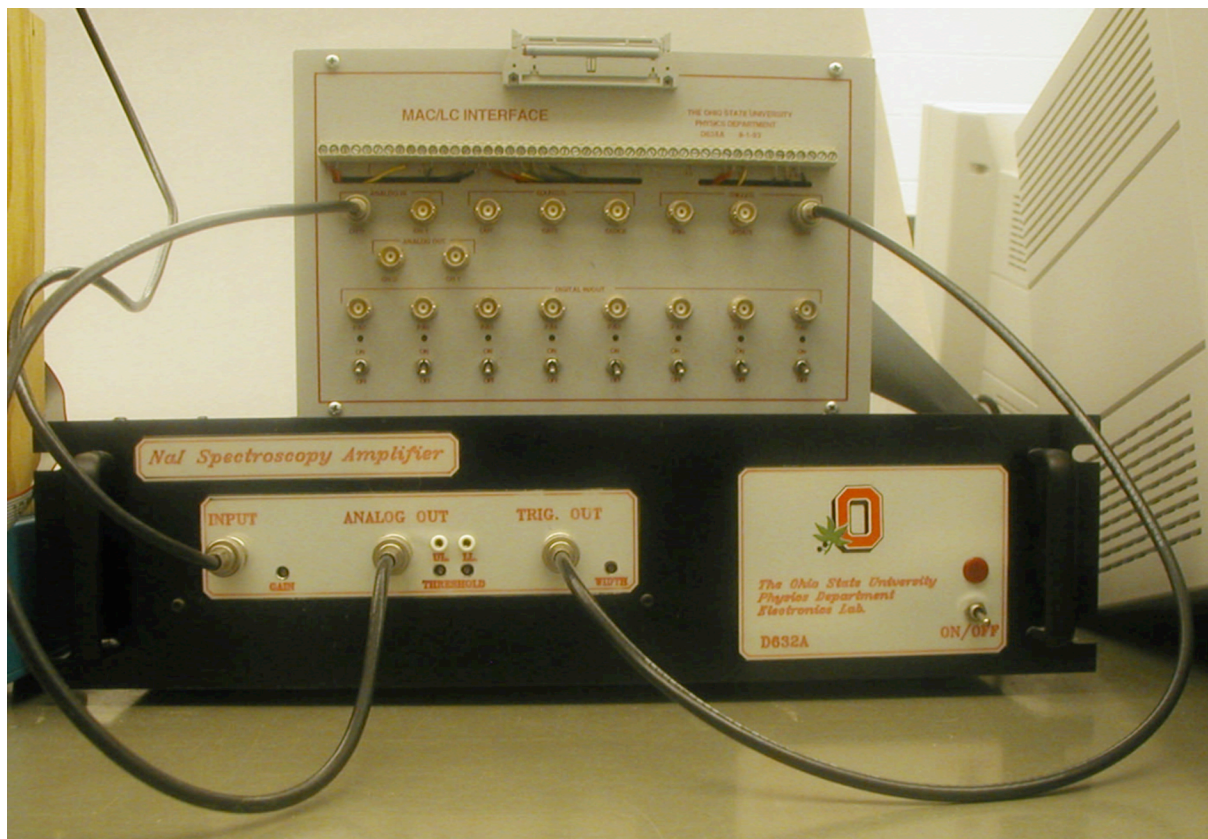
voltage signals that are sent out to the computer. For example if the upper level is set at 4 V and the lower level is set at 2 V then the computer will (theoretically) only receive a signal in the range 2 to 4 V, and a 1.5 or 4.2 V signal will not be counted. Note that you have to use a screwdriver to turn these dials and a voltmeter to figure out what the levels actually are.

f) WIDTH: This potentiometer controls the width of the TRIG OUT signal. Do not change this control.

#### 4) MAC/LC INTERFACE

This box routes the signals from the NaI Spectroscopy Amplifier to the data board located inside the PC. Note that this board was originally designed for a Macintosh computer, but works fine for our PC as well. The ANALOG OUT from the NaI Spectroscopy Amplifier should be connected to CH0, ANALOG IN of the MAC/LC INTERFACE, and the TRIG OUT of the NaI Spectroscopy Amplifier should be connected to CONV, TRIGGER of the MAC/LC INTERFACE.

The picture below shows the spectroscopy amplifier and MAC/LC interface box:



**Note:** The NaI Spectroscopy Amplifier and MAC/LC INTERFACE were designed and built by the OSU physics department electronics shop. The spectroscopy amplifier is described in detail in a note titled D632A, which can be obtained from the electronics shop and is included in the special notes for P616 experiment N3.

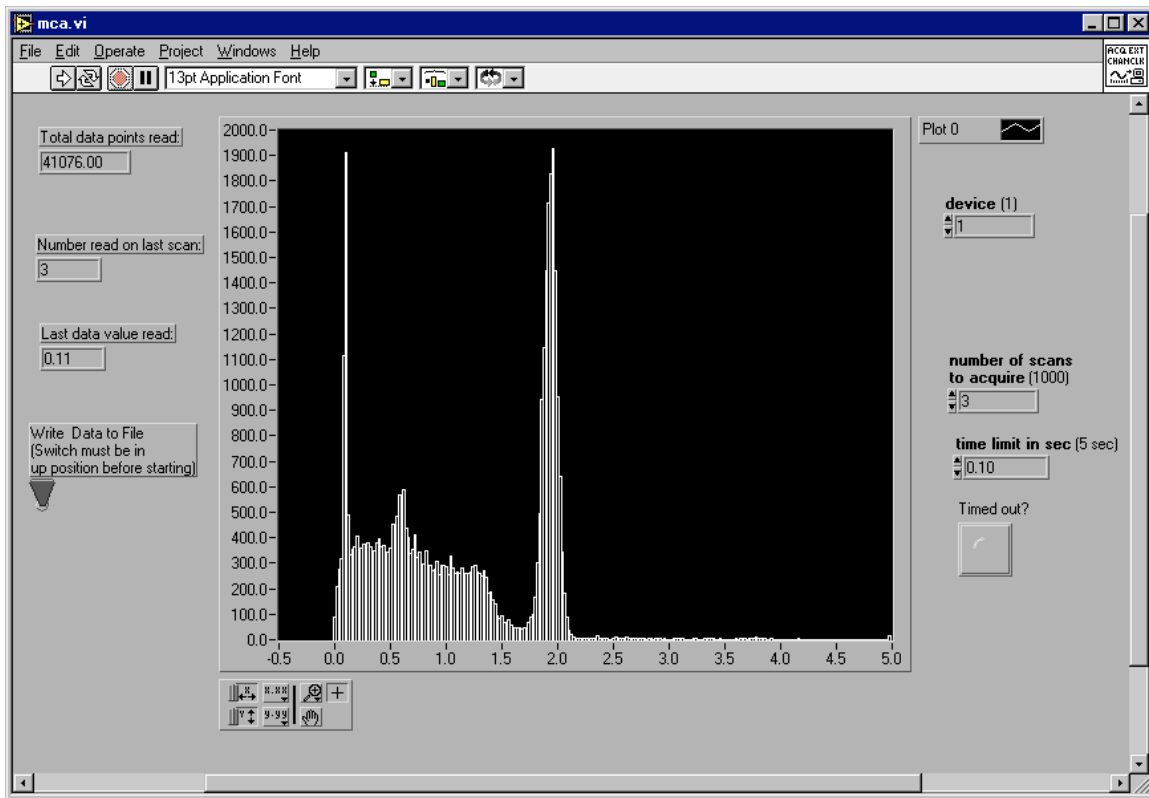
#### IV) Voltage to Energy Calibration:

At some point in the experiment, you will have to calibrate the horizontal axis, making a conversion from Volts to keV or MeV. To do this calibration one needs several  $\gamma$  rays of known energy. Useful radioactive sources are Cs137 which gives off a  $\gamma$  ray at  $E = 0.662$  MeV and Co60 which gives off two  $\gamma$  rays with  $E = 1.172$  and  $1.333$  MeV. The picture shown below is the spectrum obtained using a Cs137 source. The peak at  $\sim 1.9$  V corresponds to an energy of  $0.662$  MeV. The sharp peak on the left at  $\sim 0.1$  V is a combination of the Cs137  $K_{\alpha}$  ( $E = 32.1$  keV) and  $K_{\beta}$  ( $E = 36.6$  keV) x-rays. One can get an accurate reading of the voltages corresponding to the peaks of the  $\gamma$  rays by writing the histogram to a file and then open the file with Kaleidagraph to identify the voltages with maximum number of entries. Note, it is best to use at least two  $\gamma$  rays of known energy for the calibration as there can be a DC voltage offset so zero Volt is not zero energy!

#### V) Taking data with MCA:

As an example of using MCA, let us go step by step through the process of measuring the  $\gamma$  ray energy spectrum of Cs137. After setting up the NaI calorimeter, adjusting the PM Control, and making the appropriate connections between the MAC/LC INTERFACE and the NaI Spectroscopy Amplifier we are now ready to take data.

To start collecting data with MCA, click on the arrow button in the upper left corner of the display screen. Make sure that the *Write Data to File* switch is in the up position. MCA then begins to collect data, 100 events at a time (this number is set by the software). The program will continue to take data until the user stops it. The box labeled **“Total data points read”** gives the total number of events recorded so far. As this number increases, our histogram will (hopefully) form to indicate a few definite peaks in the energy spectrum. After collecting data for a few minutes, the histogram looks like this:



In this example 41,076 events have been collected so far. To stop counting events, we click on the stop sign in the upper left corner of the screen.

**Remember:** If you want to write your data to a file, you need to click on the *Write Data to File* switch **before** clicking on the stop sign.

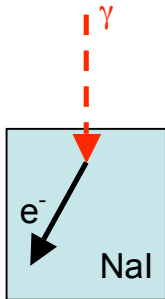
**Note:** Each time MCA is started it re-initializes all variables to their default values, therefore the histogram starts off with zeros in all bins. The data from a previous run will be lost unless you saved the data to a file.

## Basic Physics Processes in a Sodium Iodide (NaI)

NaI is a “scintillator”. As a charged particle traverses the NaI it loses energy. The energy lost is absorbed by the NaI molecules and puts the molecules into an excited state. NaI gives off light (“scintillates”) when it de-excites back to the ground state. **The amount of light given off by NaI is proportional to the amount energy absorbed.** The light yield is  $\sim 1$  photon produced per 100 eV deposited in NaI ( $10^4$  photons produced per MeV). However, not all photons are collected as the efficiency of the photocathode is  $\sim 20\%$ .

### Photoelectric Effect

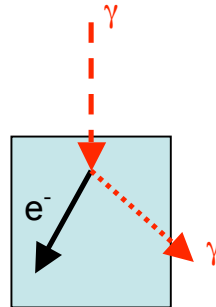
$\gamma$  absorbed by material,  
electron ejected



$h\nu < 0.05 \text{ MeV}$

### Compton Scattering

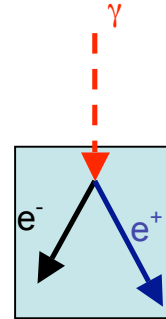
$\gamma e^- \rightarrow \gamma e^-$   
“elastic scattering”



$0.05 < h\nu < 10 \text{ MeV}$

### Pair Production

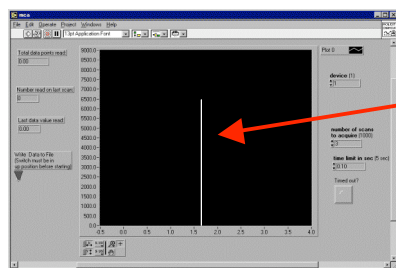
$\gamma \rightarrow e^+ e^-$   
creates anti-matter



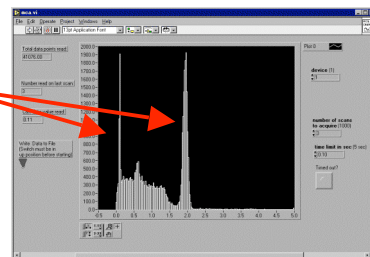
$h\nu > 1.02 \text{ MeV}$   
 $\gamma$ -ray must have  $E > 2m_e$

## How do we get a PEAK in our energy spectrum?

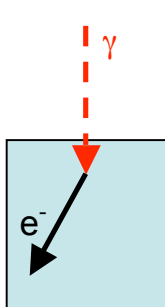
A peak in the energy spectrum corresponds to the case when all of the  $\gamma$ -ray's energy is absorbed in the NaI calorimeter.



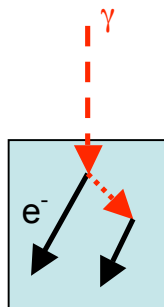
perfect energy resolution  
all  $\gamma$  energy totally absorbed



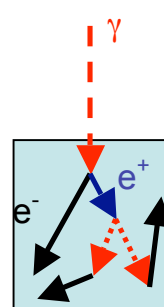
actual energy resolution  
not all  $\gamma$  energy totally absorbed



Photoelectric effect  
and electron stops  
in NaI.

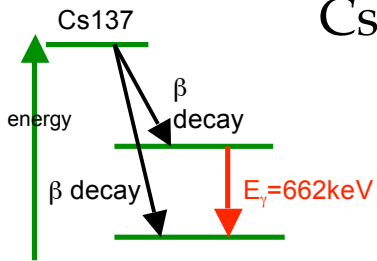


Compton scatter followed  
by photoelectric effect



Pair production  
 $e^-$  is absorbed in NaI  
 $e^+$  annihilates into 2  $\gamma$ 's  
 $\gamma$ 's undergo photoelectric effect

# Cs137 $\gamma$ -ray Spectrum



$\beta$  decay gives off electrons with a range of energies  
 $E_{\text{max}} = 514\text{--}1170\text{ keV}$   
 $\gamma$  decay gives off a monochromatic photon  
 $E = 662\text{ keV}$

