

# SCINTILLATION SPECTROMETRY

## OBJECTIVES :

To demonstrate the principles of pulse-height analysis and scintillation spectrometry.

To illustrate applications of scintillation spectrometry for the measurement of radiation energy and for the identification of nuclides.

## THEORY

A scintillation spectrometer is an instrument for the measurement of energy distribution of radiation. It is of great utility in the radioisotope laboratory and finds widespread application in the fields of radiation characterization and nuclear identification and measurement.

The measurement of radiation energy is accomplished electronically by determining the intensity of each scintillation produced by radiation as it impinges on a phosphor. A block diagram of a scintillation system is shown in figure S-3. The basic mode of detection, the types of fluors used, and the role of the photomultiplier tube, the high voltage supply and the preamplifier were discussed in experiment above. The function of these components in a scintillation spectrometer are basically the same.

In scintillation spectrometry there is one important aspect which must be considered if accurate, quantitative measurements of radiation energy are to be made; namely, the intensity of the scintillation produced by the incident radiation is proportional to the energy **absorbed** by the fluor. If the energy of the incident radiation is totally absorbed, or not at all, no problem is created. If the energy of the incident radiation is only partially absorbed by the fluor, a part being lost through scattering, a distortion of the facts will result.

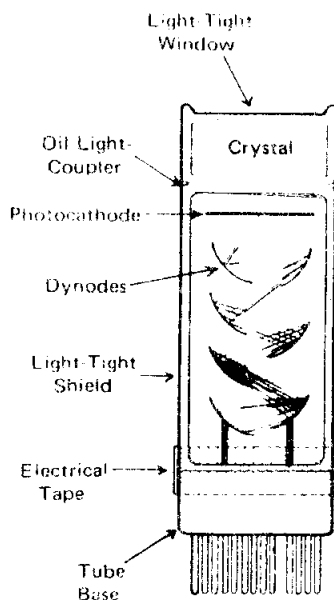


Figure s-1 Scintillation detector.

**Beta fluors**-Beta-ray spectrometers which utilize magnetic fields are superior to scintillation spectrometers but these instruments are quite expensive. Beta scintillation detectors do not have the accuracy and resolution available with the magnetic type. This is due largely to backscattering of beta particles from the surface of the fluor. When backscattering occurs, only a part of the beta energy is dissipated in the fluor so the distribution of scintillation intensities is not proportional to the true distribution of beta energies. Beta fluors for scintillation detection should have a low Z to minimize backscattering. It is for this reason that anthracene and other fluorescent carbon compounds are preferred to sodium iodide. In addition, backscattering can be minimized by a careful consideration of the geometry.

**Gamma fluors** - The energy of electromagnetic radiation is transferred to a fluor usually a sodium iodide crystal -almost exclusively by two processes, the photoelectric effect and the Compton effect. Pair production become predominant at high photon energies.

In a photoelectric interaction, the entire energy of the photon is transferred to an electron call - a photoelectron. An electron is a highly ionizing particle and has a path length of less than a millimeter in the crystal. The intensity of the scintillation produced along the path of this photoelectron is proportional to the incident photon energy.

A Compton electron acquires only a part of the incident photon energy, the balance often being lost from the crystal as a scattered photon. See figures S-2 (a) Sometimes this scattered photon may undergo a collision itself before it emerges from the crystal. If this second collision involves the photoelectric effect (figure s-2 (b)), then again the entire energy of the incident photon is dissipated in the crystal and the proportionality of total scintillation intensity to incident photon energy is preserved.

If the incident photon energy is in excess of 1.02 MeV, pair production also occur. This process is always accompanied by 0.51 MeV annihilation radiation. Thus, a spectral peak will occur not only at an energy  $E_\gamma$  corresponding to that the incident photon but also at  $E_\gamma - 0.51$  MeV and at  $E_\gamma - 1.02$  MeV due to the loss of either one or both of the annihilation rays.

Two things can be done to assure maximum absorption of photon energy in a gamma fluor. First, the fluor should be as dense as possible.

That is why a crystal of sodium iodide is used in preference to anthracene. Secondly, the crystal should be as large as possible. Small crystals are satisfactory for low energy photons but they will produce distorted spectra of high energy photons. Large crystals are always more satisfactory and give much better resolution of photon energies. Their disadvantage is expense.

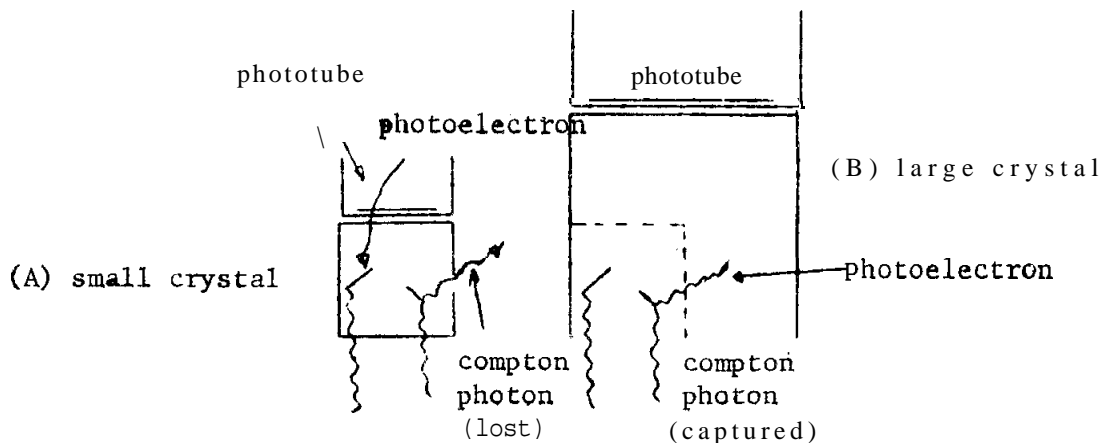


Figure s-2 ABSORPTION OF GAMMA ENERGY BY A SCINTILLATION CRYSTAL.  
 The larger the crystal the greater the probability of retaining the entire energy of the incident gamma ray within the crystal.

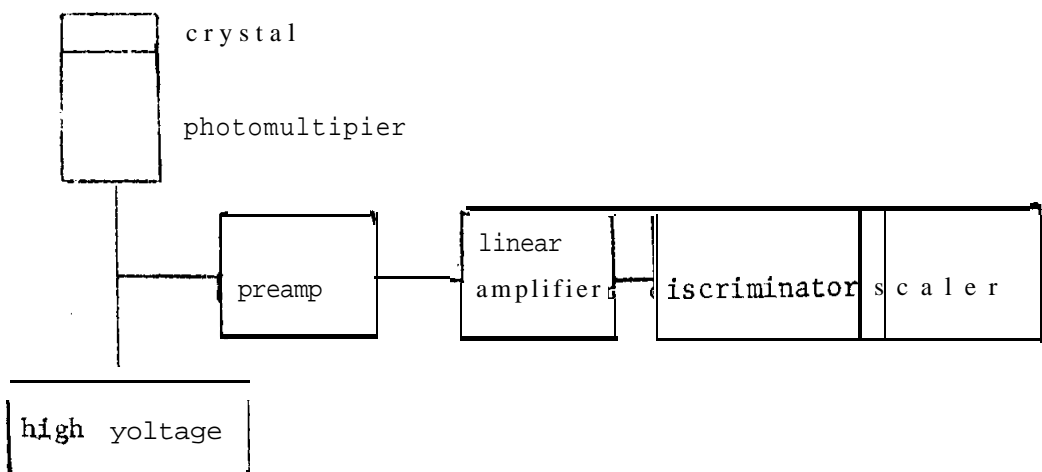


Figure s-3 BLOCK DIAGRAM OF A BASIC SCINTILLATION COUNTING SYSTEM.

**Pulse-Height Analysis** - By means of a photomultiplier tube, an electrical pulse is produced by each scintillation in the crystal. If it is assumed that the efficiency of light collection by the photocathode is independent of the location of pulse in the crystal, and that an electron is emitted from the photocathode for each photon striking it, then the pulse-height is proportional to the scintillation intensity. This is not entirely true, however, and accounts, in part, for the dispersion of spectral peaks.

A preamplifier transmits these small pulses to an amplifier where they are linearly amplified to produce output pulses ranging from 0-1000 volts (0-10 volts in transistorized equipment)

As its name implies, the pulse-height analyzer or sorts pulses according to their height (amplitude of voltage). Since pulse-height is proportional to the incident radiation energy, the pulse-height analyzer is, in fact, analyzing the radiation energy. The **base-line** setting  $E$  of the analyzer establishes the lower discriminator level. Pulses with an amplitude less than  $E$  are rejected and do not appear at the analyzer output. The **window**  $\Delta E$  establishes the range of pulse amplitudes greater than  $E$  which will be passed by the analyzer and which will consequently appear at the analyzer output. Pulses with an amplitude greater than  $E + \Delta E$  are also rejected by analyzer. Thus, of all the pulses appearing at the analyzer input, only those with an amplitude between  $E$  and  $E + \Delta E$  pass through to the scaler or rate meter.

**Differential Spectra** - If the base line (lower level)  $E$  is adjusted to 0.0 volt and the window  $\Delta E$  to 1.0 volt (i.e., 1% of the range of 100 volts) the activity recorded by the scaler will be equal to the number of pulses with amplitudes between 0 and 1 volt. If  $E$  is now adjusted to 1 volt,  $\Delta E$  remaining the same, the activity recorded will be equal to the number of pulses with an amplitude between 1 and 2 volts. This process is repeated,  $E$  being increased by increments of 1 volt, until a series of 100 measurements have been made. These activities, plotted as a function of  $E$ , will yield a **differential spectrum**.

In the instance cited, 100 observations were recorded, each representing the activity of 1 volt increments. These increments are referred to as **channels** and here 100 channels have been measured. The instrument described, however, is a **single channel analyzer** because the measurements must be made a single channel at a time. **Multichannel analyzers** allow pulses in all channels to be recorded simultaneously, the time requirement is reduced proportionately. If the spectra of very short-lived isotopes are to be measured, a multichannel analyzer is essential.

**Analysis of Gamma Spectra** - Figure S-4 depicts the theoretical spectrum for cobalt-60. The spectrum obtained in practice is illustrated in figure s-5. The obvious differences between these spectra are caused by instrumental and geometrical limitations.

That the 1.17 and 1.33 MeV gamma rays emitted by cobalt-60 are monoenergetic is well established. They should produce the line spectrum of figure s-4. Such a spectrum would be obtained only if :

1. none of the energy of an incident photon were lost from the crystal through scattering. (If loss were to occur through the use of a crystal of finite dimensions, the theoretical spread of Compton photon energies is given by the area enclosed by the dotted line.)

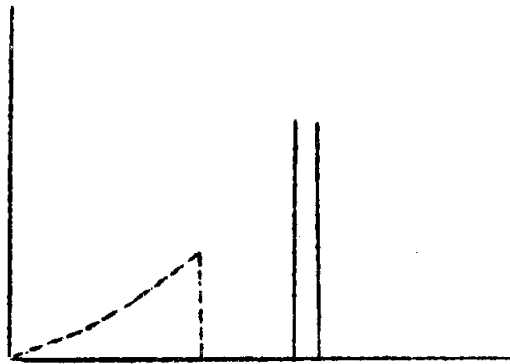


Figure s-4 - THEORETICAL SPECTRUM FOR COBALT - 60. The area within the dotted line represents theoretical Compton scattering with finite crystal.

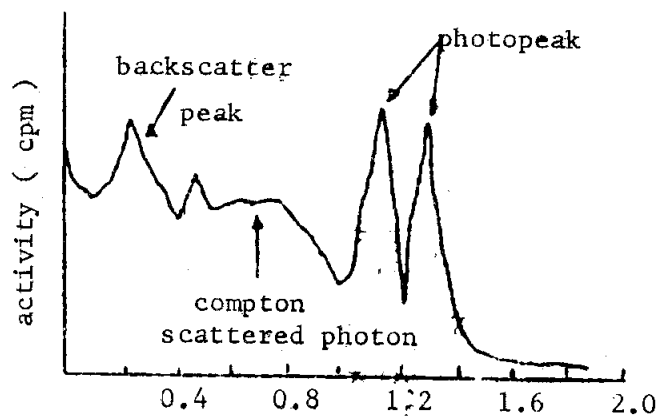


Figure s-5 - PRACTICAL SPECTRUM FOR COBALT - 60. Prepared by use of a single channel, recording spectrometer.

2. the scintillation intensities produced in the crystal were strictly proportional to the incident energy dissipated in the fluor,
3. the number of photons reaching the photocathode were strictly proportional to the number of photons produced in a scintillation,
4. the number of electrons emitted from the photocathode were proportional to the number of photons striking it, and
5. perfect proportionality were obtained throughout the electronic section of the pulse-height analyzer.

The first problem of a practical instrument concerns resolution. Resolution (See figure s-6) is calculated as the ratio of the width of a photopeak (measured at a point equal to one-half the amplitude of the peak) to its energy.

$$\% \text{ Resolution} = 100 \Delta E/E \quad (1)$$

Thus, if a photopeak with a maximum at 80 volts had width of 8 volts at the midpoint of its amplitude, the resolution of the system would be  $100 (8/80) = 10\%$ . The dispersion of activities about the maximum of a peak is approximately Gaussian.

A second problem concerns Compton scattering, Compton scattered radiation accounts for most of the activity observed at energies below the photopeak.

The **Compton edge** (75) corresponds to the maximum energy  $E_{ce}$  which can be imparted to an electron in a scintillation crystal through Compton scattering. This occurs when the Compton photon is emitted at an angle of  $180^\circ$  to the incident ray. Thus

$$\frac{0.511}{E'} - \frac{0.511}{E_\gamma} = 1 - \cos \theta = 2 \quad (2)$$

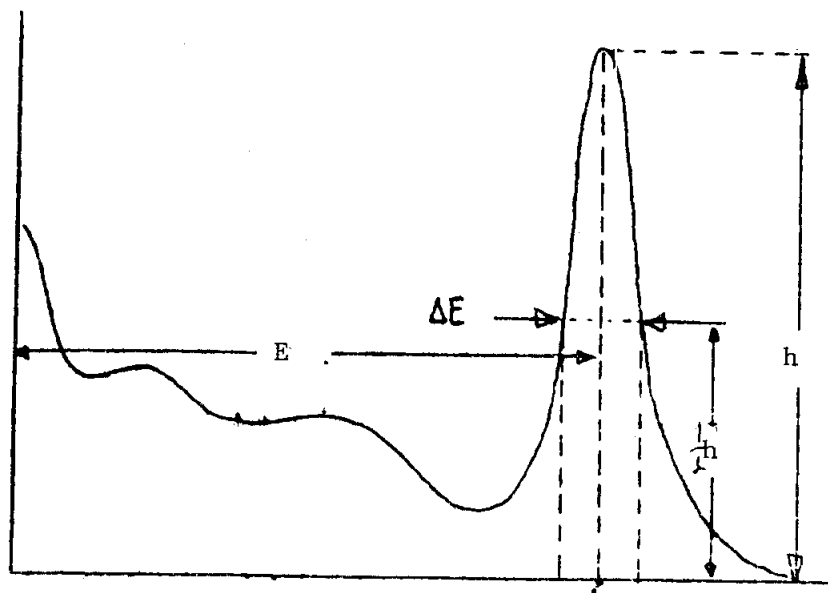
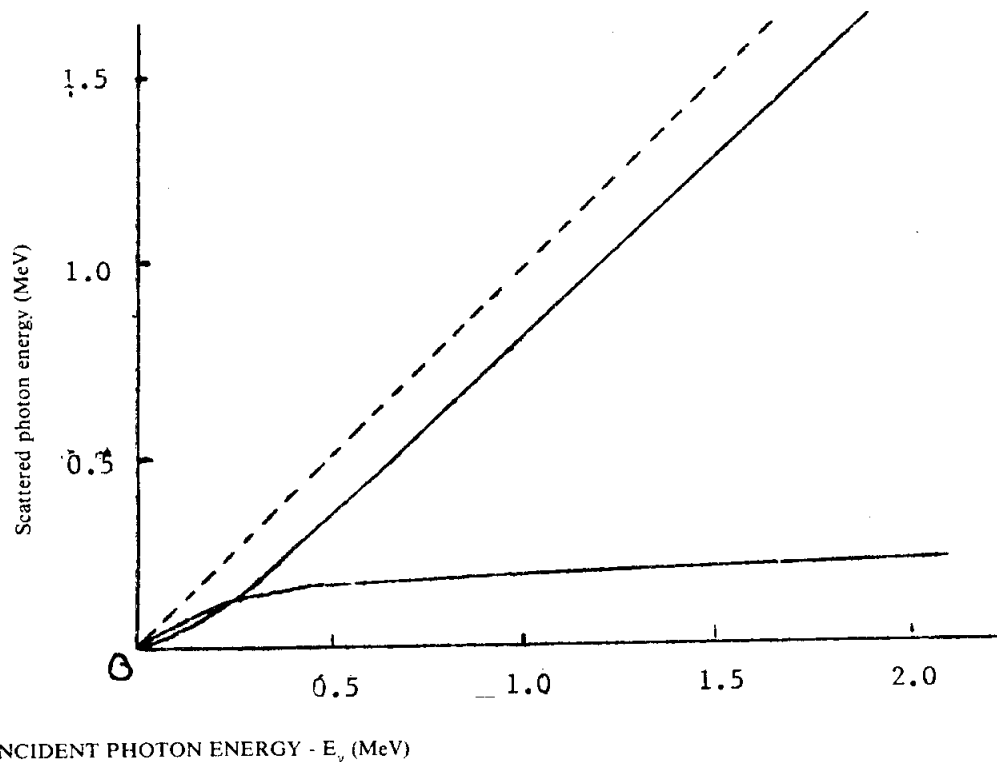


Figure s-6 - PHOTOPEAK RESOLUTION Resolution is usually expressed as  $\% \text{ Resolution} = 100 \Delta E/E$



INCIDENT PHOTON ENERGY -  $E_\gamma$  (MeV)

Figure s-7 - COMPTON EDGE AND BACKSCATTER ENERGIES.

Since the Compton photon and the Compton Electron share the incident gamma energy,

$$E_{ce} = E_\gamma - E' \quad (3)$$

Simultaneous solution of equations 2 and 3 for  $E_{ce}$  yields

$$E_{ce} = \frac{E_\gamma^2}{E_\gamma + 0.255} \quad (4)$$

A **backscatter peak** will often appear in a spectrum. It is caused by radiation which passes completely through the crystal without interaction and which is then scattered through  $180^\circ$  by the shielding or by parts of the detecting equipment, back into the crystal where it is detected. The energy of the backscatter peak can also be calculated from

$$E_{bs} = E - E_{ce} \quad (5)$$

### MATERIALS :

Gamma-ray spectrometer ;  $^{137}\text{Cs}$  and other gamma sources.

### PROCEDURE :

1. Calibrate the spectrometer against  $^{137}\text{Cs}$  or other standard source.
2. Plot a differential spectrum for a gamma emitting isotope.

3. Calculate the gamma energies of the nuclide and compare with the values given in the literature.

4. From the photopeak energies, calculate the energies of anticipated backscatter peaks and determine if peak appear in the spectrum at these energies.

**PANAX** SCINTILLATION COUNTERS HAVE TWO CONNECTORS, one for the EHT and one for the signal, and these should be connected using the EHT cables supplied with the instrument as follows :-

The EHT lead uses a PET type connector and this should be connected to the 'low Impedance Output' socket of the EHT module.

The signal lead is connected the input socket of the AAU-IO module.

NOTE that it is quite in order to use either of the two input sockets (one front and one rear)

The instrument is now ready for use and should be calibrated as follows :

- 1) Lower the Caesium <sup>137</sup> standard (supplied with the instrument) into the well of the scintillation crystal.
- 2) Set the EHT 'Remote/Normal' switch to normal and the EHT dial to 200V.
- 3) Set the attenuation switch on the AAU-IO to x 16 and 'Function' switch to 'lower+ Window'. Set the 'Lower Level' potentiometer to 65.2mV, 'Upper Level' to 2mV. (This is now the window width control) and scan switch to Manual. The position of the 'Fine Attenuation' control is not critical but as this is intended as a fine trimmer for the photopeak, it should be set approximately mid-way.
- 4) Set the Scaler/Timer preset switch to OFF and Test Switch to 'Normal'. Select Set Time. Display count and push the reset/start button.
- 5) Slowly increase the EHT voltage from 220V until a count rate is observed on the scaler. Continue to increase the voltage until the count rate is at maximum. Observe that further increase in EHT reduces the count rate.
- 6) Lower the EHT such that it is set about 20 volts below the peak count-rate voltage and set the scaler/timer to preset time 10 seconds.
- 7) Start the scaler/Timer and note the EHT and count rate for 10 seconds.
- 8) Increase the EHT by 2 volt steps (small divisions on inner dial) and note the count rate at each step. Continue until a peak count rate is observed in the results but ensure that this is not a false peak by doing a few more steps which should show a reduction in the count rate.
- 9) Determine the optimum EHT (peak) from these results and set and lock the EHT dial at this level.



- 10) The discriminator is now calibrated in terms of gamma ray energies between the range 20KeV (2mV) and 1MeV (100mV.) It is now only necessary to determine the shape of the energy spectrum for Caesium to enable the final window width and discriminator levels to be established.
- 11) Proceed as follows :  
Lower the disc threshold to 2mV and using the scaler/timer set to 10 seconds to obtain the count rate, note the disc level and count rate and increase the disc level to 4mV, count and note the results. Continue with this procedure up to 100 mV.
- 12) Plot the count rate (Y axis) against disc threshold (X axis) and note that the photopeak for Caesium appears at 66mV. The optimum settings can now be obtained bearing in mind that the background is directly proportional to window width and so some compromise may be necessary to achieve the best  $\frac{E^2}{B}$   
where E is the count rate  
and B is the background  
Once the settings to count the photopeaks have been obtained select 'Lower to Upper' on the function switch of the AAU-10 and dial up the required levels.  
NOTE that the lower level must also remain lower than the upper level although it is possible to cross these over.  
Ensure in setting up that neither of the two levels are set on a steep part of the curve as this would lead to an excessive drift problem.
- 13) In selecting an attenuation setting, choose a range which gives the photopeak at approximately mid-point on the discriminator. For instance, an isotope with an energy of 250KeV would best be counted on attenuation  $\times 8$ . As the attenuation is reduced by a factor of two each time, so the energy range is reduced by two at each step. Therefore, having calibrated the analyser for Caesium 137 on attenuation  $\times 16$ , this gives the following ranges :

Attenuation	Energy Range
64	80KeV - 4MeV
32	40KeV - 2MeV
16	20KeV - 1MeV
8	10KeV - 500KeV
4	5KeV - 250KeV
2	2.5KeV - 125KeV
1	1.25KeV - 62.5KeV

The gamma ray energies for any particular isotope may be obtained from physical Data and once an energy range has been established then the spectrum for that isotope should be obtained by repeating sections 11 and 12. This will enable suitable settings

for discriminator bias and window width to be found.

- 14) For automatically plotting out the spectrum on a chart recorder the AAU-10 and RTM-10 should be used in conjunction with the Panax Sweep Voltage Generator SVG-10. Calibrate the AAU-10 for Caesium as above and then determine the attenuation figure most suitable to count the isotope in question. Using the analyser on the lower + window setting with a window of 2 mV a spectrum can then be dotted by using the SVG-10 to scan the discriminator. The scan switch should be set to EXT for Automatic operation.

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