

MEASUREMENTS OF THE RATIOS OF INTERNAL CONVERSION
COEFFICIENTS OF CASCADE TRANSITIONS FOLLOWING
ELECTRON CAPTURE BY A SUM
COINCIDENCE TECHNIQUE

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PREFACE AND ACKNOWLEDGEMENTS

This thesis has been written in two parts. Part I contains the theory, description and results of an experiment to measure the ratios of the conversion coefficients of cascade gamma rays using a new sum coincidence technique. To do this work a solid state electron detector was used, the properties of which were not fully known. Part II contains the work carried out on the electron detector, this work being directed primarily in such a way as to yield that data concerning the detector which was necessary to complete Part I of this thesis.

I must first express my sincere gratitude to Dr. S. K. Sen for his helpful and extremely enthusiastic supervision throughout this work. I wish also to thank Dr. K. I. Roulston for many constructive discussions, Dr. R. D. Connor for the use of the beta ray spectrometer and Dr. B. G. Hogg for the use of the multi-channel analyser. I am deeply indebted to Mr. R. D. Ross for his help with the work on the beta ray spectrometer and to Dr. D. P. Kerr for his friendly and valuable assistance on many occasions. My thanks are also due to the National Research Council of Canada for some financial assistance in carrying out this work.

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ABSTRACT

A recently proposed sum coincidence technique, for the direct measurement of the ratios of internal conversion coefficients of cascade transitions, has been shown to yield values for these ratios which are in excellent agreement with those obtained by other methods. This new method is independent of the relative intensities of the cascade transitions and of the half life of the parent isotope. Cascade transitions in the levels of As^{75} and Cs^{131} have been studied.

The ratios of the total internal conversion coefficients for cascades from the 401 keV level in As^{75} have been found to be: $\frac{\alpha_{121}}{\alpha_{280}} = 5.5 \pm 0.6$; and $\frac{\alpha_{136}}{\alpha_{265}} = 4.0 \pm 0.3$.

The value obtained for the ratios of the K conversion coefficients of the 124 keV - 496 keV cascade in Cs^{131} was 65 ± 5 .

Measurements on the K/(L+M) ratios for the 124, 216, 373 and 496 keV transitions in Cs^{131} yielded the following values:

$$(K/(L+M))_{124} = 2.6 \pm 0.2; \quad (K/(L+M))_{216} = 3.1 \pm 0.3;$$

$$(K/(L+M))_{373} = 4.6 \pm 0.5; \quad (K/(L+M))_{496} = 6.1 \pm 0.5.$$

INTRODUCTION

A knowledge of the internal conversion coefficients, or their ratios, is of importance to obtain some picture of the excited states of a particular nucleus. Theoretically, from the internal conversion coefficients of transitions it is possible to predict the spin and parity changes involved in nuclear transitions, and hence the experimental values of the internal conversion coefficients provide a good test for the theories of nuclear energy levels. In this thesis is presented a direct method of measuring the ratio of the internal conversion coefficients of cascade transitions. The method has been applied here only to cascade transitions following electron capture as the beta spectra are much simplified for this type of decay.

The method described in this thesis utilizes a sum coincidence technique and has the following main advantages over the usual method employing a beta ray spectrometer.

- i) It is a direct method since it involves only one experimental measurement as opposed to other methods which require a knowledge of both the conversion electron and the gamma ray intensities.

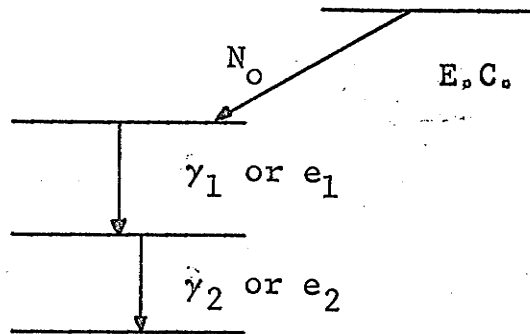
ii) The method is independent of the half life of the decaying parent isotope.

THEORY OF THE SUM COINCIDENCE TECHNIQUE

This method of measuring internal conversion coefficients of cascade transitions by a sum coincidence technique was proposed by S. K. Sen¹⁾ and subsequently reported by Sen and Hogg²⁾. The method relies upon a sum coincidence between a conversion electron from one part of the cascade and a gamma ray from the other part as shown in Fig. 1.

Fig. 1:

Simple Cascade Transition



Electron capture sources had the advantage that all electron gamma coincidences that were observed were from cascade transitions. The internal conversion coefficient, α , is defined by the equation:-

$$\alpha = \frac{N_e}{N_\gamma}$$

where:

N_e is the number of conversion electrons and N_γ is the number of gamma rays from the same transition. If we consider a simple cascade transition, such as that shown in

Fig. 1, then the following equations can be deduced:

$$N_{e_1} = \frac{N_0}{(1 + \alpha_1)} \cdot \alpha_1 \cdot e_{\beta_1} \cdot \omega_{\beta} \quad \dots (1)$$

where:

N_{e_1} is the number of conversion electrons from the first transition which give a pulse in the total absorption peak of the electron detector;

N_0 is the number of cascade transitions;

α_1 is the conversion coefficient of the first transition;

e_{β_1} is the peak efficiency of the electron detector for conversion electrons from the first transition;

and ω_{β} is the solid angle of the electron detector, as seen by the source.

Similarly, for conversion electrons from the second transition:

$$N_{e_2} = \frac{N_0}{(1 + \alpha_2)} \cdot \alpha_2 \cdot e_{\beta_2} \cdot \omega_{\beta} \quad \dots (2)$$

If we now look for coincidences between conversion electrons of the first transition and the following cascade gamma ray we obtain:

$$N_{e_1 \gamma_2} = N_{e_1} \cdot \frac{1}{(1 + \alpha_2)} \cdot e_{\gamma_2} \cdot \omega_{\gamma} \quad \dots (3)$$

where:

$N_{e_1 \gamma_2}$ is the number of pulses of type N_{e_1} which are recorded in coincidence with a photo-peak pulse in the gamma detector caused by a gamma ray from the second part of the cascade;

e_{γ_2} is the photo-peak efficiency of the gamma detector for photons from the second transition;

and ω_γ is the solid angle of the gamma detector as seen by the source.

Similarly, for coincidences between a conversion electron from the second transition and the preceding gamma ray, we obtain:

$$N_{e_2 \gamma_1} = N_{e_2} \cdot \frac{1}{(1 + \alpha_1)} \cdot e_{\gamma_1} \cdot \omega_\gamma \quad \dots (4)$$

Dividing equation (3) by equation (4) and substituting for N_{e_1} and N_{e_2} from equations (1) and (2), we obtain:

$$\frac{N_{e_1 \gamma_2}}{N_{e_2 \gamma_1}} = \frac{\alpha_1}{\alpha_2} \cdot \frac{e_{\beta_1}}{e_{\beta_2}} \cdot \frac{e_{\gamma_2}}{e_{\gamma_1}} \quad \dots (5)$$

If we now display these coincidence pulses from the electron detector on a multi-channel pulse height analyzer, we will get an area A_1 corresponding to $N_{e_1 \gamma_2}$ and an area A_2 corresponding to $N_{e_2 \gamma_1}$ so that equation (5) can be written as:

$$\frac{\alpha_1}{\alpha_2} = \frac{A_1}{A_2} \cdot \frac{e_{\beta_2}}{e_{\beta_1}} \cdot \frac{e_{\gamma_1}}{e_{\gamma_2}} \quad \dots (6)$$

Hence we are able to find $\frac{\alpha_1}{\alpha_2}$.

By dividing equation (1) by equation (2) we obtain:

$$\frac{N_{e_1}}{N_{e_2}} = \frac{\alpha_1}{\alpha_2} \cdot \frac{N_0}{(1+\alpha_1)} \cdot \frac{1+\alpha_2}{N_0} \cdot \frac{e_{\beta_1}}{e_{\beta_2}} \quad \dots (7)$$

From the singles electron spectrum displayed on a multi-channel analyser we can obtain the areas A_1' and A_2' corresponding to N_{e_1} and N_{e_2} respectively in equation (7), so that:

$$\frac{N_0}{1+\alpha_1} \cdot \frac{1+\alpha_2}{N_0} = \frac{A_1'}{A_2'} \cdot \frac{\alpha_2}{\alpha_1} \cdot \frac{e_{\beta_2}}{e_{\beta_1}} \quad \dots (8)$$

Now $\frac{N_0}{1+\alpha_1} = N_{\gamma_1}$ for this simple cascade,

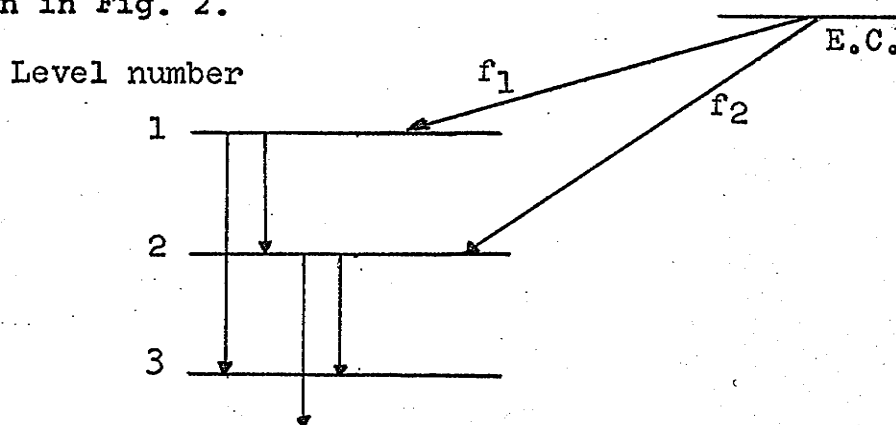
$$\therefore \frac{N_{\gamma_1}}{N_{\gamma_2}} = \frac{A_1'}{A_2'} \cdot \frac{e_{\beta_2}}{e_{\beta_1}} \cdot \frac{\alpha_2}{\alpha_1} \quad \dots (9)$$

thus enabling us to find the ratio of the gamma ray intensities of the two transitions.

There are however very few decay schemes of the simple type shown in Fig. 1 and it is shown below how equations (6) and (9) may be derived in the case of a more complicated decay scheme shown in Fig. 2.

Fig. 2:

Complex cascade transition.



Suppose we are interested in the cascade from level 1 to level 3 via level 2.

Let the fraction of transitions from level 1 to level 2 be X_1 , and from level 2 to level 3 be X_2 .

If we consider first the equations for a sum coincidence then the number of conversion electrons from the 1 to 2 transition is equal to $\frac{N_{01}\alpha_1}{(1+\alpha_1)}$ where N_{01} is the total number of transitions from level 1 to level 2 and is equal to $X_1 f_1 N_0$ where N_0 is the total number of decays, and f_1 is the fraction of the total number of electron capture transitions leading to level 1.

Hence equation (1) will become:-

$$N_{e_1} = N_{01} \frac{\alpha_1}{(1+\alpha_1)} \cdot e_{\beta_1} \cdot \omega_{\beta} \quad \dots (10)$$

The proportion of transitions from level 1 to level 2 followed by a transition from 2 to 3 is X_2 and equation (3) becomes:-

$$N_{e_1 \gamma_2} = N_{e_1} \cdot x_2 \cdot \frac{1}{(1+\alpha_2)} \cdot e_{\gamma_2} \cdot \omega_{\gamma} \quad \dots (11)$$

The number of gamma rays from level 1 to level 2 is $\frac{N_{01}}{1+\alpha_1}$ and the proportion of these followed by a 2 to 3 transition is X_2 and equation (4) becomes:-

$$N_{e_2 \gamma_1} = \frac{N_{01}}{(1+\alpha_1)} \cdot e_{\gamma_1} \omega_{\gamma} \cdot \frac{x_2 \alpha_2}{(1+\alpha_2)} \cdot e_{\beta_2} \omega_{\beta} \quad \dots (12)$$

Dividing (11) by (12) and substituting for N_{e_1} using equation (10) we obtain:-

$$\frac{N_{e_1} \gamma_2}{N_{e_2} \gamma_1} = \frac{\alpha_1}{\alpha_2} \cdot \frac{e_{\beta_1}}{e_{\beta_2}} \cdot \frac{e_{\gamma_2}}{e_{\gamma_1}} \quad \dots (13)$$

which is identical to equation (5).

In the case of the singles, we have already found N_{e_1} for this complex decay scheme and this is given in equation (10). In this equation we can substitute N_{γ_1} for $\frac{N_{o1}}{(1+\alpha_1)}$ to obtain:-

$$N_{e_1} = N_{\gamma_1} \cdot \alpha_1 \cdot e_{\beta_1} \cdot \omega_{\beta} \quad \dots (14)$$

and similarly we write for the total number of transitions

from level 2 to level 3, $N_{o2} = X_2 N_o (X_1 f_1 + f_2)$ and then

$$N_{\gamma_2} = \frac{N_{o2}}{(1+\alpha_2)} \quad \text{so that, } N_{e_2} = N_{\gamma_2} \cdot \alpha_2 \cdot e_{\beta_2} \cdot \omega_{\beta} \quad \dots (15)$$

Dividing equation (14) by (15) we obtain:-

$$\frac{N_{e_1}}{N_{e_2}} = \frac{N_{\gamma_1}}{N_{\gamma_2}} \cdot \frac{\alpha_1}{\alpha_2} \cdot \frac{e_{\beta_1}}{e_{\beta_2}} \quad \dots (16)$$

$$\dots \frac{N_{\gamma_1}}{N_{\gamma_2}} = \frac{A_1^i}{A_2^i} \cdot \frac{\alpha_1}{\alpha_2} \cdot \frac{e_{\beta_2}}{e_{\beta_1}} \quad \dots (17)$$

which is identical to equation (9).

Detectors

The electron detector was a gold-silicon p-n junction type supplied by ORTEC. It has a circular area of 25 mm^2 and the depletion layer at a bias of 200 volts was 400 microns thick, which is the range of a 400 keV electron in silicon. The pulses from this detector were amplified by an ORTEC 103-203 low noise system designed to produce double delay line clipped pulses. This type of pulse was necessary to drive a crossover pickoff fast coincidence unit.

The gamma ray detector was a $1\frac{1}{2}$ " diameter by 1" thick NaI(Tl) crystal mounted in an integral line assembly with a Dumont 6292 photo-multiplier tube. Pulses from this unit were fed, via a cathode follower, to a Nuclear Enterprises 5202 double delay line amplifier.

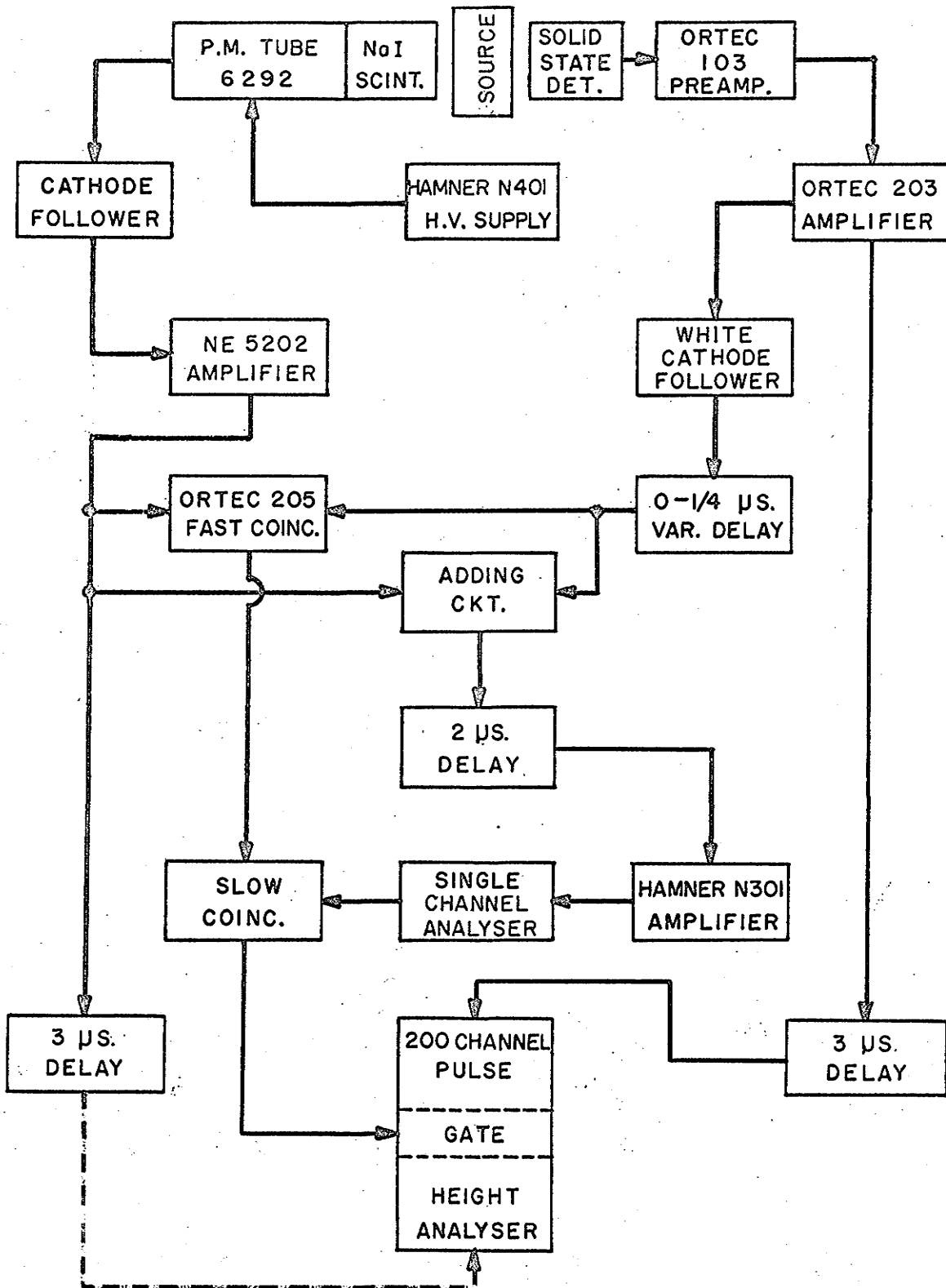
Electronics

Figure 3 shows a block diagram of the electronics used in the sum coincidence experiment. The function of this apparatus was to select those pulses from the electron detector which were in coincidence, i.e. in cascade, with a detected gamma ray, to sum these two pulses and to select only those pulses whose sum fell in a predetermined range. These pulses were then analyzed on a 200 channel analyzer and from the data the ratio of the conversion coefficients of the two

FIGURE 3

Block Diagram of the Electronics

BLOCK DIAGRAM OF THE APPARATUS



parts of the cascade was calculated using equation (6). Since the ORTEC detection and amplifying system was somewhat faster than the Nuclear Enterprises amplifier, a small delay had to be introduced between the ORTEC amplifier and the ORTEC 205 fast coincidence unit. A typical curve for the setting of this delay is shown in Fig. 4.

In parallel with the fast coincidence unit was a linear adding unit, a circuit diagram of which is given in Fig. 5. The large attenuating resistor was required for pulses from the Nuclear Enterprises amplifier as these signals were much larger than the corresponding pulses from the ORTEC amplifier. The diode was used to eliminate the negative portion of the double delay line signals since this portion created difficulties in the next amplification stage.

The time taken for the ORTEC 205 coincidence unit to give an output pulse from coincident input pulses was 2.0 microseconds, and so the added pulses were delayed by 2.0 microseconds before going to the slow coincidence unit.

The sum pulses were then amplified, to compensate for attenuation in the delay line, and sent to the slow coincidence via a single channel analyzer. This single channel analyzer set the sum level and so the slow coincidence unit triggered only when there was an electron-gamma coincidence which summed

FIGURE 4

**Coincidence Counting Rate Versus Delay Line Setting for
the 0-0.25 Microsecond Delay Line**

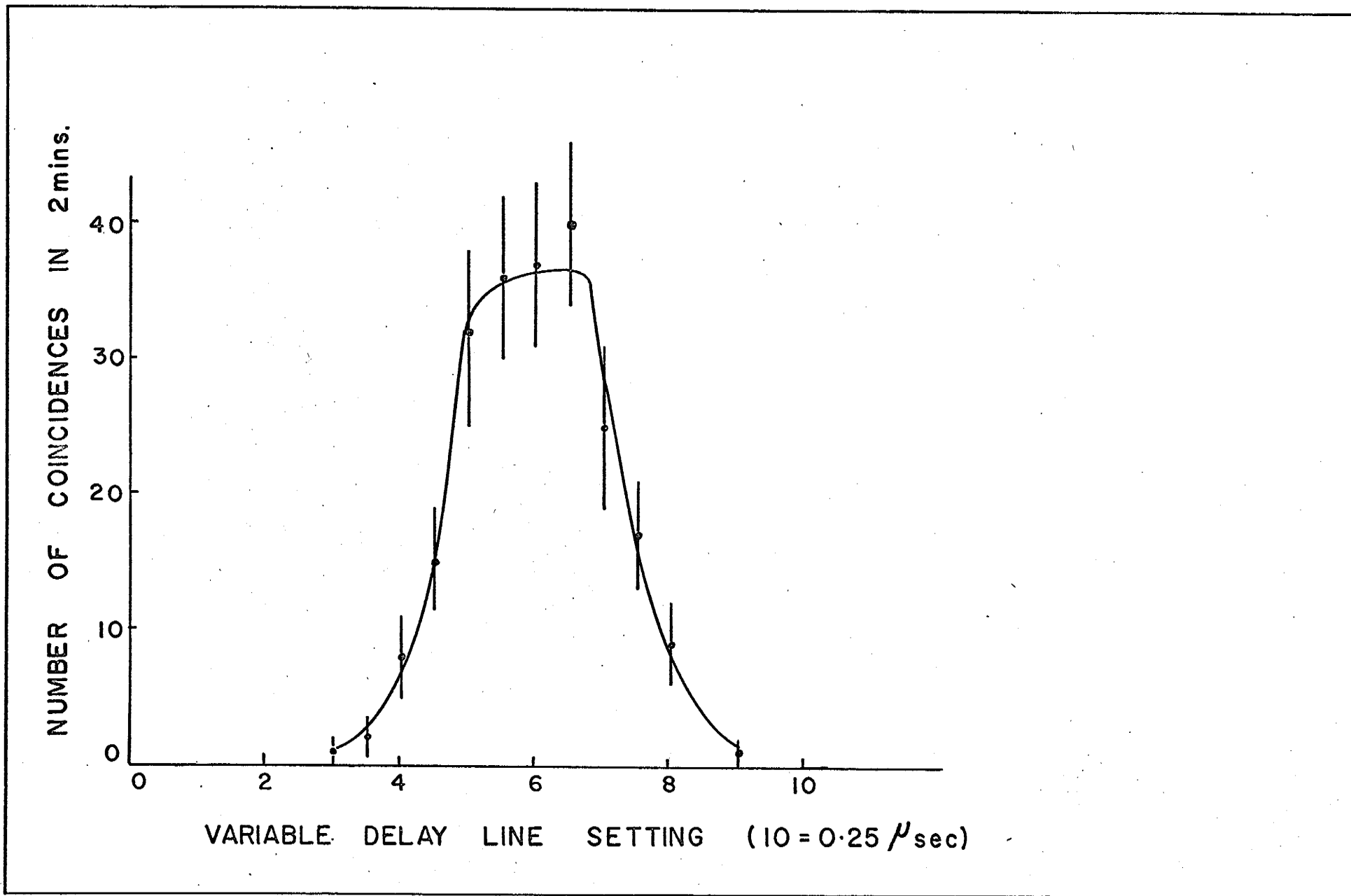
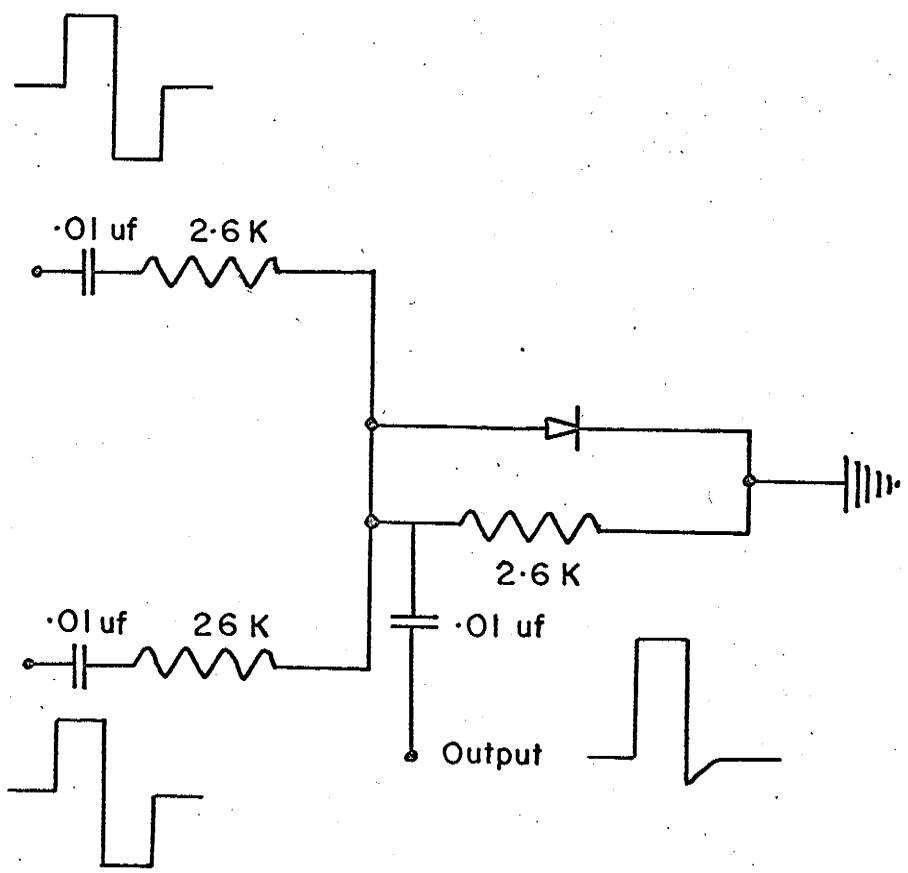


FIGURE 5

Circuit Diagram of Adding Unit

Input from ORTEC
main amplifier
(electron side)

Input from N.E.
amplifier
(gamma side)



to a preset value. The output of this slow coincidence was therefore used as a gate for the 200 channel pulse height analyzer. The latter received its signal pulses from the 203 post amplifier after a 3 microsecond delay to allow for the working time of all the logic circuits.

It was also possible to look at the sum coincidence pulses from the gamma detector, instead of those from the electron detector, and this was done whilst setting up the experiment. However, since the resolution of the pulses from the electron detector was superior to that from the gamma detector, the electron pulses were always analyzed in the sum coincidence experiment.

Setting up of the Electronics

The ORTEC surface barrier detector was used at a bias of 200 volts. The amplification gains on the 103-203 system were changed until both conversion lines of interest could be displayed together on the analyzer. Low bias values were set on the fast coincidence unit and on the single channel analyzer, and with both inputs of the fast coincidence connected to the ORTEC amplifier, the gated electron spectrum was displayed on the 200 channel analyzer. As expected, this spectrum was the same as a singles spectrum indicating that the

delay lines were of the correct length. The lower level of the single channel analyzer was then raised and the readings at which the electron conversion lines were cut off were noted.

This procedure was then repeated for the gamma ray signals from the Nuclear Enterprises amplifier, with the exception that the gain of the amplifier was adjusted so that the gamma rays of the cascade were cut off at the same discriminator settings as were the electron conversion lines.

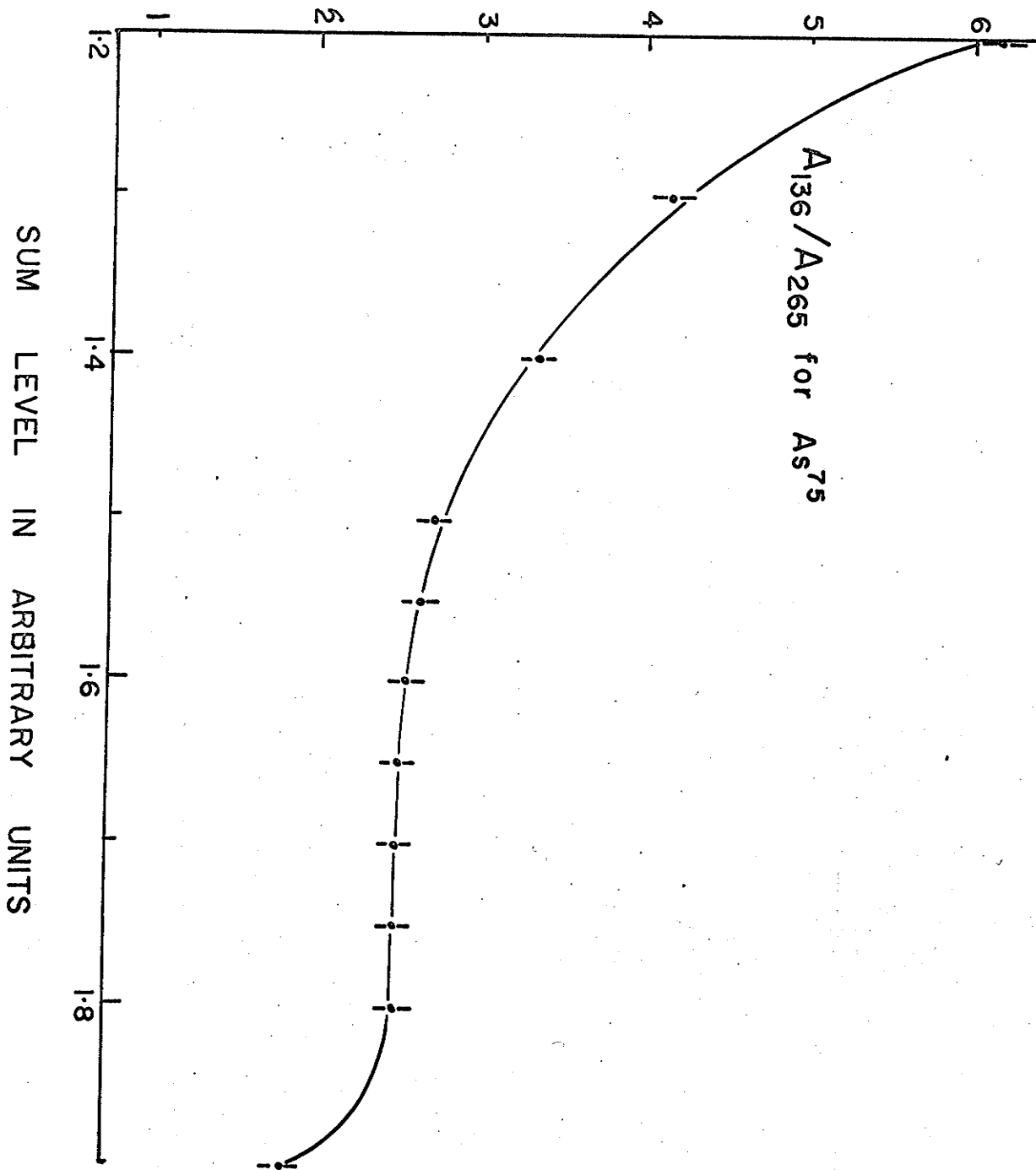
The apparatus was then reconnected as in Fig. 3 and the single channel analyzer set at a value just above that for a single transition energy, but below that for the sum energy. The 0-0.25 microsecond delay line was then set for the maximum number of gating pulses from the slow coincidence output (see Fig. 4). The single channel analyzer was then set at a value close to the one for the cascade sum and the spectrum viewed on the 200 channel analyzer. A number of spectra were taken at slightly different single channel analyzer settings to ensure that the spectrum did not change with this setting. This ensured that the correct value for the sum level was being used. Fig. 6 shows the variation of sum coincidence areas over a wide range of sum levels.

From these spectra the areas under the conversion peaks were measured and these values were used in equation (6)

FIGURE 6

Variation in the Ratio of Sum Coincidence Areas With Sum
Level. (The Ratio Shown is for the Areas Under
the 136 and 265 keV Peaks for As⁷⁵)

RATIO OF SUM COINCIDENCE AREAS



to yield the ratios of the conversion coefficients. However the ratios of the photo-peak and total absorption peak efficiencies of the two detectors at the two energies under investigation had to be known. The efficiencies of the NaI crystal were taken from the Handbuch der Physik³⁾ and the efficiencies of the electron detector were measured using a beta ray spectrometer (see Part II of this thesis).

Sources

We were limited in our choice of sources by four major considerations.

1) We required a source which decayed by electron capture so that there would be no background beta radiation. This radiation would make background subtraction of the singles spectra very difficult and would also partially invalidate equation (6).

2) Conversion electrons should have energies within the energy range from 60 to 500 keV. The lower limit was set by the rapid build up of pulses due to backscattering of the electrons from the detector and thus distorting the conversion peak; the upper limit was set by the depletion depth of the detector (see Part II).

3) The transition energies of the cascade should differ by about 50 keV so that the conversion lines from each

transition could be separately resolved.

4) It was necessary to have as large an intensity as possible for the cascade transitions in order that counting times should not be longer than 2 days to get approximately 10,000 counts in one of the conversion peaks.

Two sources were chosen which satisfied these requirements and they were Se^{75} (120 days) and Ba^{131} (12 days) which decay, by electron capture, to excited states of As^{75} and Cs^{131} respectively. The levels of As^{75} had been thoroughly investigated recently^{4,5)} and hence provided us with a guide as to whether this method was feasible, whereas information on the excited levels of Cs^{131} was sparse and quite old^{6,7)} and we hoped to provide useful information on this isotope.

The isotopes were obtained from Oak Ridge National Laboratory U.S.A. as chlorides dissolved in concentrated hydrochloric acid. Their specific activities were 7.6 mc/ml for the Se^{75} and 0.15 mc/ml for the Ba^{131} .

Source Preparation

One drop of the radioactive source solution was dried at the centre of a gold plated V.Y.N.S. film which was supported on an aluminum planchette ring. Details of the preparation of the source backing and gold plating are given in a previous thesis from this department⁸⁾.