Chapter II

THEORY

2.1 The Coincidence Phenomena in Nuclear Transformations

In nuclear transformations it was known that both alpha emitters and beta-emitters may also emit gamma rays. The presence of the gamma radiations means that the product nucleus is formed in an excited state and passes to its ground state by emitting one or more gamma rays. If no gamma ray is emitted, the transition is directly to the ground state of the product nucleus. The γ-ray transitions have all been considered to have very short half-lives. Howerver, in over one hundred cases there are delayed gamma-transitions from the excited state to the lower energy states. The observed half-lives range from the order of 10^{-8} second to many years.

Since the cascade of most of radiations emitting from a nucleus undergoes transformation takes only a very short time, we may consider this succession to be a coincidence event. The study of the cascade beta-ray and gamma ray is called beta-gamma coincidence and the study of the cascade between gamma rays in nuclear transformation is called gamma-gamma coincidence.

Some experiments designed to measure nuclear constants and nuclear reaction cross sections are dependent upon the knowledge of source strength. For radio nuclides emittings at least two gamma rays in cascade the detections of gamma-gamma coincidence events of these nuclides was introduced as simple method for absolute activity measurement.

2.2 The Coincidence Circuit

A coincidence circuit is a non linear circuit having two or more imputs and one output. A pulse is delivered from the output only when the two inputs have received pulsed within a short time of each other. This short time is the resolving time of the coincidence circuit. Based on the resolving time of the coincidence circuit we may classify the coincidence events according to Chase[1] into two types. These deal with the resolving time of the order of 10^{-8} sec and longer are defined to be the slow and medium coincidence. Those deal with the resolving time of less than 10^{-8} sec is defined as the fast coincidence.

2.3 The Coincidence Counting System

The coincidence counting system for nuclear study was developed in order to detect nuclear events that occur simultaneously. In the case of the detection of two gammas transition which occur simultaneously, the system for counting may arrange in Fig. 1.

The single channel analyzer in each branch is set up in order that the restrictive energy criterion can be chosen. If a multichannel analyzer is available the coincident multichannel spectrometry system can be arranged. These arrangements have been described in details by Wapstra[2].

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[1] R. L. Chase, Nuclear Pulse Spectrometry, (New York: McGraw-Hill Book Co., 1961)

[2] A. H. Wapstra, "The Coincidence Method; Procedures for Investigation of Disintegration Schemes," in Alpha-, Beta- and Gamma-Ray Spectroscopy, ed. K. Siegbahn (Amsterdam: North Holland Pub., Co., 1968) p. 539-555.

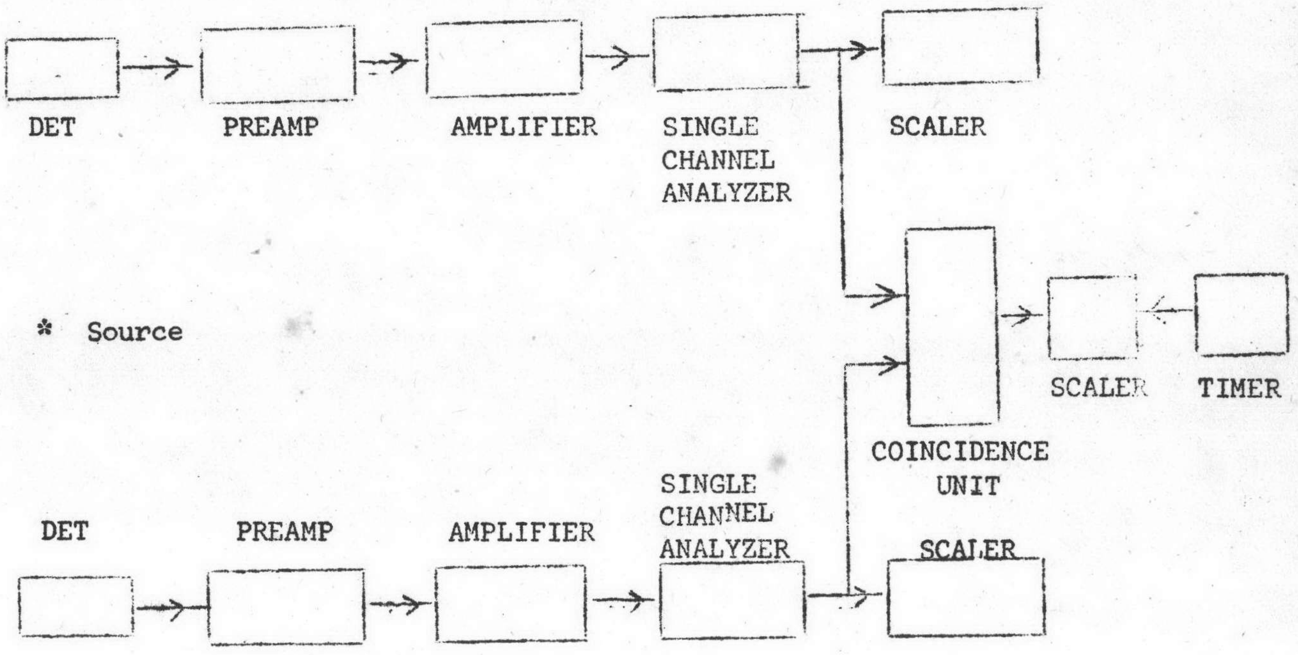

Fig. 1 Block diagram of the simple coincidence counting system.

2.4 Absolute Activity Measurement by Gamma-Gamma Coincidence Method

Consider two successive gamma radiations says A and B emitted in coincidence, and suppose there are N_o radiations of type A emitted per unit time interval and hence N_o radiations of type B. If two detectors are set up such that one is sensitive to radiation B, the count rates in each detector n_A and n_B simply $N_o \Sigma_A$ and $N_o \Sigma_B$ where Σ_A and Σ_B are the overall efficiencies of the detectors for radiation A and B respectively. The chance of observing a count in coincidence in detectors A and B is $\Sigma_A \Sigma_B$ and the coincidence rate n_c is $N_o\Sigma_A\Sigma_B$.

Since $n_A = N_o \Sigma_A$, $\Sigma_A = \frac{n_A}{N_o}$

and $n_B = N_o \Sigma_B$, $\Sigma_B = \frac{n_B}{N_o}$

$$n_c = \frac{n_A n_B}{N_o} \qquad (1)$$

Equation (1) shows that the coincidence technique in principle, affords a method of determining emission rate without the knowledge of the individual efficiency.

However complication arises in gamma-gamma coincidence counting that both counters are sensitive to both radiations. In practical gamma-gamma coincidence system a single channel analyser is useful with a channel set to cover a fraction of the photopeaks and reduce the effect of scattered radiation. Allen[3] pointed out that the over all accuracy is about 1% to 2%, improved accuracy is limited by the cross efficiency.

2.5 Short Half Life Materials

If the half life of the nuclide being measured is so short that the disintegration rate reduces significantly during the measurements, allowance must be made for the decay. Suppose the number of radioactive nuclides at the start of the measurement is N_o and at the end of the measurement, after time t, it is N_t. Hence,

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[3] R. A. Allen, "Measurement of Source Strength," in Alpha-, Beta- and Gamma-Ray Spectroscopy, ed. K. Siegbahn (Amsterdam: North Holland Pub., Co., 1968) p. 425-466.

$$N_t = N_o \{1-\exp(-\lambda t)\}$$

The number of disintegrations N in time t is

$$N = N_o \{1-\exp(-\lambda t)\}$$

$$\text{Since } N = \frac{n_{At}\, n_{Bt}}{n_{Ct}}$$

$$\frac{n_{At}\, n_{Bt}}{n_{Ct}} = N_o \{1-\exp(-\lambda t)\}$$

$$N_o = \frac{n_{At}\, n_{Bt}}{n_{Ct} \{1-\exp(-\lambda t)\}} \tag{2}$$

where n_{At} and n_{Bt} are the counts detected by detector A and detector B in time t respectively and n_{Ct} is the coincidence counts detected in time t, λ is the decay constant of the radioactive nuclides.

The activity of the radioactive nuclides at the start of the counting is,

$$A_o = \frac{\lambda n_{At}\, n_{Bt}}{n_{Ct} \{1-\exp(-\lambda t)\}} \tag{3}$$

2.6 Decay Schemes of Co-60 and Mn-56

Gamma rays emitted from the decaying nuclides of Co-60 and Mn-56 are shown in the decay schemes of Fig.2 and Fig.3.

According to the decay schemes of Co-60 and Mn-56 the coincidence between 1.17 MeV and 1.33 MeV gamma rays may be used to determine the absolute activity of Co-60 source and the coincidence between 1.811 MeV and 0.847 MeV gamma rays from Mn-56 source may be used to

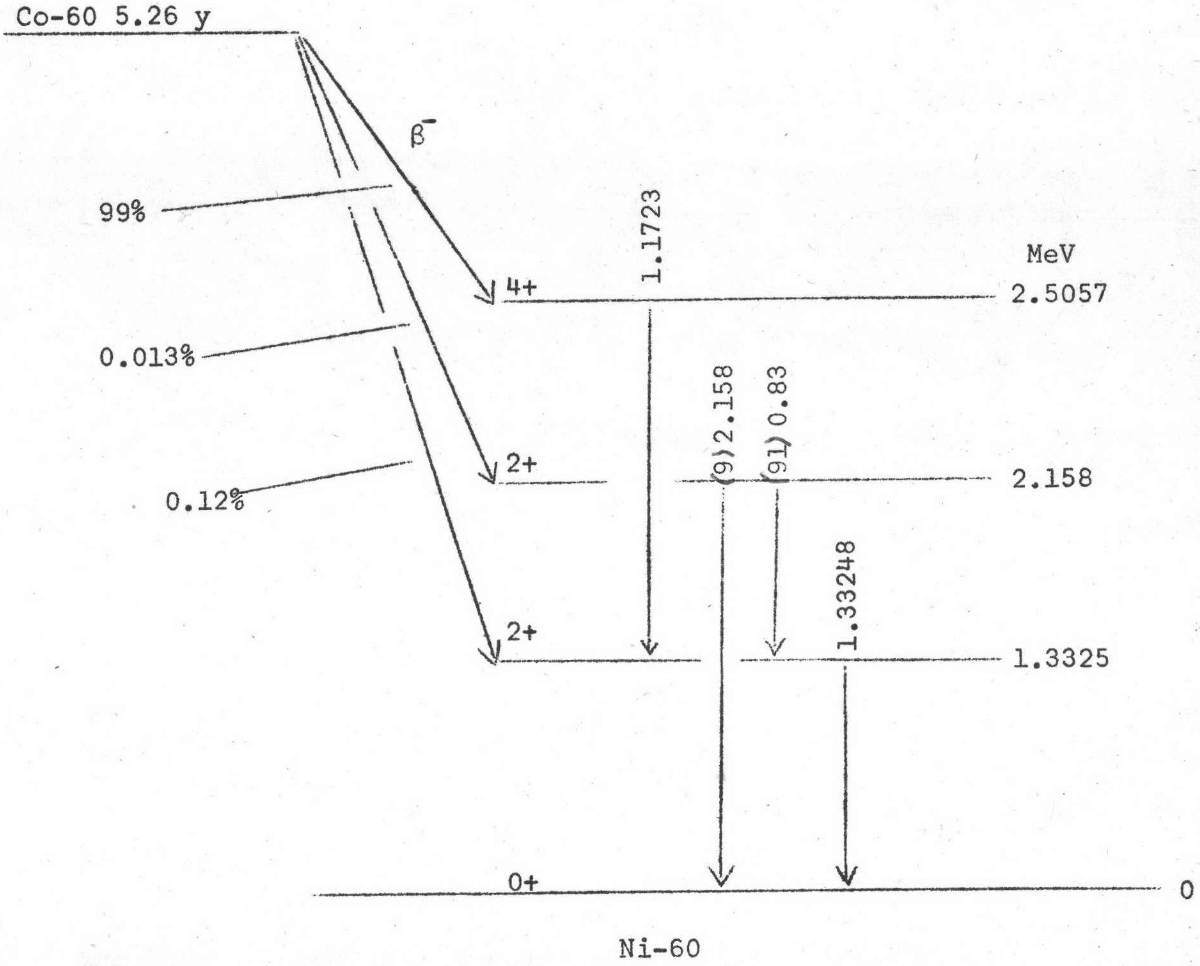

Fig. 2 Decay scheme of Co-60[4]

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[4] C. M. Lederer., J. M. Hollander and I. Perlman, Table of Isotopes 6th. ed., (New York: John Wiley and Sons., Inc., 1968), p. 194.

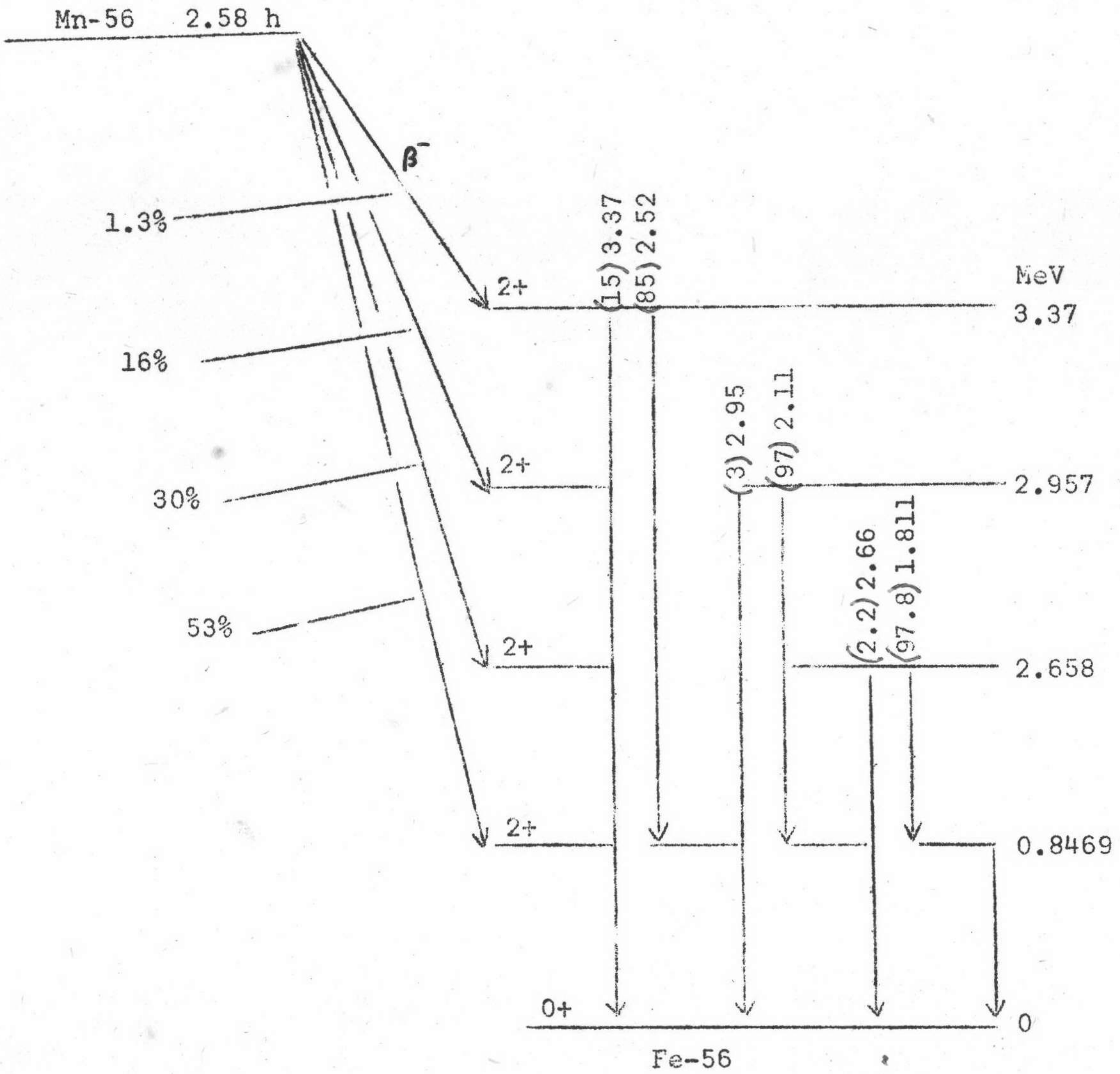

Fig. 3 Decay scheme of Mn-56[5]

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[5] Ibid., pp. 189.

determine the absolute activity of Mn-56 source.

2.7 The Absolute Activity of Co-60 and Mn-56

From the decay scheme of Co-60, the cascade of 1.17 MeV and 1.33 MeV gamma rays is 99% of the total activity. The absolute activity of the Co-60 measured by coincidence counting must be corrected. Therefore the activity of Co-60 is

$$A_o = \frac{\lambda n_{At} n_{Bt}}{0.99 n_{Ct}} \qquad (4)$$

In the decay of Mn-56, the half life of this radionuclides is only 2.58 hours and the fraction of the transition passing through the cascade of 1.81 MeV and 0.84 MeV gamma rays is only 30%, the absolute activity of the Mn-56 source is calculated from the following equation:

$$A_o = \frac{\lambda n_{At} n_{Bt}}{0.30 n_{Ct}\{1-\exp(-\lambda t)\}} \qquad (5)$$