

# Instruction Manual

for

## EN-08 Student Beta Spectrograph

### Introduction

Most experiments on radioactivity deal with the absorption properties of materials to radiation without illustrating the quantitative difference between types of radiation. Beta and gamma radiation are absorbed by matter in a similar, although not identical, manner; beta being absorbed much more easily of course. The fact that beta radiation is due to charged particles, while gamma radiation is due to photons, is overlooked in demonstrations or laboratory experiments. The EN-08 Beta Spectrograph makes it easy to show the difference between these radiations. Beta particles from a source are collimated and directed through a magnetic field provided by a pair of ceramic magnets, which deflect them into a detector. The beam deflection varies from  $0^\circ$  to  $90^\circ$  depending upon the energy of the particles. The beam intensity is measured by an EN-04 Geiger Tube mounted in the magnet support structure. The source is mounted on a rotating arm so that the beam passes through the magnetic field and enters the Geiger Tube through an aperture in the cast iron frame. Rotating the arm permits the measurement of the intensity as a function of angle. The deflection angle is inversely related to the energy of the beta particles so that the beam intensity as a function of energy can be determined from the data.

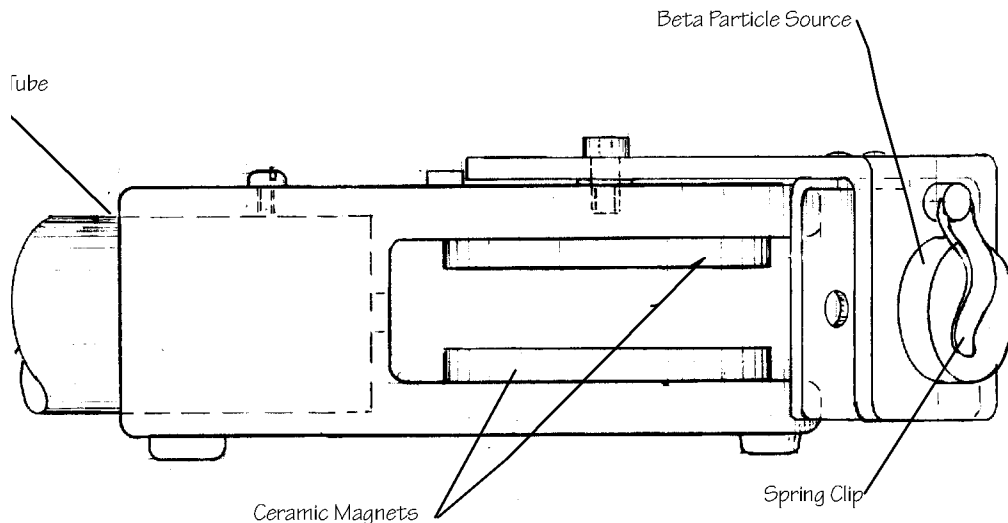


Figure One



## Operation

In addition to the EN-08 you will need:

EN-01 or EN-04 Geiger Tube  
EN-05 Geiger Connecting Cable  
EN-15 Geiger Counter or  
EN-30 Precision Geiger Counter  
Thallium 204  $\beta$  Source supplied or  
EN-02 Strontium 90  $\beta$  Source

The  $\beta$  Sources are shipped separately from the apparatus and must be installed by the user.

1. Set the magnet frame on a level table with space around it for the other pieces of apparatus. The Source should be mounted in the arm as shown in Figure One. The Source is held by the small spring clip on the back of the rotating arm. It should be centered on the vertical part of the arm and in line with the aperture in the lead absorber.

Two sources are recommended for use with the apparatus; either Sr90 or Tl204 gives good results. C14, which is a good beta emitter, does not work because its beta particles have low energy and are deflected out of the magnetic field before they can reach the Geiger Tube. Since the count rate is much higher with Tl204, it is suggested that this source be used.

2. Carefully place the Geiger Tube into the pocket provided for it in the back of the magnet frame. Don't let the window of the tube touch the end of the cavity. Tighten the nylon screw on the top of the frame to hold it in place.
3. Connect the Geiger Tube to the Geiger connector on the rear of the Geiger Counter.
4. Turn on the Geiger Counter to the CONTINUOUS mode.

The Counter is continuously active in this mode and should show a few counts from the source or from background radiation.

5. Make sure all of the connections are correct. The easiest way to do this is to hold a gamma radiation source, if you have one, near the side wall of the Geiger Tube. This will cause the tube to count rapidly and verify that all connections are correct.

To start the measurements, remove the gamma source and anything else that might add to the background count.

6. Rotate the source arm to 90° on the right side. Reset the Counter to zero and using a stop watch, record the number of counts for three minutes.

7. Move the source arm to the 90° left position and repeat the measurement. The count rate will be higher on one side than the other. This will enable you to determine in which direction the beta particles are deflected. The deflection is determined by the polarity of the magnetic field and the charge on the beta particle. Can you confirm the polarity of the charge on the beta particle?

### Measuring the Energy Spectrum of the Beta Source

The determination that beta radiation consists of charged particles is the most significant conclusion of this experiment because it establishes the nature of this fundamental radiation. The measurement of the energy spectrum of the beta particles is of almost equal importance, for the nature of the energy spectrum led to the discovery of the neutrino by Fermi in 1934.

It is intuitively clear that the slower a beta particle is moving, the easier it will be to deflect in the magnetic field. The path of particles of any energy will bend but the radius of curvature will depend upon the energy.

By measuring the strength of the magnetic field and the radius of the path of the beta particle, one can determine the energy of the particle. To derive the required formulae, let us start by determining the radius of the path through the field by measurement of the deflection angle. The geometry of the beam passing through the field is shown in Figure 1. The beam enters the magnetic field at point B and follows an arc of a

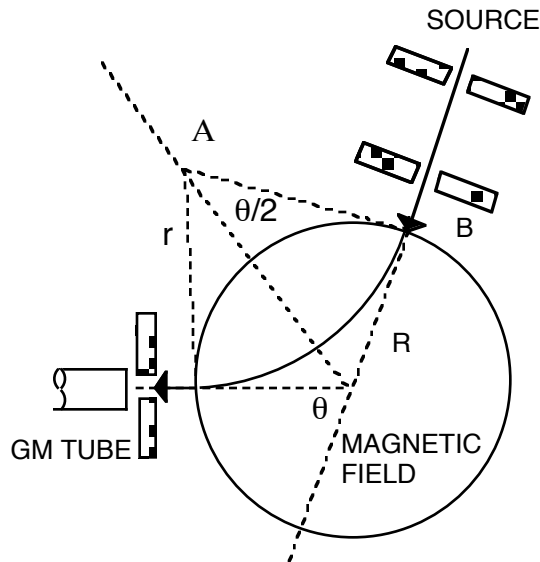


Figure One

circle until it leaves and enters the Geiger Tube. The radius of the arc  $r$  can be determined from the radius of the field  $R$  and the deflection angle. In the triangle ABC,

$$\tan(\theta/2) = R/r$$

so that

$$r = \tan(\theta/2)/R$$

The energy of a beta particle is the total of the potential and kinetic energy and can be given by

$$E = ((pc)^2 + (m_0 c^2)^2)^{1/2} - m_0 c^2$$

where  $c$  is the velocity of light and  $m_0$  is the rest mass of the electron. Dividing through by  $m_0c^2$

$$E = m_0c^2 \left( \left( \frac{p}{m_0c} \right)^2 + 1 \right)^{1/2} - 1$$

The centripetal force required to keep a particle moving on a circular path is given by

$$F = mv^2/r$$

This force is produced by the charge of the particle  $e$  moving through the magnetic field  $B$ , so that

$$F = eBv$$

These two expressions for the force are equal,

$$mv^2/r = eBv$$

and

$$mv = eBr$$

but  $mv = p$  the momentum of the particle, so that we can substitute in the energy equation and obtain

$$E = m_0c^2 \left( \left( \frac{eBr}{m_0c} \right)^2 + 1 \right)^{1/2} - 1$$

and substituting for  $r$

$$E = m_0c^2 \left( \left( \frac{eBR}{m_0c \tan(\Theta/2)} \right)^2 + 1 \right)^{1/2} - 1$$

all of the quantities in this equation can be determined.

For the EN-08 apparatus,  $R = 2.8 \times 10^{-2}$  m and  $B = 6.9 \times 10^{-2}$  T. The remaining values can be taken from tables of physical constants. Making these substitutions gives

$$E = .511 \left( \left( \frac{1.15}{\tan(\Theta/2)} \right)^2 + 1 \right)^{1/2} - 1 \text{ Mev}$$

This is the required formula relating the energy of the beam in units of Mev, as a function of the deflection angle of the beam as measured by the angle scale on the arm of the EN-08. Remember, this equation is derived from an apparatus that had a field of  $6.9 \times 10^{-2}$  T. This is likely close to the value of the field for your apparatus but it would be well to check the assumption. If a Daedalon EP-15 Flux Density Meter is available, the field can be measured by placing the probe in the gap between the magnets. Take several measurements and average your results.

### Measurement of the Intensity as a Function of Angle

It is convenient to measure the count for  $5^\circ$  increments in angle. Smaller steps than this are close to the resolution of the apparatus and waste time. Larger steps have too few points to make a convincing

graph. If time is limited,  $10^\circ$  steps can be used without too great a sacrifice in credibility.

8. Set the Source arm on the side that gives the higher intensity as measured in the first part of the experiment. Time the count for 5 minutes.

For weak sources and large angles, the count can be very low so that the time it takes to collect large counts is quite long. Since laboratory time is very limited, it is best to decide on a data collection procedure that can be completed in the available time. Usually, counting for fixed time intervals is best, say three or five minutes, so that the total time is predictable even though the accuracy will not be very high for the low count rates.

9. Measure the count for each five degree interval starting at  $90^\circ$ . The count rate will change significantly between settings. Continue until 10 points have been measured.
10. Measure the background radiation. This measurement is important, since the background count must be subtracted from all of the other readings. Count four times as long as your count for the angle measurements. The source arm should be set to  $90^\circ$  on the opposite side. The magnetic field will sweep the  $\beta$  radiation away from the Geiger Tube so that the tube will be responding to cosmic ray and environmental radiation rather than the source.

The background is usually fairly constant for a given Geiger Tube and amplifier in the same environment. After the background has been measured by several groups in the laboratory and found constant, its value can be used so that later measurements are unnecessary, thus saving laboratory time. It is always safest to measure the background before and after the measurements, if serious work is undertaken.

If the EN-30 Precision Geiger Counter is used, all of the measurements can be made to fixed accuracy. The Precision Geiger Counter will measure the count rate for a fixed number of counts. This is very convenient for measurement of the low count rates and background count which can take almost three hours to reach 4000 counts. The EN-30 holds the measured count rate until the operator comes to retrieve it.

### Data Reduction

Plotting the count rate minus the background is the first plot that should be made. This plot will show if an error has been made and the count for a particular angle should be repeated. A sample of data plotted this way is shown in Figure 2. This figure shows two sources, Thallium

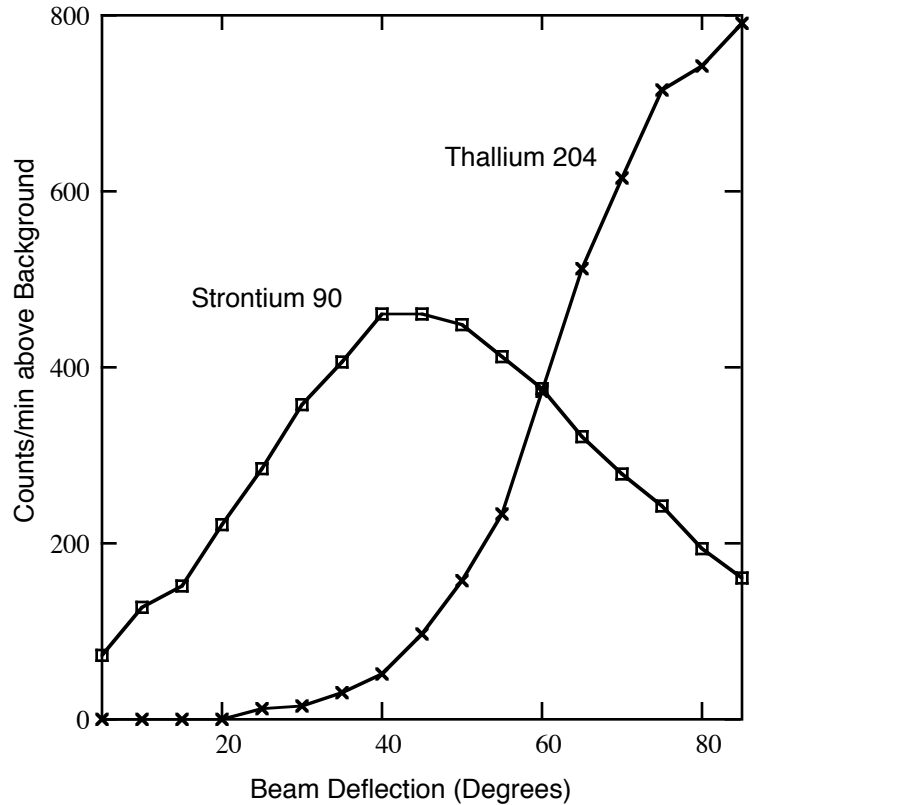


Figure Two

204 and Strontium 90, both good sources of  $\beta$  radiation. It can be seen that the peak intensity for Sr90 occurs at a smaller deflection angle than for T1204. This suggests that the  $\beta$  particles from Sr90 are more energetic than those from T1204. This is effectively true. Actually the  $\beta$  decay of Sr90 is a two step process. The first is a  $\beta$  particle of .54Mev and the Sr90 becomes Yr90 which decays by another  $\beta$  to become Zr90. The second  $\beta$  has an energy of 2.27Mev and it is this higher energy that dominates the experimental results.

You may find that the points on your curve are more scattered than those in the figure. This is because the data are based on the count rate for 4000 counts, so that the points are very accurate, but it took several days to collect the data. You may not have time to use this many counts. The curve is a sample of what you could achieve if you had the time to do it.

A second comment should also be made about the figure. The Sr90 source used had only 1% of the intensity of the T1204 source. This doesn't change the results but it makes the data difficult to plot. To correct this, the Sr90 data were increased by a factor which made the two sources have the same apparent intensity.

Of greater interest than the count rate, which is after all only a characteristic of the source and the apparatus, is the count rate versus angle which is equivalent to the count rate as a function of energy. It was shown earlier that with a knowledge of the magnetic field, the deflection angle could be used to determine the energy of the particle.

The Tl204 data plotted in Figure 2 are tabulated in Table One, together with the energy and the rate of change of energy with angle.

Table One

Source: Thallium 204

Background Count: 24 /m

Angle	Energy Mev	E/ $\Delta\theta$	Count/min	(C <sub>min</sub> Bkgd)	(C/m- Bkgd)/ $\Delta\theta$
90	.343				
85	.394	.051	816	792	792
80	.452	.058	767	743	657
75	.517	.065	739	715	555
70	.592	.075	639	615	417
65	.679	.087	536	512	300
60	.780	.101	398	374	188
55	.900	.120	258	234	99
50	1.044	.144	183	159	56
45	1.219	.175	121	97	28
40	1.438	.219	77	53	12
35	1.720	.282	55	31	6
30	2.095	.375	39	15	2
25	2.620	.525	35	11	1

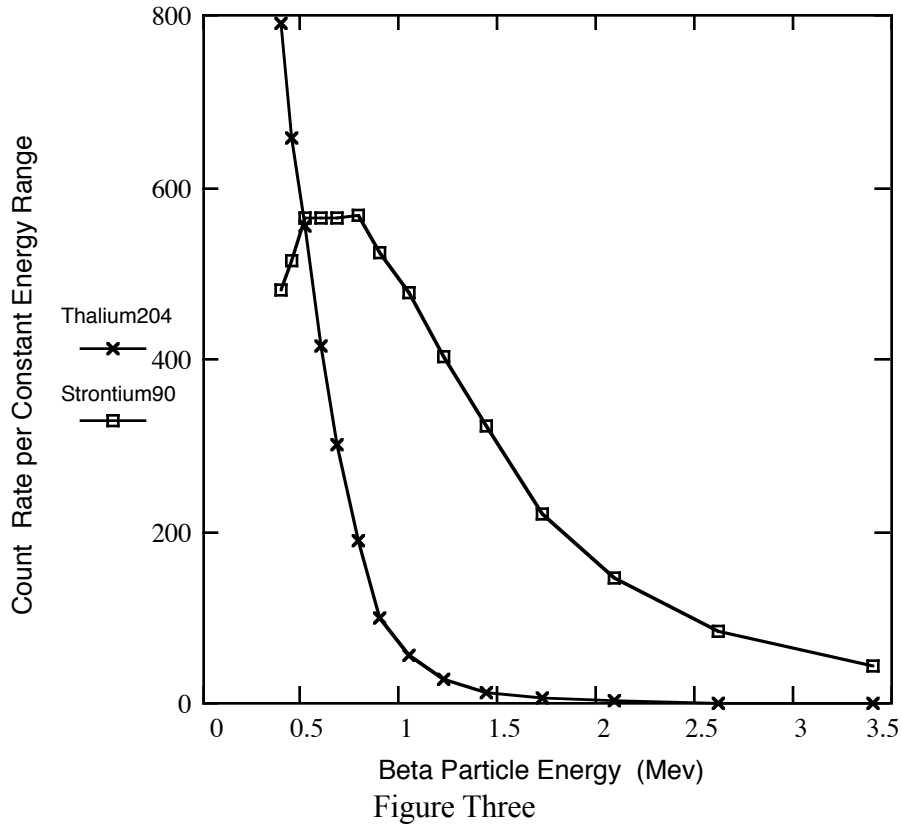
It can be seen from this table that the energy increases with angle in a very nonlinear manner. The energy increase for a change in angle becomes very large as the energy is greater. Since the geometry of the collimator and collector in the Spectrograph have a fixed collection angle of about 5°, the result is that the range of energies collected for a given angle changes with the angle. The data of interest are the counts for a constant energy range, so a correction must be made.

The simplest correction has been used in the above Table. The differences for successive energies in column two are tabulated in column three. The (Count/m - Background) value is divided by this number and multiplied by the value for 85°, i.e.,.041, so that the count for a given angle is reduced to the range of energy that the apparatus collects at 85°.

A sample calculation for 50° gives

$$(183 \text{ (C/m)} - 24 \text{ (Background)}) / (.144 \text{ (E}/\Delta\theta \text{ at } 50^\circ)) \times (.051) \\ = 56 \text{ C/m}/\Delta E$$

This correction makes the data comparable to other published beta spectrum data. The spectrum of Tl204 and Sr90 are shown in Figure 3 corrected for constant  $\Delta E$  by the above procedure. As before, the Sr90 curve is adjusted upward to plot with the Tl204 curve.



The most significant characteristic of the beta spectrum is the energy cutoff value. This is the value referred to in tables of energy of beta radiation. From Figure 3, it is clear that most of the energy of the radiation occurs at lower energies than this cutoff value. The nature of the spectrum was difficult to understand, since there seems to be no other change in the nucleus except that it changes to the next higher positive species. But if the beta particles emerge with a wide range of energy, how is momentum and spin conserved? Conservation was maintained by the additional emission of a very hard to detect particle, the neutrino, that carried off the balance of the energy and spin. A beta particle emerging at maximum energy takes it all. For lesser energies, the balance is carried off by the neutrino. So this little experiment establishes the charge of the beta particle and gives the experimental basis for the existence of the neutrino.