1-1-1965

A beta-gamma angular correlation experiment using arsenic-74.

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A β-γ ANGULAR CORRELATION EXPERIMENT USING As^{74}

BY

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A Thesis
Submitted to the Faculty of Graduate Studies through the
Department of Physics in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
at The University of Windsor

Windsor, Ontario

1965

ABC 5894

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ABSTRACT

In this thesis, the theory of beta-gamma angular correlation is discussed briefly. Beta decay is analysed including allowed and first forbidden beta decay as well as a method of analysing data from the A_2 coefficient to determine which nuclear model is applicable. The corrections applied to the experimental measurements are introduced. An experiment is performed which measures the beta-gamma angular correlation coefficient, A_2, for the cascade $2^-(\beta^+)2^+(\gamma)0^+$ in the positron decay of As^{74} to Ge^{74} and for the cascade $2^-(\beta^-)2^+(\gamma)0^+$ in the negatron decay of As^{74} to Se^{74}, as a function of energy (W).

NEGATRONS

W	A_2
1.6	0.012 ± 0.005
1.8	-0.045 ± 0.006
2.0	-0.044 ± 0.006

POSITRONS

1.8	0.015 ± 0.006
2.0	0.019 ± 0.004
2.1	0.030 ± 0.005
2.2	0.025 ± 0.005

The positron data is used to examine the structure of the first excited level in Ge^{74}. The negatron data was not used due to insufficient precision or not enough points. Both the shell model and the collective model can be made to fit the positron data. The satisfactory shell model configurations found are $(f_{5/2})^2\ (g_{9/2})^{\nu}$, $(f_{5/2})^{\pi}\ (g_{9/2})^2$, and $(f_{5/2})^{\pi}\ (g_{9/2})^4$, where π and ν are even numbers of protons and neutrons respectively. In order to distinguish between the above configurations and a rotational excitation, more data, such as the shape factor and the beta-circularly polarized-gamma directional correlation coefficient, is required.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr. E.E. Habib; without whose guidance and counsel this experiment could not have been carried out.

My thanks go to Dr. Ogata who performed the calculations to determine which nuclear model was applicable. I would like to express my gratitude to Mrs. Robert Armstrong for typing the manuscript.

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THEORY

1. Angular Correlations

The probability of emission of a particle or quantum by a radioactive nucleus depends in general on the angle between the nuclear spin axis and the direction of emission. Under ordinary circumstances the total radiation and the radiation for an individual transition $I_A \xrightarrow{R} I_B$ from a radioactive sample is isotropic because the nuclei are randomly oriented in space.

However, in a two step cascade transition, such as $I_A \xrightarrow{R_I} I_B \xrightarrow{R_{II}} I_C$, where R denotes the type of radiation, eg. (γ, α, β, e^-), there is often an angular correlation between the directions of emission of two successive radiations, R_I and R_{II}, which are emitted from the same nucleus.

The existence of an angular correlation arises because the direction of the first radiation is related to the orientation of the angular momentum, I_B, of the intermediate level. This orientation can be expressed in terms of the magnetic-angular-momentum quantum number, m_B, with respect to the direction of the first radiation. If I_B is not zero, and if the lifetime of the intermediate level is short enough so that the orientation of I_B persists, then the direction of emission of the second radiation will be related to the direction of I_B and hence to the first radiation.

Many of the details of the complicated theory of these angular correlations have been worked out. Experimental and theoretical developments have been summarized in a number of

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excellent review articles. (BLATT.52, FRAUN.53, and DEUTSCH.51).

For the generalized $R_{,}-R_{,,}$ cascade $I_A(l_{,})I_B(l_{,,})I_C$ the angular-correlation function $W(\varphi)$ for the angle φ between the successive R's can be shown to be, (FALK. 50)

$$1.a\text{--}\quad W(\varphi)\,d\Omega = \sum_{i=0}^{i=L} A_{2i}P_{2i}(\cos\varphi)\,d\Omega$$

where A_{2i} are coefficients which depend on $l_{,}$ and $l_{,,}$, the orbital angular momentum transferred by $R_{,}$ and $R_{,,}$ respectively.

L is the [redacted] angular-momentum quantum number.

$P_{2i}(\cos\varphi)$ are the even Legendre Polynomials.

There are rigorous restrictions on the number of terms in eqns. 1.a; the highest even power of $\cos\varphi$ is determined by $l_{,}$, I_B, or $l_{,,}$ whichever is smallest. Thus 2L is not larger than $2l_{,}$ or $2I_B$, or $2l_{,,}$ and will be one unit less than the smallest if the smallest is odd. For example, if $I_B=0$ or $\frac{1}{2}$, $W(\varphi)=1$, and the angular correlation distribution will be isotropic.

A convenient experimental quantity is the

$$\text{Anisotropy}=A=\frac{W(180^\circ)}{W(90^\circ)}-1\,.$$

The conditions of validity of eqn. 1.a must include all the assumptions made in its derivation (for these consult EVANS.55).

The information that can be obtained from angular correlation work depends on the type of radiation observed (α, β, γ, e^-) and on the properties that are singled out by the experiment (direction, polarization, energy), and on the extranuclear fields acting on the nucleus. Here we assume that the decaying nuclei are free, ie., that negligible extranuclear fields act on the nucleus and disturb its orientation in the intermediate state. From $\alpha-\gamma$ and $\gamma-\gamma$ directional correlation information about the spins of the nuclear levels, but not the parities, can be obtained. The relative parities can be determined, however, if one observes in addition to the direction also the polarization of the gamma-rays, or if one measures the directional correlation between conversion electrons(e^-). The directional correlation of a beta-gamma cascade depends not only on the nuclear spins and parities, but also on the matrix elements involved in the beta-transition.

In the first transition of a beta-gamma cascade, an electron and a neutrino are emitted simultaneously. Formally, this event is described by treating the process as if a neutrino (antineutrino) enters the nucleus and a negatron (positron) is emitted. In a beta-gamma correlation experiment one measures the direction of the electron while the neutrino escapes unobserved. The theoretical calculation of the angular correlation thus necessitates an averaging over all neutrino directions and over the spins of the neutrino and the electron. In our case for a first forbidden beta-transition the expression for the beta-gamma directional correlation is (MAT.63). Units used $\hbar = m_0 = c = 1$

1.b— $N(W,\varphi) = 1+A_2P_2(\cos\varphi) = 1 + \epsilon(W)(\text{[illegible]})(\frac{3}{2}\cos^2\varphi - \frac{1}{2})$

2. <u>Beta Decay Theory</u>

In "Beta Decay" three processes can take place,

1.1 — $n \rightarrow p + e^- + \bar{\nu}$

1.2 — $p \rightarrow n + e^+ + \nu$

1.3 — $p + e^- \rightarrow n + \nu$

In 1.1, a neutron changes into a proton plus an antineutrino and a negatron; in 1.2, a proton changes into a neutron, positron and neutrino; in 1.3, a proton captures a negatron to form a neutron and a neutrino. 1.1 is called "Negatron Emission", 1.2 is called "Positron Emission", and 1.3 is called "Electron Capture".

The leptons (electron and neutrino) may be emitted with spins parallel or anti-parallel. In the first case, the net spin $S = 1$, (triplet case), and in the second case, $S = 0$, (singlet case). In addition, these particles may possess orbital angular momentum with respect to the neucleus. The case where the orbital angular momentum, L, is zero, is called the allowed beta decay, L = 1, 2,···, 1st forbidden, 2nd forbidden,·······. The total angular momentum, J, of the leptons must obey the conservation of angular momentum

i.e. $J = L + S, \; |I_f - I_i| \leq J \leq |I_f + I_i|$ —1.4

where I_i and I_f are the initial and final nuclear spins of the transition states.

$$\text{If } \left.\begin{matrix} S = 0 \\ L = 0 \end{matrix}\right\} \text{ then } J = 0 \quad \Delta I = 0 \qquad \text{—1.5}$$

$$\text{Also if } \left.\begin{matrix} S = 1 \\ L = 0 \end{matrix}\right\} \text{ then } J = 1 \quad \left.\begin{matrix} I_i = I_f \neq 0 \\ \Delta I = 0, \pm 1 \end{matrix}\right\} \qquad \text{—1.6}$$

In these cases since L = 0, the parity of the transforming nucleus is not changed. The condition 1.5 is called the "Fermi Interaction" and 1.6 the "Gamow-Teller Interaction". Thus we have pure Fermi radiation ($\Delta I = 0$, $0 \rightarrow 0$ transition) as well as pure Gamow-Teller radiation ($I \rightarrow I \pm 1$). The allowed $\Delta I = 0$, $I_i = I_f \neq 0$ consists of both Fermi and Gamow-Teller radiation in proportions depending on the relative ease with which the requisite final nuclear states can be formed by the Fermi or Gamow-Teller couplings respectively. (KON. 59) The above rules may be generalized for higher values of L.

TABLE # I

Fermi and Gamow-Teller Interactions

Order Of Forbiddeness	Fermi F	Gamow-Teller G.T.
L = 0	$\Delta I = 0$	$\Delta I = 0, \pm 1, 0 \not\to 0$
L = 1	$\Delta I = 0, \pm 1$ $0 \not\to 0$	$\Delta I = 0, \pm 1, \pm 2$ no $0 \to 0$ no $1 \leftrightarrow 0$

Fermi Theory

The Fermi theory has been very successful in describing beta decay. Fermi constructed his theory on the model of the theory of electromagnetic radiation. Fermi assumed that the nucleons generate beta radiation in proportion to the current associated with the neutron to proton transformation or its reverse.

Where $\psi_p (\psi_n)$ describes a proton (neutron) if one agrees to treat as identical the neutron and proton co-ordinates of the transforming nucleon, then from the requirements of relativistic invariance we get the coupling energy density

$$h = g(\bar{\psi}_p \gamma_\mu \psi_n) \cdot (\bar{\psi}_e \gamma_\mu \psi_\nu) + \text{c.c.}$$

c.c. is the complex conjugate.

g is Fermi's fundamental coupling constant and is responsible for the magnitude of the interaction.

Covariant densities other than the four-vector current can be constructed within the Dirac description of the "internal state" of spin $\frac{1}{2}$ particles. The latter can be analyzed into just five independent "states of internal motion" described by a scalar (S), a tensor (T), an axial vector (A), and a pseudoscalar (P), besides the four vector (V) used by Fermi. There was not a priori reason for not expecting beta radiation to be generated by any of these. However from experimental and theoretical investigations, the form of the nuclear beta-decay interaction is well-established. We know that beta-decay violates parity completely and can be written V-A (vector-axial vector) for electron (negatron) emission (reference REV. M. 59). Parity conservation is equivalent to saying that a system is invariant under reflections; just as conservation of total angular momentum, around any axis requires invariance under rotations. The parity of a state of a nucleus is fixed but the parity of the leptons during transitions from one state of fixed parity to another is random.

TABLE II

Summary of Allowed and First Forbidden Matrix Elements

Matrix Element		λ	ΔJ	$\Delta\pi$	F or GT	L
Allowed	$C_V \int 1$	0	0	+1	F	0
	$C_A \int \sigma$ [redacted]	1	0, $\pm$ 1 (no 0 → 0)	+1	GT	0
First Forbidden	$C_A \int \gamma_5$ $C_A \int (\sigma \cdot r/i)$	0	0	-1		+1
	$C_V \int ri$ $C_V \int \alpha$ $C_A \int (\sigma \times r)$	1	0, $\pm$ 1 (no 0 → 0)	-1		+1
	$C_A \int iBij$	2	0, $\pm$ 1, $\pm$ 2 (no 0 → 0, no 1 ↔ 0)	-1		+1

Allowed and first forbidden nuclear elements and their selection rules (λ designates the rank of the transition operator, when regarded as a tensor.)

(ΔJ is the change in angular momentum or nuclear spin.)

($\Delta \pi$ is the change in parity.)

(L is the orbital angular momentum.)

2.(ii) First Forbidden Beta-Decay (WEID. 61)

From Konopinski, the interaction density, H_β , for the beta decay interaction is given by

$$H_\beta = \sum_i \sum_\mu \int \left[\psi_f^* \gamma_4^{(i)} \gamma_\mu^{(i)} (C_V - C_A \gamma_5^{(i)}) \tau_i^- \psi_i\right] \left[\psi_e^* \gamma_4 \gamma_\mu (1 + \gamma_5) \psi_\nu\right] d\tau + \text{herm. conj.}$$

where ψ_i and ψ_f are the initial and final wave fcns.

C_V and C_A are the vector and axial-vector coupling constants with values $C_V = (1.415 \pm 0.004) \times 10^{-49}$ erg cm^3

$$\frac{C_A}{C_V} = -1.19 \pm 0.04$$

The index i refers to the nucleons building up the initial and final wave fcns. ψ'_e and ψ_ν are the wave fcns for electron and neutrino, respectively.

We can compare this interaction for beta decay with the interaction of an electromagnetic current $j_\mu(r)$ with the electromagnetic field given by its vector potential $A_\mu(r)$ which is

$$\sum_\mu \int j_\mu(r) A_\mu(r) d\tau$$

The similarity is noted when the beta decay interaction is put in the form.

$$\sum_\mu \int B_\mu(r) L_\mu(r) d\tau$$

where $L_\mu(r) = \left[\psi_e^* \gamma_4 \gamma_\mu (1 + \gamma_5) \psi_\nu\right]$

which is the "lepton current", a four vector, dependent on a space co-ordinate r. $L_\mu(r)$ also depends on the magnetic quantum numbers of electron and neutrino. This "lepton current" interacts with the "baryon current"

$$B_\mu(r) = \left[\psi_f^* \gamma_5 \gamma_\mu (c_V - c_A \gamma_5) \tau^- \psi_i\right]$$

In each case two four-vectors have a point interaction. Considering first the approximations made in the simpler case of γ radiation. Here, the usual procedure consists in a multipole expansion of the vector potential of the radiation field which is suggested by the fact that the nuclear levels can be characterized by their total spin I. This is justified because a multipole of order L has a factor $(kr)^L$ in the expansion, where k is the γ energy, and r in the interaction integral is limited by the spatial extension of the current, that is, by the nuclear radius R.

Keeping the lowest order terms amounts to keeping two types of matrix elements, e.g., the M1- and E2- matrix elements in the simplest case. M1- is of order v/c in the nucleon velocities compared to the leading electric dipole term, E2- is of order kR compared to the leading term. In many transitions v/c and kR are of the same order of magnitude and therefore, in many nuclei M1- and E2- transitions have comparable widths.

In nuclear β-decay, we have the same situation, except for two facts, L_μ is not divergenceless and we have two types of interaction - vector and axial vector - rather than one, which increases the number of pertinent nuclear matrix elements.

A_μ is a divergenceless quantity with a gauge-invariant interaction. This has the consequence that there are no electromagnetic monopole transitions. This is not true for L_μ, and the transitions corresponding to the electric monopole case are called allowed transitions in β -decay.

The first nonvanishing term in the multipole expansion of A_μ is the dipole term. It has a matrix element which we can briefly denote by $\int r$ and it is (neglecting retardation) of order kR and obeys the selection rule $\Delta J = 0, \pm 1$ (no $0 \rightarrow 0$), $\Delta\pi = -1$. The corresponding terms in the expansion of L_μ lead to the matrix elements for first-forbidden β -decay.

The interaction has been found to be one of Vector-Axial Vector. The vector interaction consists of two parts, α and 1. The latter is an allowed term and contributed to the allowed transition. The former is of order v/c in the nuclear co-ordinates, and has the selection rule $\Delta J = 0, \pm 1$, (no $0 \rightarrow 0$), $\Delta\pi = -1$, and is, therefore, a first forbidden term. By keeping terms of order qr and kr in the lepton currents where k and q are electron and neutrino momentum respectively, the matrix element with the operator 1 becomes $\int r$, which obeys the selection rules for first-forbidden decay. Thus there are two first-forbidden nuclear matrix elements originating from the vector interaction, $\int\alpha$ and $\int r$.

Correspondingly, the axial vector interaction consists of two parts, σ and γ_5. The first term gives rise to an allowed matrix element if one replaces the lepton current by one. If one again keeps terms of the order qr and kr in the lepton current, this interaction gives rise to the following three first-forbidden matrix elements:

$$\int \sigma \cdot r, \quad \int \left[\sigma x r\right], \quad \int Bij = \int \left[\sigma_i x_j + x_i \sigma_j - \frac{2}{3}\delta_{ij}(\sigma \cdot r)\right]$$

Here Bij is a symmetric tensor of second rank with trace zero.

This is a convenient form because the trace is already contained in $\int \boldsymbol{\sigma}\cdot r$. The matrix $\int \gamma_5$ is already of first-forbidden type, being of order v/c.

The selection rules obeyed by the axial vector first-forbidden nuclear matrix elements are obvious:

They all have $\Delta\pi = -1$, and $\int \gamma_5$ and $\int \boldsymbol{\sigma}\cdot r$ have $\Delta J = 0$, the operators being psudeoscalars, $\int [\boldsymbol{\sigma} \times r]$ has $\Delta J = 0, \pm 1$, (no $0 \rightarrow 0$), and Bij has $\Delta J = 0, \pm 1, \pm 2$, (no $0 \rightarrow 0$)(no $0 \leftrightarrow 1$).

In an expression involving the matrix elements $\int \gamma_5$ and $\int \alpha$, which are of order v/c, the lepton current may be treated in the "allowed" approximation, i.e., electron and neutrino wave fcns may be replaced by their values for $r \rightarrow 0$. This does not hold for expressions involving the other four matrix elements, where the next term in the expansion of either the electron or the neutrino wave functions has to be taken.

2.(iii) ξ Approximation

In the ξ-approximation, we assume the following;

$$\frac{\alpha Z}{R} \gg W_o$$

where W_o is the maximum total energy of the β particles, and has its name from the fact that,

$$\frac{\alpha Z}{2R} = \xi ,$$

α is the fine structure constant,

Z is the nuclear charge,

R is the nuclear radius.

This assumption is the same as saying that the distortions due to

Coulomb forces in the wave fcn. of the electron, ψ_e, are much more important than the next term in the expansion of the plane wave, which is of order kr. Therefore, all terms of order αZ are kept, whereas, terms of order qR or kR are dropped. (k and q are the electron and neutrino momenta.) As a result of this, all first-forbidden quantities in this ξ approximation have the same energy and angular dependence as the allowed ones.

The spectrum shape factor, $\beta - \gamma$ angular correlation co-efficient, etc. can be obtained from the allowed case by making the following substitutions for the allowed matrix elements (KOT. 59)

$$\left.\begin{aligned} -C_V\int 1 &\rightarrow + C_A\int \gamma_5 + \xi C_A \int (\sigma\cdot r)/i = V \\ C_A \int \sigma &\rightarrow - C_V \int \alpha + \xi C_A \int \sigma \times r + \xi C_V \int ir = -Y \end{aligned}\right\} \quad 1.7a$$

The notation used for the nuclear matrix elements is

$$\left.\begin{aligned} \eta w = C_A\int \sigma\cdot r, \quad \eta\xi' v = C_A\int i\gamma_5, \quad \text{for } \lambda = 0, \\ \eta u = C_A\int i\sigma \times r, \quad \eta\xi' y = \mp C_V \int i\alpha, \eta x = \mp C_V\int r, \quad \text{for } \lambda = 1 \\ \eta z = C_A\int B_{ij}, \quad \text{for } \lambda = 2 \end{aligned}\right\} \quad 1.7b \; (\mp \text{ for } \beta^{\mp})$$

The nuclear parameters u, v, w, x, y and z, are the ratios of the various matrix elements compared to a standard matrix element, η, so that $|\eta|^2$ can be taken out as a common factor in the transition probability. The magnitude of $|\eta|^2$ is determined only from the ft value. (KOT. 59)

$$f_c t = \pi^3 \ln \frac{2}{|\eta|^2}$$

$$f_c = \int_1^{W_o} F(Z,W)pWq^2 \left(\frac{p^2 + q^2}{12}\right) dW$$

is called the Corrected Integrated Fermi Function.

$$f = \int_1^{W_o} F(Z,W)pWq^2 \, dW$$

is called the Integrated Fermi Function.

where $F(Z,W)$ = Fermi function

W_o = transition end point energy.

The factor ξ^1 appearing in the definitions of v and y, is introduced so that y and v are of order unity. One of the interesting unsolved problems of forbidden β-decay is to determine the magnitude of the parameter ξ^1 relating the relativistic to the non-relativistic matrix elements. (Crudely perhaps, $\xi = \xi^1$. It is, however, indicated in reference KOT. POSS. 58 that this relation probably does not hold for low Z.)

By substituting 1.7b into 1.7a we get

$$V = \xi^1 v + \xi w \quad \text{for } \lambda = 0 \qquad - 1.8$$

$$Y = \xi^1 y - \xi (u + x) \quad \text{for } \lambda = 1 \qquad - 1.9$$

Strictly, the parameters in the ξ expansion should be Y and V, instead of ξ.

The ξ-approximation corresponds to the assumption that

$$|V| \sim |Y| \; (\sim \xi) \sim 10 >> |w| \sim |u| \sim |x| \sim |z| \qquad - 1.10$$

If the ξ approximation holds exactly, then all the measurable quantities will have the same behavior as in the allowed case, and will depend only on the ratio of V to Y. Therefore, transitions which show deviations from the ξ approximation are examined very thoroughly.

The <u>cancellation effect</u> means, for example, that $\xi^1 y$ in Y is nearly equal to $\xi (u + x)$. Thus, this effect makes either V or Y (or both) be of the same order as the other nuclear parameters.

That is

$$|V| \text{ or } |Y| \gtrsim |w| \sim |u| \sim |x| \sim |z| \qquad - 1.11$$

The Selection Rule Effect

(a) K forbiddenness

K is the projection of the nuclear total angular momentum (J) on the nuclear axis of symmetry. The K selection rule is, for the Bohr Mottelson model,

$$|K_o - K_1| \equiv \Delta K \leq \lambda \leq |K_o + K_1| \qquad - 1.12$$

for a transition from a state with quantum number (K_o, J_o, π_o) to another state (K_1, J_1, π_1).

π stands for the parity.

λ designates the rank of the transition operator, when regarded as a tensor.

The regions established especially well for this nuclear model are $150 < A < 190$ and $A > 225$. There is no clear experimental evidence for the applicability of the Bohr-Mottelson model to the nuclei with $A < 150$, but some lighter nuclei may deform so that the K forbiddenness is applicable.

Due to K forbiddenness we have relations like,

$$\left.\begin{array}{l} |z| > |x| \sim |u| > |w| \\ \text{and } |Y| > |V| \text{ if there is no cancellation in Y.} \end{array}\right\} \qquad - 1.13$$

Since Y includes the large numerical factor ξ, we cannot say which of z and Y is larger, unless the reduction factors due to the K forbiddenness and its perturbation are known. With K forbiddenness there are large log ft values.

(b) j forbiddenness

j is the total angular momentum of a nucleon in a shell. The j selection rule is, for the shell model with spin-orbit(or jj) coupling,

$$|j_o - j_1| \leq \lambda \leq |j_o + j_1| \qquad - 1.14a$$

where j_o and j_1 stand for the initial and final nucleon spins in the beta decay for a transition from ([redacted], J_o, π_o) to ([redacted], J_1, π_1).

λ is the rank of the nuclear matrix elements. j forbiddenness is applicable to nuclei which are in the region of $50 \leq Z$. $N \leq 82$. Z and N are the numbers of protons and neutrons respectively.

According to j forbiddenness, if $\Delta j \geq 2$, then the available nuclear matrix element with $\lambda = 2$ makes the main contribution. In this j forbiddenness, we have the condition

$$|z| > |x|, \ |u|, \text{ and } |w| \qquad - 1.14b$$

We cannot say anything about the relative magnitudes of V, Y and z. In contrast to K forbiddenness which suggests an inequality, $|Y| > |V|$, j forbiddenness does not.

The opposite extreme to the ξ-approximation is the "unique forbidden" case, where $\Delta J = 2$, $\Delta\pi = -1$, so that only the matrix element B_{ij} contributes. The unique case is the case when only ONE matrix element B_{ij} contributes. The non-unique case is the case when MORE than ONE matrix element contributes; in this case the B_{ij} may or may not be among those contributing.

The $\beta - \gamma$ directional correlation coefficient (ϵ) is given by the ratio of the second term ξ to the first one (ξ^2) in descending ξ expansion. In the nonunique forbidden β-decay ϵ has an energy dependence proportional to (p^2/W). In the ξ approximation, the order of magnitude of $\epsilon\,(p^2/W)^{-1}$ is normally expected to be of order $\frac{1}{\xi}$ ($\approx \frac{1}{10}$). The cancellation effect gives rise to ϵ of order $\frac{1}{\xi}$ or larger, because of the smaller value of the first term in the ξ expansion. In the unique β-decay, ϵ has a unique energy dependence, and is of order unity.

The cancellation or selection rule effect gives a relatively large coefficient (ϵ) for the $\beta - \gamma$ directional correlation. When the ξ approximation is applicable then we have:

a large Y and V,

a constant shape factor,

an angular correlation with a p^2/W energy dependence, and a log ft value around 6.0 (a larger value will indicate a deviation).

In the case where the B_{ij} term is predominant we expect:

a large ft value, with unique 1st forbidden transitions

$$\log ft = 7 \rightarrow 9$$

with 1st forbidden parity unfavoured transitions

$$\log ft = 6 \rightarrow 8,$$

a large $\beta - \gamma$ anisotropy

a non-statistical spectrum shape

2.(iv) <u>Modified B_{ij} Approximation</u>

In this approximation we assume that $z \neq 0$, $Y \neq 0$, $V \neq 0$ but $x = u = w = 0$. ie. There are contributions from matrix elements of rank 0 and 1, which are not negligible in comparison with the B_{ij} matrix of rank 2. (MAT. 63) In the $2^- \rightarrow 2^+$ 1st forbidden β trans. there are six nuclear matrix elements which are applicable. In the modified B_{ij} approximation we need only two parameters, V and Y

$$V = (\ \xi \int \delta . r + \int i\, \gamma_5) \;/\; (\int B_{ij})_2 \qquad - 1.15$$

$$Y = (\ \xi\, C_V \int r - \xi\, C_A \int i\, \delta \times r + C_V \int i\, \alpha\ )/C_A (\int B_{ij})_2 \qquad - 1.16$$

The angular correlation coefficient $\epsilon(W)$ and the shape factor $C(W)$ for a $2^-(\beta)\ 2^+(\gamma)0^+$ cascade are

$$\epsilon(W) = \frac{p^2}{W}\left[(\tfrac{1}{2})(\tfrac{1}{14})^{\frac{1}{2}}\,Y - (\tfrac{1}{21})^{\frac{1}{2}}\,V - (\tfrac{1}{112})\,W\right] C^{-1} \qquad - 1.17$$

$$C(W) = Y^2 + V^2 + (\tfrac{1}{12})\left[p^2 + (W_o - W)^2\right] \qquad - 1.18$$

It should be noted that for large Y and V the energy dependence of C(W) (eqn. 1.18) may become negligible and depending on the sign of V and Y the energy dependence of $\epsilon(W)$ may also become negligible and the decay will have the characteristic features of the ξ approximation, namely, a constant shape factor and an angular correlation coefficient with a p^2/W energy dependence.

2.(v) The Method of Using the Experimental Data to Distinguish Between Two Models.

To see the effects due to both selection rules "j and K" the Modified B_{ij} Approximation may be used. The nuclear matricies for the Modified B_{ij} Approximation are given by eqns 1.15 and 1.16. The expression for the $\beta - \gamma$ directional correlation is

$$N(W,\theta) = 1 + A_2P_2(\cos\theta) = 1 + \epsilon(W)\,(\tfrac{3}{2}\cos^2\theta - \tfrac{1}{2}) \qquad - 1.19$$

where $A_2 = \epsilon(W)$

The asymmetry, $a(W) = \dfrac{W(\pi) - W(\pi/2)}{W(\frac{\pi}{2})}$ $\qquad$ - 1.20

is measured and is related to A_2 by the eqn. $A_2 = \dfrac{2a(W)}{3 + a(W)}$ $\qquad$ - 1.21

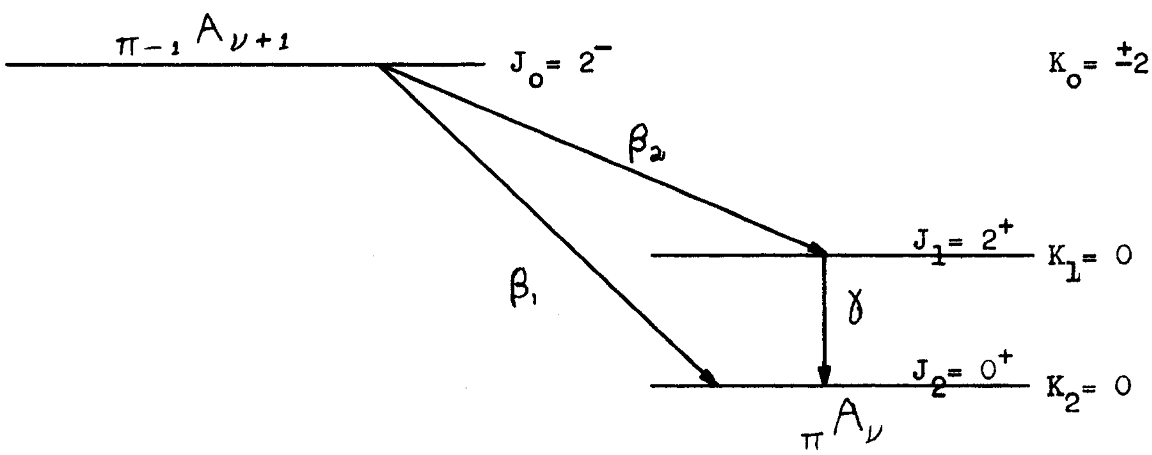
where $W(\pi)$ and $W(\pi/2)$ are the number of coincidence counts at 180° and 90° respectively.

For convenient analysis the eqns 1.15, 1.16, 1.17 and 1.18 can be written in the form (MAT. 63)

$$(V - V_o)^2 + (Y - Y_o)^2 = R^2 \qquad - 1.22$$

where $V_o = -(\tfrac{1}{4})(\tfrac{1}{21})^{\frac{1}{2}}(p^2/W)\dfrac{3 + a(W)}{a(W)}$ $\qquad$ - 1.23

Figure 1.1 $2^-(\beta)2^+(\gamma)0^+$ cascade



K_i's (i = 0,1,2) are the projections of the nuclear total angular momentum (J_i) on the nuclear axis of symmetry.

$$Y_o = -(\tfrac{1}{2})(\tfrac{3}{2})^{\frac{1}{2}} V_o \qquad - 1.24$$

$$R^2 = V_o^2 + Y_o^2 + (W/8)(\tfrac{3}{7})^{\frac{1}{2}} V_o - \tfrac{1}{12}(q^2 + p^2) \qquad - 1.25$$

Eqn 1.22 describes a circle in the V - Y plane whose radius and center depends upon the experimentally observed coefficient ϵ (W).

Experimentally one determines ϵ (W) at several values of W, and each determination yields a circle with an uncertainty in radius and center. Two circles may be drawn corresponding to the limits of experimental data. The region common to all the experimental data will be a meniscus and represents all possible values of V and Y consistent with the angular correlation experimental data. Another relationship between V and Y may be obtained from the branching ratios to the ground state and first excited state in the daughter nucleus figure 1.1. This relationship depends on the particular model assumed and is given by MAT. 63 as

$$V^2 + Y^2 = R'^2 = \left(\frac{f_{c2}}{f_2}\right)\left\{\frac{a_2}{5a_1}\frac{f_{c1}}{f_{c2}}\left[\frac{\left|\left(\int B_{ij}\right)_1\right|}{\left|\left(\int B_{ij}\right)_2\right|}\right]^2 - 1\right\} \quad -1.26$$

The term $\frac{\left|\left(\int B_{ij}\right)_1\right|}{\left|\left(\int B_{ij}\right)_2\right|}$ is the nuclear model dependent term.

a_1, a_2 = beta branching ratios of β_1 and β_2.

f_{c_1} = corrected integrated Fermi function of β_1.

f_2 = integrated Fermi function of β_2.

f_{c2} = corrected integrated Fermi function of β_2.

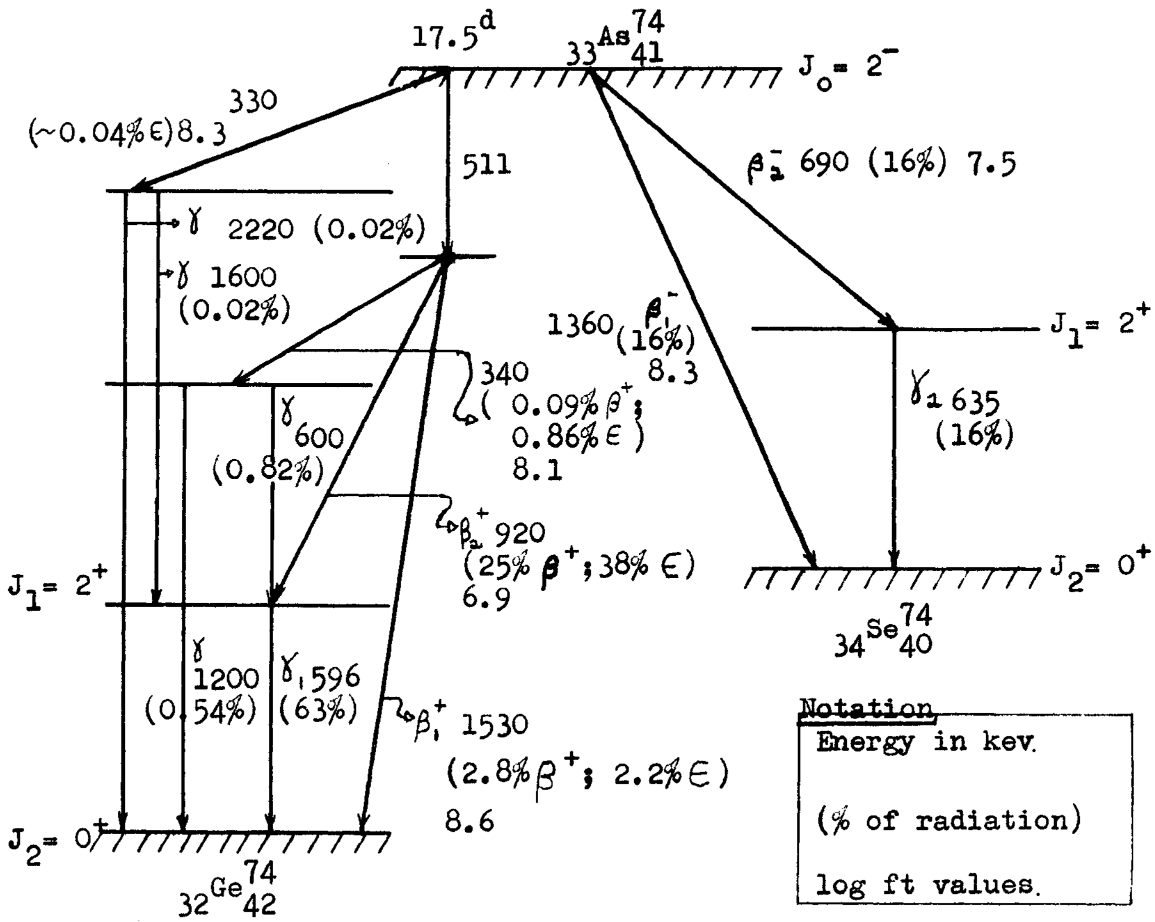
The values of $\frac{\left|\left(B_{ij}\right)_1\right|}{\left|\left(B_{ij}\right)_2\right|}$ have been calculated for different nuclear models by MAT. 63. If the theoretical circle for a given model intersect with the meniscus of the experimental circles, then that model is possible. The values of V and Y at the intersections may be used to calculate the value of $\epsilon(W)$ as a function of W. The extent of agreement with the experimental data may confirm or reject the model.

The expression used by MAT. 63 is given by

$$A_2 = \frac{p^2}{W}\frac{-\left(\frac{1}{2}\right)\left(\frac{3}{7}\right)^{\frac{1}{2}} V + \left(\frac{3}{4}\right)\left(\frac{1}{14}\right)^{\frac{1}{2}} Y - \frac{3}{224} W}{V^2 + Y^2 + \frac{1}{2}\sqrt{\frac{1}{21}}\left(\frac{p}{W}\right)^2 V - \frac{1}{4}\sqrt{\frac{1}{14}}\left(\frac{p}{W}\right)^2 Y + \frac{1}{12} q^2 + \frac{59}{672} p^2} \quad -1.27$$

However, this expression assumes x = u = w = 0. A more accurate formula from KOT. ROSS. 59 may be used.

Figure 2.1 Decay Scheme of As^{74}



Some useful formula's

$$p = \frac{1}{c}\sqrt{E(E+2m_oc^2)}$$

$$q = \frac{1}{c}(E_o - E)$$

$$W = \frac{E + m_oc^2}{m_oc^2} \quad \text{or} \quad \frac{\#\text{ of kev}}{511} + 1$$

$$p^2+1 = W^2$$

p (and q) = momentum of β-ray (and corresponding neutrino).

W = Total energy of the electrons, W_o = max. energy of the electrons.

T = E = energy of the electrons in kev.

As^{74} E X P E R I M E N T

1. Apparatus

The angular correlation spectrometer used consisted of a magnetic lens and two gamma spectrometers which could be rotated with respect to the lens. The two gamma spectrometers were mounted on the same arm with axis 90° apart. They were moved together using the automatic scanning device (YOUNG. 64) one over the range 90° - 180°, the other over the range 180° - 270°. Spiral baffles were used to separate the electrons from the positrons. (GERHOLM.) This equipment has been described by COLCLOUGH. 63 and also by YOUNG. 64. In the present version the second gamma spectrometer was added to the equipment described by YOUNG. 64.

A block diagram of the electronic counting circuit is shown in figure 2.2 and differs from the one previously described in that a "two fold" fast coincidence circuit has been added. This circuit is shown in figure 2.3. Short pulses $\sim$10 n secs are produced by the 404A limiters figure 2.2 and appear at the inputs β, γ_1 and γ_2 as labelled in figure 2.3. Coincidences between inputs β and γ_1, and β and γ_2 produce output pulses. Coincidences between γ_1 and γ_2 produce no output. These output pulses are then applied to the slow triple coincidence circuits, the output of which go to the scalars. The system is essentially the same type as described by BELL. GRAHAM. PETCH. 52, except, that the short pulses are produced directly at the anodes of the 404A limiters and that in the rest of the circuits transistors are used instead of vacuum tubes.

When the T.M.C. kicksorter was used to observe the gamma spectrum in coincidence with the betas, the fast coincidence pulses (doubles) were applied to two inputs of the slow triple coincidence

Figure 2.2 A Block Diagram of Circuit Layout

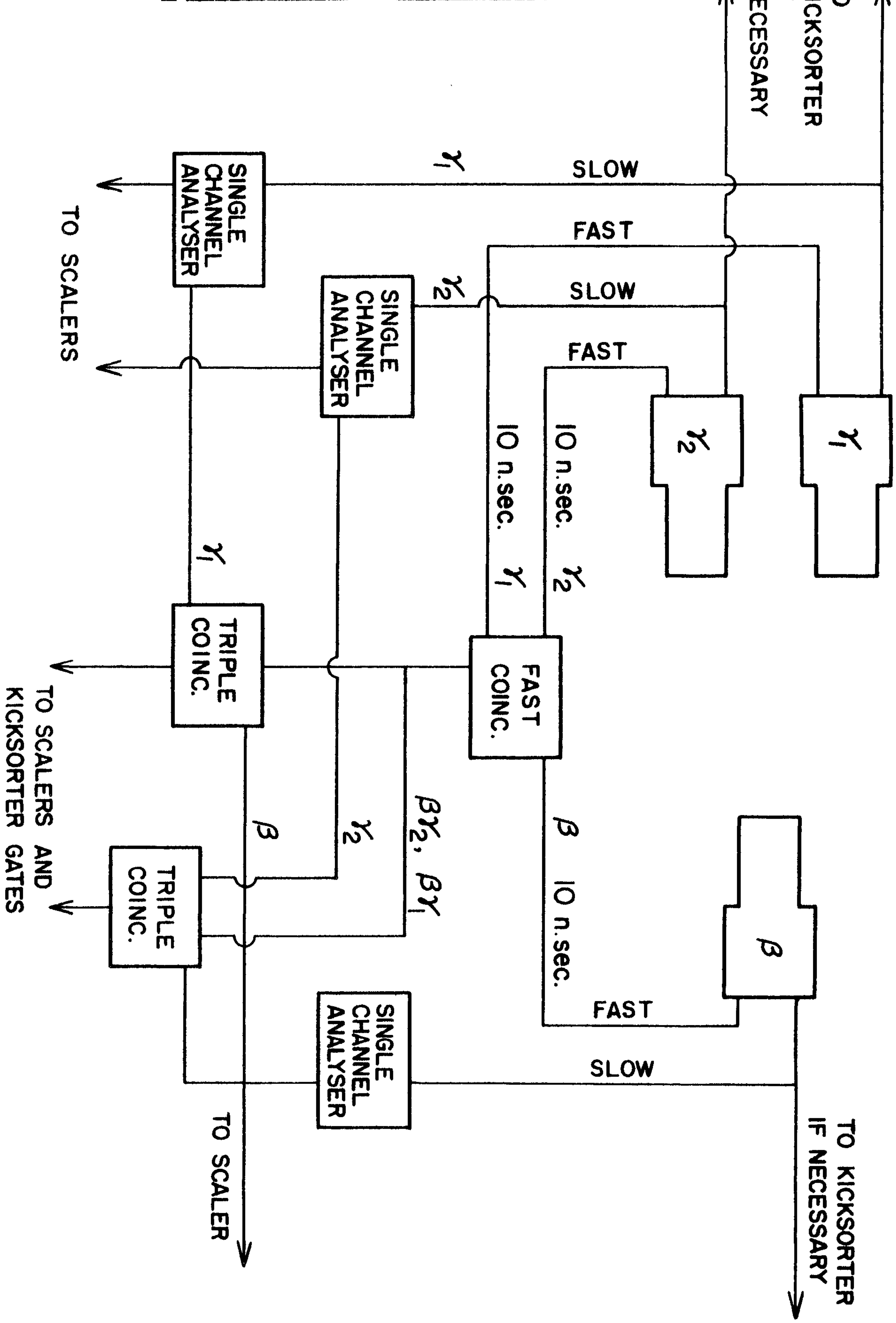
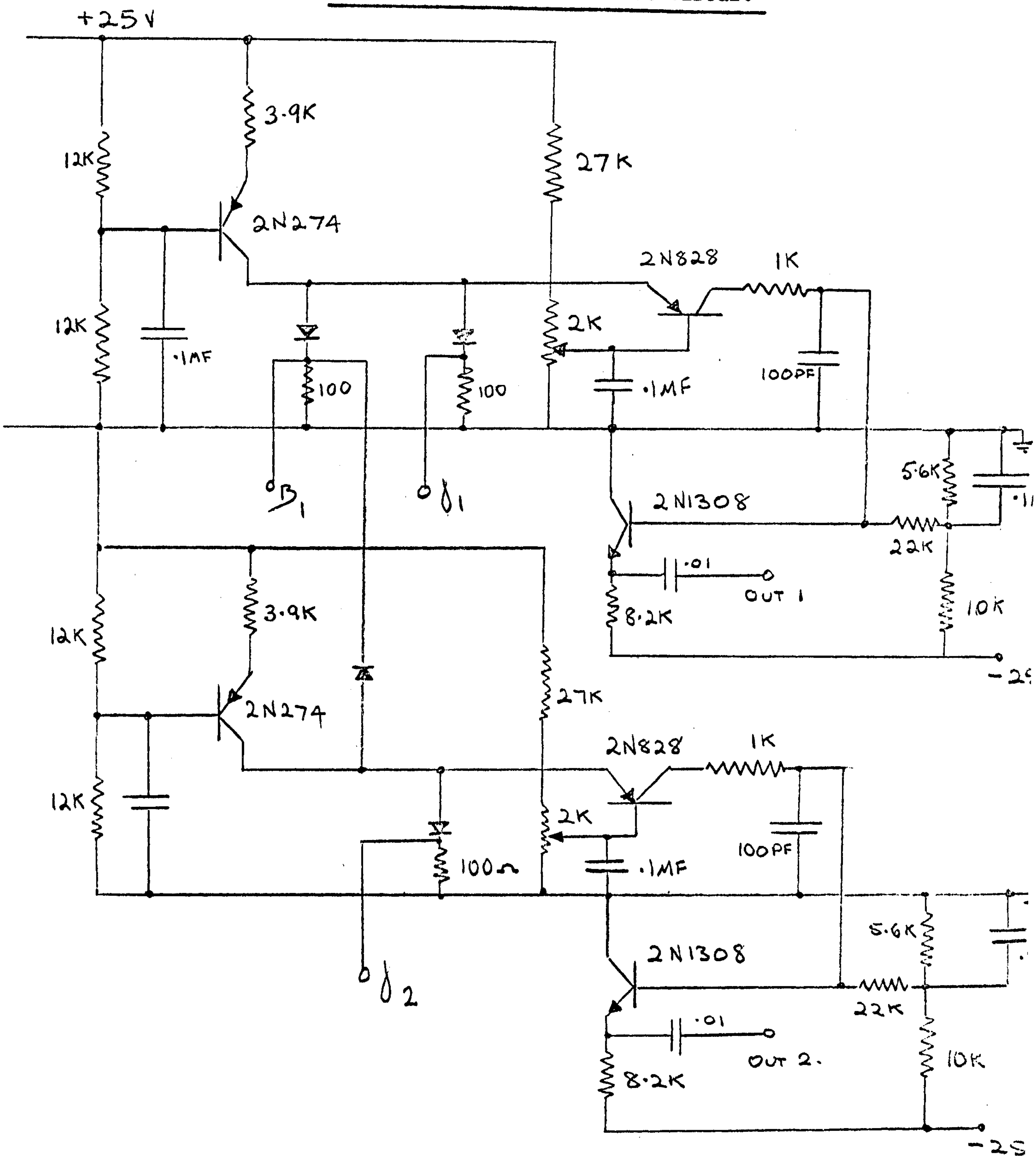


Figure 2.3 **A Two Fold Fast Coincidence Circuit**



circuit, the beta pulses were applied to the third and the output was used to gate the kicksorter.

To obtain the chance rate, the fast beta pulses were delayed by $\sim$100n secs and the coincidence rates observed.

2. Source Preparation

As^{74} as sodium arsenate solution was obtained from "The Radiation Biological Laboratories " Amersham, England. The specific activity was greater than 120 mc/ml. A few drops of the solution was evaporated to dryness in a tungsten boat using a heat lamp. The boat was placed in a Balzer vacuum coating unit. A substrate of Al of about 0.001 inches thickness was used and was placed directly over the tungsten boat. A mask with a hole of 5mm in diameter was placed against the substrate. The temperature of the tungsten boat was raised slowly and the sodium arsenate evaporated and condensed on the aluminum substrate.

3. Preliminary Adjustments

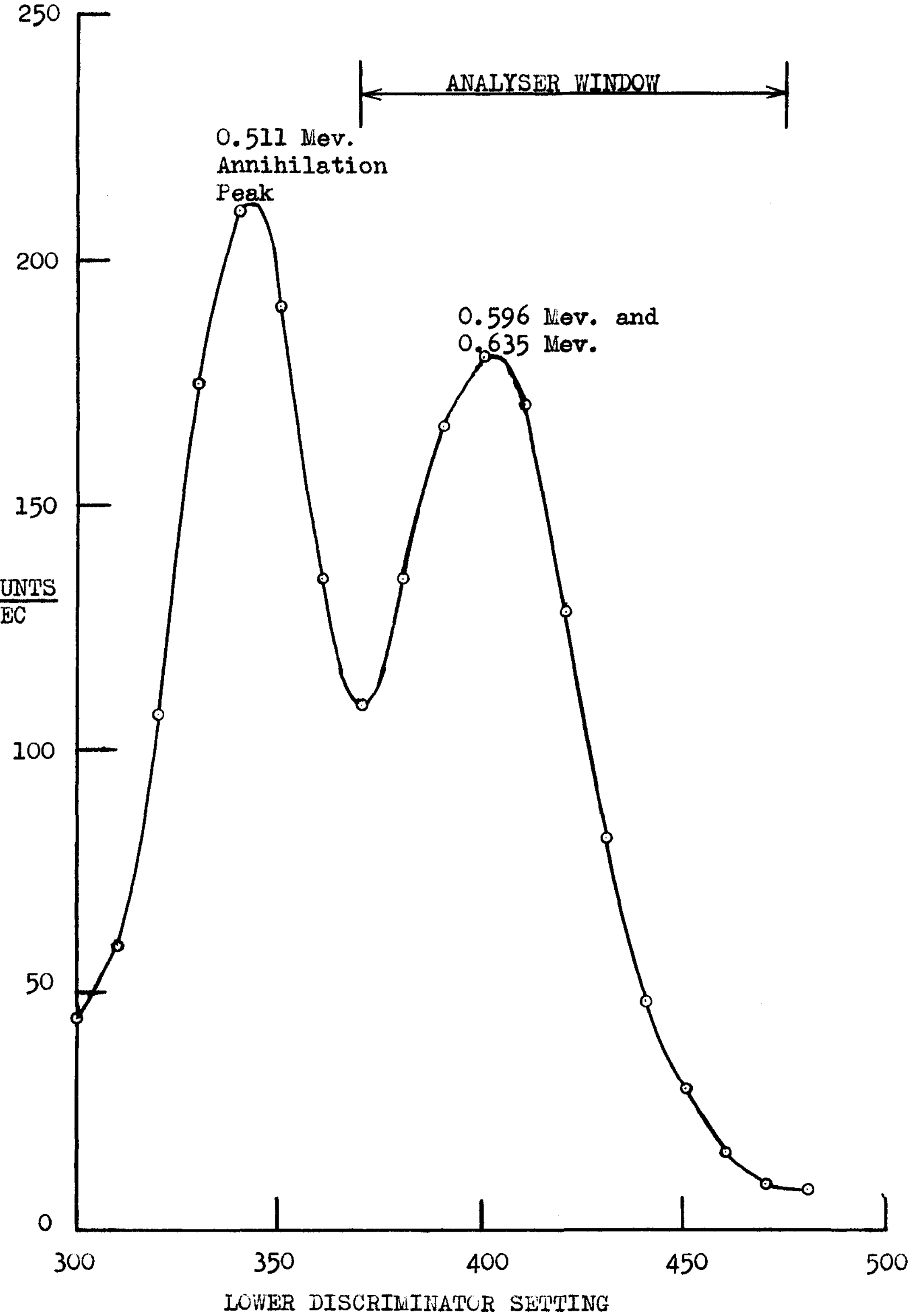
(i) Centering of the Source

The source was placed on the axis of the spectrometer using the following method. A cylinder which fits snugly in the vacuum chamber, and which has a small hole along its axis was placed in the spectrometer. This hole was then on the axis of the instrument. The source was then observed through this hole and adjusted until it was centrally located.

(ii) Centering of the γ Probe

The center of rotation of the gamma spectrometers were adjusted to obtain equal count rates at the 90° and 180° positions for gamma 1 probe, and at the 180° and 270° positions for gamma 2

Figure 2.4 **The Gamma Singles Spectra**



probe. The composite peak at 600 kev, see figure 2.4, was used. The count rates were obtained equal to $\sim 1\%$.

4. Experimental Procedures

Figure 2.1 shows the decay scheme of As^{74}. There are two intense β^- groups to the 0^+ and 2^+ levels in $_{34}Se^{74}$ and two strong β^+ groups to the 0^+ and 2^+ states in $_{32}Ge^{74}$. The higher levels in germanium are weakly fed $< 0.1\%$ in this decay and are unimportant in the experiment undertaken. The sequences $2^-(\beta^-)2^+(\gamma)0^+$ in the β^- decay and $2^-(\beta^+)2^+(\gamma)0^+$ in the β^+ decay were studied.

ie. The angular correlation between the 0.635 Mev gamma ray and the β_2^- and the 0.590 Mev gamma ray and the β_2^+. The 0.511 Mev annihilation radiation, figure 2.4, contributed to the $\gamma - \gamma$ scattered background, and not to the $\beta - \gamma$ true coincidence. This had to be excluded from the gamma channel and therefore the discriminator windows were set to accept the composite peak as shown in figure 2.4.

The equipment was set to record the gamma 1 singles, the gamma 2 singles, the betas, the doubles, and the triple coincidences due to $(\beta\gamma_1)$ and $(\beta\gamma_2)$. The data was printed out and the positions of the gamma spectrometers changed automatically every twenty minutes. The equipment was interrupted every 12 hours and the discriminator reset if necessary.

At the beginning and end of each such sequence, the chance rate and the scattered $(\gamma - \gamma)$ background rate were recorded. To obtain the $(\gamma - \gamma)$ background, the baffles in the beta spectrometer were closed and the coincidence rate recorded. The procedure was repeated until more than 50,000 coincidences were recorded. The energy in the beta channel was then changed and the procedure repeated.

5. Treatment of the Data

Since the anisotropy measured is very small it is important to eliminate the effect of drifts in the gamma channel. This is accomplished in two ways.

1/ The position of the counters were changed every twenty minutes, which is an interval small enough for the drift to be negligble.

2/ The magnitude of the drifts throughout a sequence was determined and the data rejected when necessay.

The following procedure was followed. The gamma spectrum in coincidence with the betas was determined, figure 2.5 and figure 2.6. The count rate in the gamma channel as a function of the lower discriminator setting was determined, using the window used in the experiment, figure 2.7. From this graph, if the count rate in the gamma channel is known, the spectrum shift could be read off directly. The gamma channel rates in the experimental runs were plotted as a function of time, [redacted] The straight solid line passes through the 1st point and has the slope corresponding to the half-life of As^{74} (17.5 days). Deviation from this line indicated drifts in the gamma channel. From the percentage deviation, the shift of the spectrum was obtained using the graph in figure 2.8. From the gamma spectra, figure 2.7, the corrections to the data were obtained.

However, when the data deviated by as much as $\pm$ 2% from the expected value, the corrected data and the uncorrected data

Figure 2.5 The Gamma 1 Spectra in Coincidence with the Betas

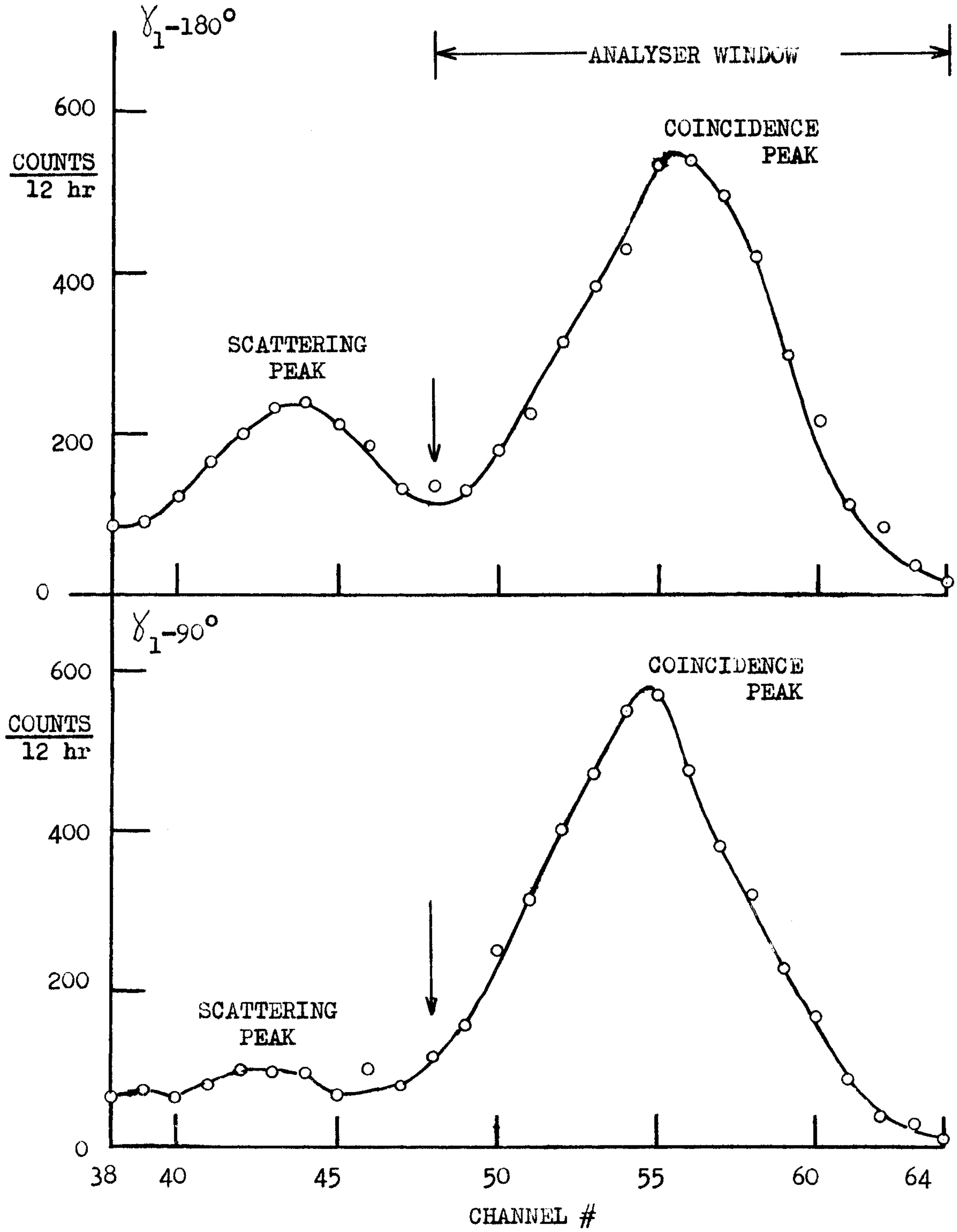


Figure 2.6 The Gamma 2 Spectra in coincidence with the Betas

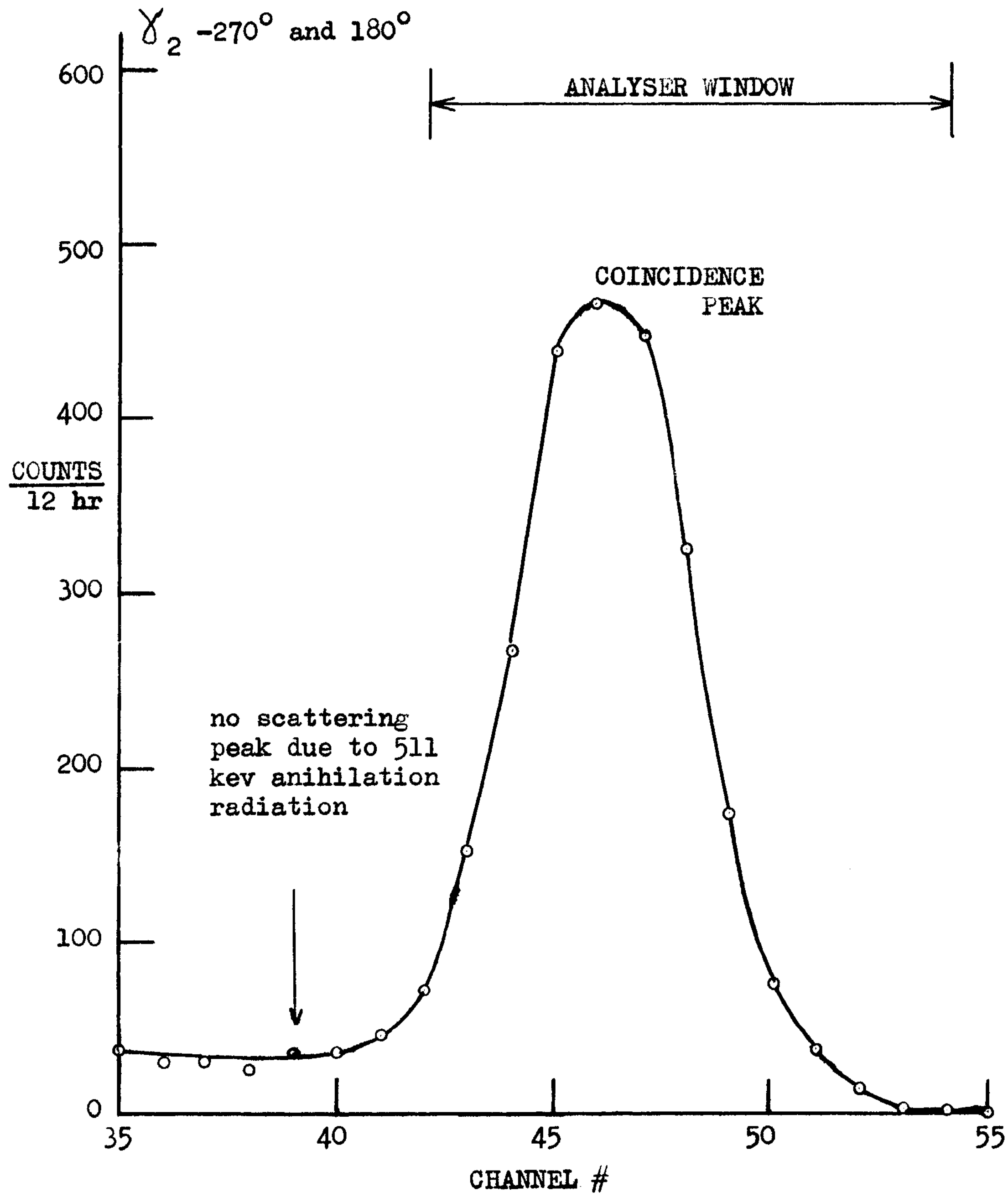


Figure 2.7 % change of # of peak counts, N, in gamma channel versus % change in Lower Discriminator

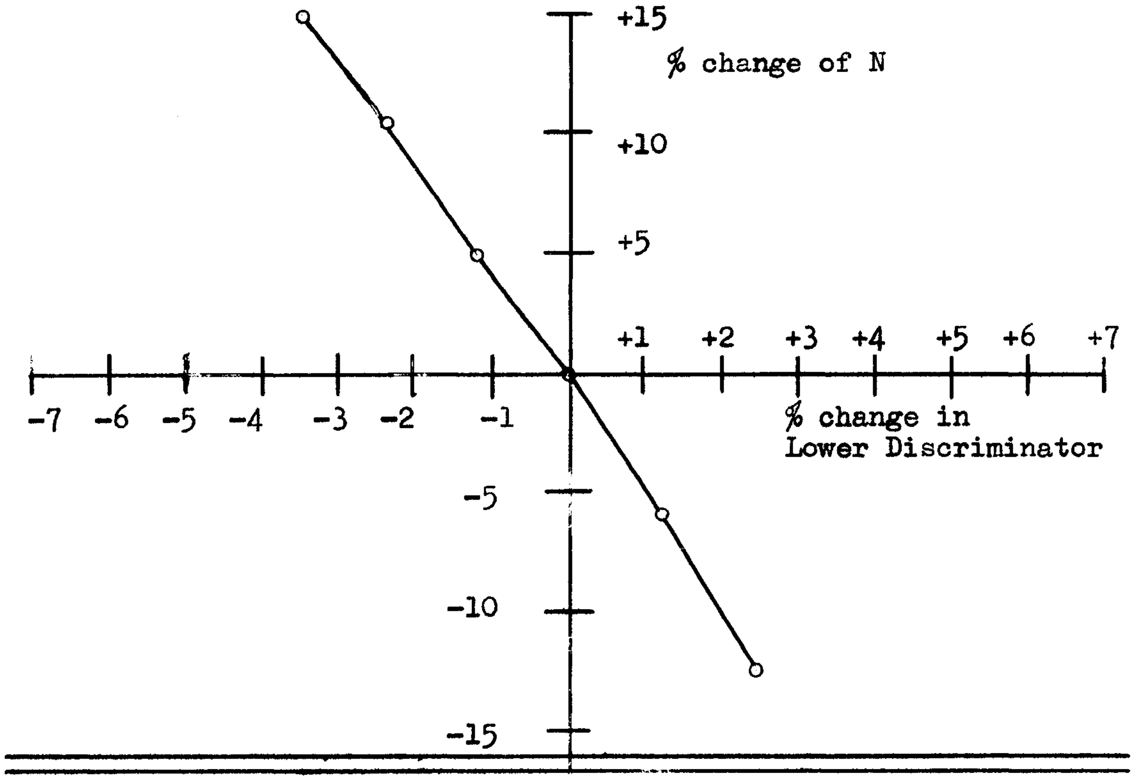
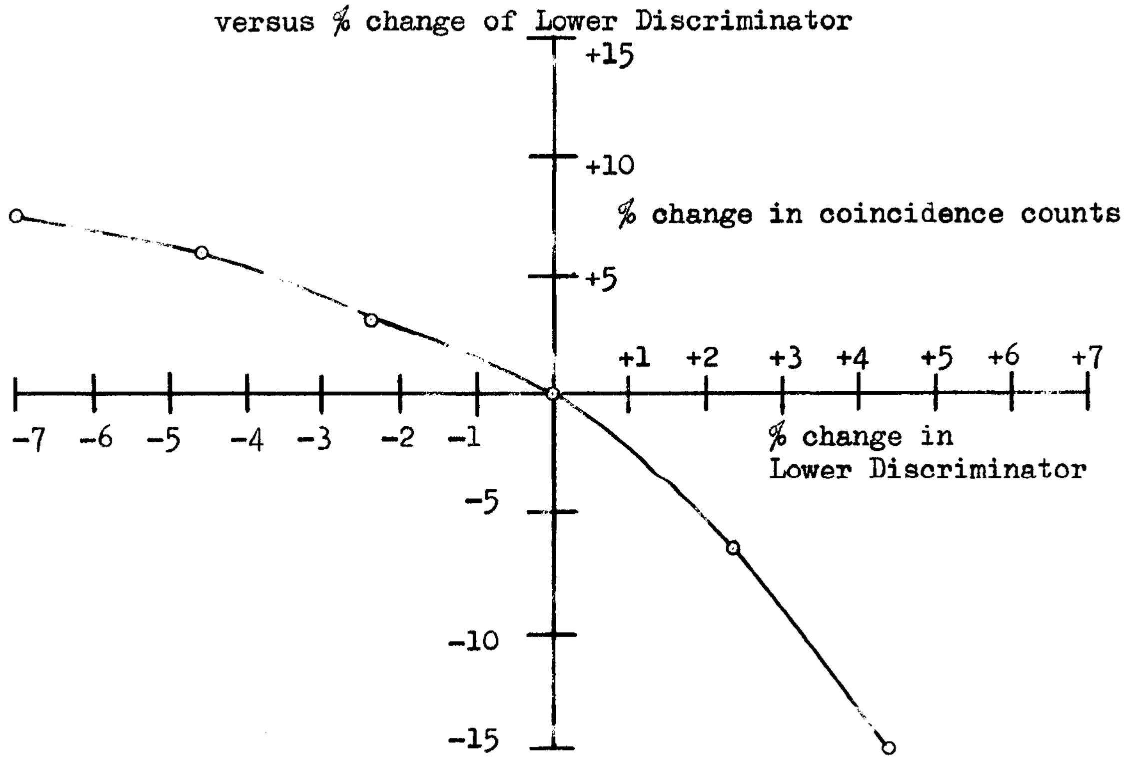


Figure 2.8 % change in coincidence count in same channel versus % change of Lower Discriminator



gave the same values. It was therfore decided to accept data points which deviated ± 1% and not apply any correction for drifts.

If the peak shifts when the gamma probe is changed from 90° position to 180°, the peak shift must be measured and the coincidence counts must be corrected for this peak shift. The percentage difference in position between the two peaks is determined, then the coincidence count for the higher peak must be reduced by a certain amount determined from figure 2.8.

TABLE III

Asymmetry, A_2 Coefficient and Solid Angle

Corrections for Negatrons

Energy W	Asymmetry, a(w) Baffles 6 Turns Open	Asymmetry, a(w) Baffles 7 Turns Open	A_2 Baffles 6 Turns Open	A_2 Baffles 7 Turns Open	Corrected for β Solid Angle	Corrected for $\gamma+\beta$ Solid Angle
1.6	0.0071	0.0147	0.0047	0.0098	0.0117	0.012 ± 0.005
1.8	-0.0488	-0.0387	-0.0331	-0.0261	-0.0439	-0.045 ± 0.006
2.0		-0.0477		-0.0323	-0.0433	-0.044 ± 0.006

To correct for β spectrometer solid angle divide A_2 by $\frac{P_2}{P_o}$

for Baffles 6 turns open $\frac{P_2}{P_o} = 0.7612 \pm 0.003$

for Baffles 7 turns open $\frac{P_2}{P_o} = 0.7453 \pm 0.003$

To correct for γ spectrometer solid angle divide A_2 by 0.973 ± 0.003 for a 1 $\frac{3}{4}$" x 2" NaI crystal 10 cms from source.

TABLE IV

Asymmetry, A_2 Coefficient and Solid Angle

Corrections for Positrons

Energy	Asymmetry a(w)	A_2	Corrected For β Solid Angle	Corrected For $\gamma+\beta$ Solid Angle	A_2 (Corrected) Average For Both Counters
(a) γ_1 Probe					
1.8	0.0147	0.00975	0.01322	0.01360	
2.0	0.0256	0.01692	0.02295	0.02358	
2.1	0.0349	0.02299	0.03118	0.03231	
2.2	0.0243	0.01606	0.02178	0.02238	
(b) γ_2 Probe					
1.8	0.0181	0.01199	0.01626	0.01680	0.015 $\pm$ 0.006
2.0	0.0151	0.01001	0.01357	0.01406	0.019 $\pm$ 0.004
2.1	0.0288	0.01901	0.02578	0.02671	0.030 $\pm$ 0.005
2.2	0.0306	0.02019	0.02738	0.02837	0.025 $\pm$ 0.005

To correct for β spectrometer solid angle divide A_2 by $\frac{P_2}{P_o}$

for baffles 7 turns open $\frac{P_2}{P_o} = 0.7372 \pm 0.008$

To correct for γ spectrometer solid angle divide A_2 by

(for 10 cm away and $1\frac{3}{4}$" x 2" NaI crystal) $\Rightarrow 0.973 \pm 0.003$

(for 10 cm away and 2" x 2" NaI crystal) $\Rightarrow 0.965 \pm 0.003$

Reference UCRL - 5451

TABLE V

Corrections for Chance and Scattering

Energy W	A_2 γ_1	A_2 γ_2	Coinc Counts : Chance Counts < γ_1-90°	γ_1-180°	γ_2-270°	γ_2-180°	Coinc Counts : Scattering Counts < γ_1-90°	γ_1-180°	γ_2-270°	γ_2-180°
POSITRONS										
1.8	0.0136 ± 0.004	0.0168 ± 0.004	:0	80:1	:0	:0	80:1	80:1	80:1	80:1
2.0	0.0236 ± 0.0028	0.0141 ± 0.0028	160:1	160:1	160:1	160:1	100:1	70:1	90:1	30:1
2.1	0.0323 ± 0.0033	0.0267 ± 0.0033	:0	:0	:0	:0	70:1	70:1	87:1	77:1
2.2	0.0224 ± 0.0031	0.0284 ± 0.0031	260:1	150:1	580:1	170:1	100:1	100:1	100:1	100:1
NEGATRONS										
1.6	0.0120 ± 0.005		6:1	6:1			Corrected for Scattering in Analysis			
1.8	−0.0451 ± 0.006		3:1	3:1			3:1	3:1		
2.0	−0.0445 ± 0.006		3:1	3:1			2:1	2:1		

TABLE VI

POSITRONS

Table of Coincidences to Get a(w)

Energy (W)	Seq # Probe	Coinc 90°	Coinc 180°	Normalizing Factor	$\frac{90^\circ}{180^\circ}$	$\frac{90^\circ/180^\circ}{\text{Normalizing Factor}}$
2.0	γ_1					
	44	9417	9455	1.0374	1.0232	0.9863
	46	8833	8976	1.0275	0.9951	0.9684
	47	4693	4841	1.0100	0.9801	0.9703
	γ_2					
	44	12034	12029	1.0227	1.0125	0.9900
	45	12845	12872	1.0246	1.0077	0.9836
	46	11438	11301	1.0121	0.9975	0.9856
	47	6316	6378	1.0133	0.9943	0.9812
2.1	γ_1					
	49	5984	6074	1.0291	0.9890	0.9610
	50	5906	5965	1.0207	0.9850	0.9650
	52	1195	1162	1.0361	1.0364	1.0002
	γ_2					
	48	7492	7650	1.0157	0.9872	0.9719
	49	6815	6888	1.0184	0.9934	0.9754
	50	6911	6967	1.0221	0.9919	0.9704
	51	5611	5700	1.0211	0.9909	0.9704
2.2	γ_1					
	53	3871	3817	1.0298	1.0510	1.0205
	54	4010	4099	1.0270	0.9559	0.9306
	55	3060	3227	1.0588	0.9766	0.9223
	56	2753	2752	1.0470	1.0625	1.0148
	57	3173	3129	1.0502	1.0879	1.0358
	58	3769	3981	1.0597	0.9894	0.9336
	γ_2					
	53	4274	4408	1.0140	0.9753	0.9618

	54	4416	4499	1.0173	0.9894	0.9725
	55	3978	4018	1.0246	0.9949	0.9710
	56	2940	2945	1.0321	0.9993	0.9682
	57	3381	3469	1.0098	0.9737	0.9642
	58	4175	4264	0.9944	0.9791	0.9846
1.8	γ_1					
	59	2429	2460	1.0445	1.0116	0.9685
	60	2254	2281	1.0334	1.0103	0.9776
	62	1573	1607	1.0542	1.0000	0.9485
	64	1319	1238	1.0717	1.0784	1.0062
	γ_2					
	60	2801	2795	1.0235	1.0071	0.9839
	61	2363	2447	1.0231	0.9736	0.9516
	63	2104	2150	1.0021	0.9688	0.9667
	64	1340	1319	0.9900	1.0060	1.0161

The ratio $\frac{90^\circ}{180^\circ}$ corrected for difference in position of peak between 90° and 180°.

coinc 90° and coinc 180° are corrected for chance and scattering.

However, in TABLE VII, coinc 90° and coinc 180° are corrected for Chance, Scattering and Peak Shift.

TABLE VII

N E G A T R O N S

Table of Coincedences to Get a(w)

Energy (W)	Seq #	Coinc 90°	Coinc 180°	Normalizing Factor	$\frac{180^\circ}{90^\circ}$	$\frac{180^\circ}{90^\circ}$ X Norm. Factor
1.6	1	5152	4945		0.9598	1.0147 (seq 1–5)
	3	7588	7492		0.9873	
	4	8394	8261		0.9841	
	5	6655	6685		1.0045	
	6	3813	3685		0.9664	1.0071 (seq 6–8)
	8	3007	2991	1.0288	0.9947	
1.8	12	3630	3376	1.0310	0.9300	0.9588
	13	3656	3347	1.0380	0.9155	0.9503
	14	2971	2711	1.0330	0.9125	0.9426
	15	5417	4995	1.0320	0.9221	0.9516
	16	2254	2172	1.0392	0.9636	1.0014
	17	1877	1729	1.0318	0.9212	0.9505
	18	2000	1859	1.0296	0.9295	0.9570
	20	723	694	1.0347	0.9599	0.9932
	21	828	681	1.0322	0.8225	0.8490
	22	3747	3477	1.0257	0.9279	0.9518
	23	1666	1591	1.0309	0.9550	0.9845
2.0	30	2504	2222	1.0353	0.8874	0.9187
	31	3892	3608	1.0338	0.9270	0.9583
	32	3028	2846	1.0318	0.9399	0.9697
	33	3327	3081	1.0374	0.9261	0.9607
	34	2515	2334	1.0360	0.9280	0.9614
	35	1142	1046	1.0323	0.9159	0.9454
	37	2577	2499	1.0445	0.9697	1.0129
	38	1753	1661	1.0290	0.9475	0.9750
	39	205	181	1.0142	0.8829	0.8954
	41 γ_1	754	685	1.0143	0.9085	0.9215
	γ_2	995	994	1.0361	0.9487	0.9829
	42	3639	3174	1.0192	0.8722	0.8889

CHAPTER III

Interpretation of Results and Conclusions

1. The Shell Model

From TABLE VIII of the Shell model and from Nuclear data on As^{74} (Ref. Fig. 2.1) the reaction that takes place seems to be of two definite forms.

(i) $${}_{33}As^{74}_{41} \xrightarrow{\Delta\pi = -1} \beta^- + {}_{34}Se^{74}_{40} + \bar{\nu}$$

As^{74} has 33 protons and 41 neutrons; the last odd proton is in the $1f^-_{\frac{5}{2}}$ state and the last odd neutron is in the $1g^+_{\frac{9}{2}}$ state. An electron (β^-) is given off by As^{74} to produce Se^{74} which has 34 protons and 40 neutrons. When the electron is given off (from eqn 1.1), one neutron disappears and is replaced by a proton. The extra proton also goes into the $1f^-_{\frac{5}{2}}$ state and combines with the other proton already there to form an even-even nucleus or a STABLE ELEMENT.

(ii) $${}_{33}As^{74}_{41} \xrightarrow{\Delta\pi = -1} \beta^+ + {}_{32}Ge^{74}_{42}$$

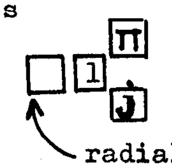
[redacted] A positron (β^+) is given off by As^{74} to produce Ge^{74}, which has 32 protons and 42 neutrons. In the neucleus one proton disappears and is replaced by a neutron (from the eqn 1.2). The extra neutron goes into the $1g^+_{\frac{9}{2}}$ state and combines with the neutron that was already there and thus an even-even (STABLE) nucleus is formed. In this model a nucleon is transformed from a $1f^-_{\frac{5}{2}}$ to a $1g^+_{\frac{9}{2}}$ state when ${}_{32}Ge^{74}_{42}$ is the product, and from a $1g^+_{\frac{9}{2}}$ to a $1f^-_{\frac{5}{2}}$ state when ${}_{34}Se^{74}_{40}$ is the

TABLE VIII

Table of the Shell Model

Levels		State	Shell	Total
1i	$i^{+}_{11/2}$			
				126
3p	$p^{-}_{1/2}$	2	44	
1i	$i^{+}_{13/2}$	14		
3p	$p^{-}_{3/2}$	4		
2f	$f^{-}_{5/2}$	6		
2f	$f^{-}_{7/2}$	8		
1h	$h^{-}_{9/2}$	10		
				82
3s	$s^{+}_{1/2}$	2	32	
1h	$h^{-}_{11/2}$	12		
2d	$d^{+}_{3/2}$	4		
1g	$g^{+}_{7/2}$	8		
2d	$d^{+}_{5/2}$	6		
				50
2p	$p^{-}_{1/2}$	2	22	
1g	$g^{+}_{9/2}$	10		
1f	$f^{-}_{5/2}$	6		
2p	$p^{-}_{3/2}$	4		
				28
1f	$f^{-}_{7/2}$	8	8	
				20
1d	$d^{+}_{3/2}$	4	6	
2s	$s^{+}_{1/2}$	2		
				14
1d	$d^{+}_{5/2}$	6	6	
				8
1p	$p^{-}_{1/2}$	2	6	
1p	$p^{-}_{3/2}$	4		
				2
1s	$s^{+}_{1/2}$	2	2	

Notation for Table VIII which gives the Occupation Number of Identical Nucleons is



π = parity

radial quantum number.

s = spin quantum number.

l = orbital angular momentum qu. no.

j = total angular momentum qu. no.

with jj (or spin-orbit) coupling $(j = l \pm s)$.

---

product. In each case there is a change in parity $\Delta\pi = -1$; therefore, this is 1st forbidden beta decay. Also in each case, the change in total angular momentum is $\Delta j = \frac{9}{2} - \frac{5}{2} = 2$. This is the angular momentum that must be carried off by the electron and neutrino. Therefore, the only matrix element that contributes is the B_{ij} term. This is the origin of the j selection rule.

2. Analysis of Data

The experimental data was analysed in accordance with the method described in Ch.I Sec. 2(v). The reason for the analysis under this method is the following: (KOT. 59)

If the selection rule effect is perfect ie. if only the B_{ij} term has a contribution, the energy spectrum should have a unique shape, and the $\beta - \gamma$ directional correlation should be negative

$$\epsilon = -\left(\frac{3}{28}\right) \lambda_1 p^2 \Big/ \left[(W_o - W)^2 + \lambda_1 p^2\right]$$

where λ_1 is the coulomb correction factor and can be found in reference KOT. ROSS. 59.

Now, the experimental data show, TABLE IV, that the β decays have positive ϵ's and from another experiment we have found that although we didn't have enough data to determine the shape factor, the deviation from the allowed shape was small. Thus, we should take into account the contribution from the other nuclear matrix elements. From KOT. 59, if there is about 10% correction due to the mixture of other states, the contributions from the V and Y terms can be the same order of, or larger than, that from the B_{ij} term, because of the large Coulomb energy factor ξ in V and Y. KING. PEASLEE. 54 conclude from their analysis of the log (ft) values for these $2^{-}(\beta)2^{+}$ transitions that the deviation from j forbiddenness is about 30% and that most of these transitions have a nearly-allowed shape energy spectrum as a result of this correction. As stated in Ch. I, sec. 2(iii), K forbiddenness requires $|V| < |Y|$ while j forbiddenness does not.

The experimental circles are shown in figure 3.1. The meniscus shown as the shaded area on the diagram does not include the origin and, therefore, V and Y cannot be zero (ie. the selection rule is not strict). The angular correlation coefficient, A_2, was calculated as a function of beta ray energy using the values of V and Y within the meniscus. The expression given by KOT. 59 was used. It was found impossible to reproduce the experimental values if u and x were set to zero.

The figure also shows the calculated circles for different shell model configurations and for the collective model. TABLE IX shows the values of V and Y corresponding to the intersections of these circles with the meniscus.

Figure 3.1 Plot of V versus Y

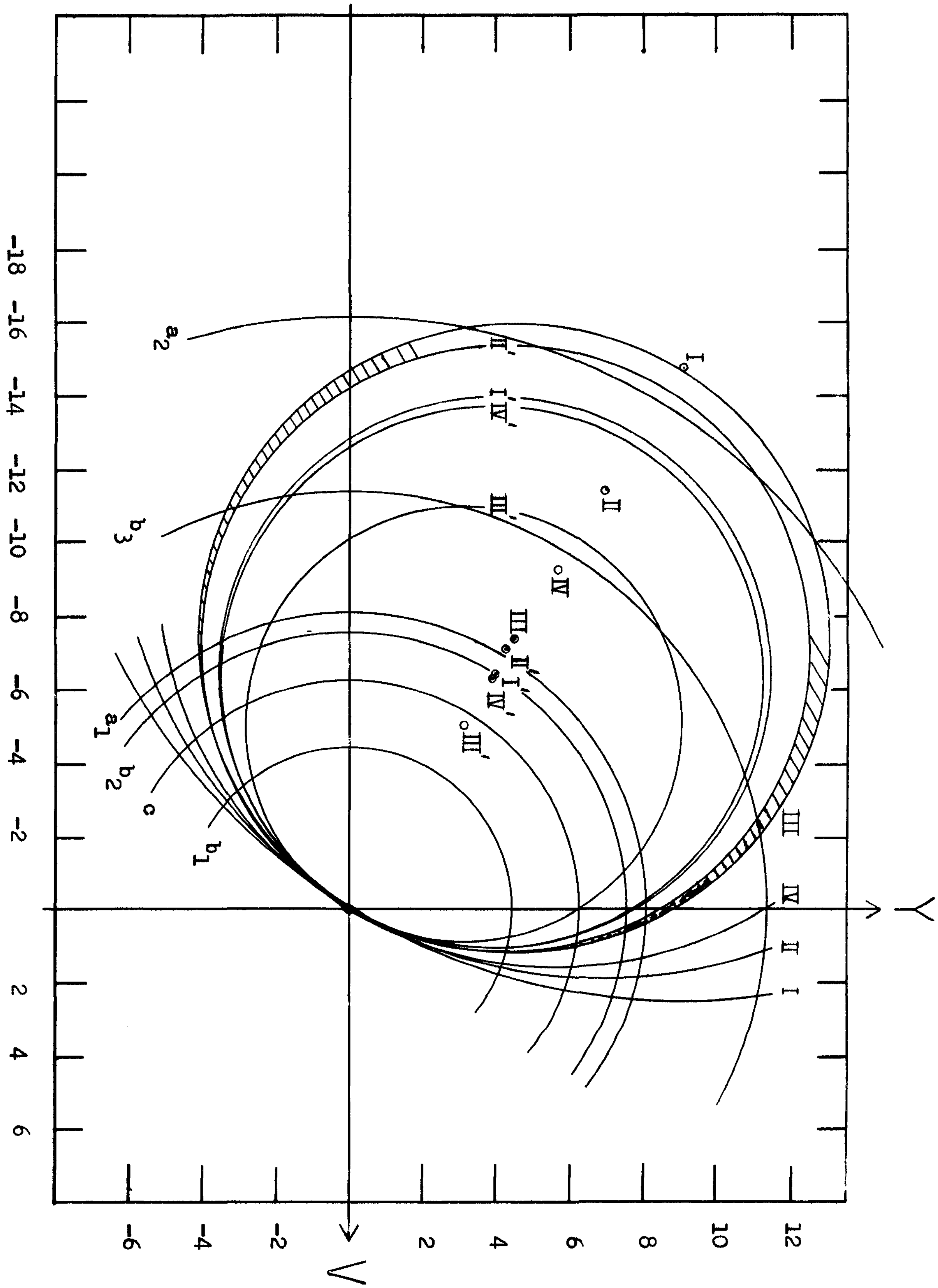


TABLE IX

V and Y Corresponding to the Intersects of the Theoretical Circles with the Meniscus

CONFIGURATION			R'	V Positive	Y Positive	V Negative	Y Negative
1. Shell Model	p State	n State					
Proton Excited							
a_1	$(f_{5/2})^2$	$(g_{9/2})^{\nu}$	8.10	+ 0.35	+ 8.09	- 7.01	-4.00
a_2	$(f_{5/2})^4$	$(g_{9/2})^{\nu}$	16.20	-11.10	+11.90	-15.50	+4.50
Neutron Excited							
b_3	$(f_{5/2})^{\pi}$	$(g_{9/2})^6$	11.30	- 2.15	+11.09	-10.78	-3.20
b_2	$(f_{5/2})^{\pi}$	$(g_{9/2})^4$	7.53	+ 0.57	+ 7.51	- 6.40	-3.95
b_1	$(f_{5/2})^{\pi}$	$(g_{9/2})^2$	4.44	+ 1.15	+ 4.30	- 3.25	-3.00
2. Collective Model							
Rotational Excitation			6.22	+ 0.98	+ 6.12	- 4.96	-3.69

TABLE X

Calculated Centres of Circles and Radii (Matumoto's Method)

W	DESIGNATION	V_o	Y_o	R
1.8	I	-14.76	9.04	17.30
1.8	I'	- 6.40	3.92	7.49
2.0	II	-11.37	6.96	13.31
2.0	II'	- 7.05	4.32	8.25
2.1	III	- 7.35	4.50	8.60
2.1	III'	-5.08	3.11	5.92
2.2	IV	-9.24	5.66	10.82
2.2	IV'	-6.31	3.86	7.37

It was found that all values V and Y in TABLE IX, except b_3 and a_2, could be made to reproduce the experimental data for appropiate though different values of u and x. It is, therefore, impossible on the basis of the beta-gamma angular correlation experiment alone to distinguish between the possible configurations listed in TABLE IX.

It may be noted that some of the shell model configurations yield large values of V and Y (eg. a_2 and b_3) with respect to the B_{ij} term, and are, therefore, incompatible with a selection rule. For simplicity one would favour $(f_{5/2})^{\pi} (g_{9/2})^2$ above the configuration $(f_{5/2})^{\pi} (g_{9/2})^4$. However one cannot distinguish between any of the shell model configurations and the collective model. Calculations of the shape factor were performed using the values of V and Y for the configurations listed in TABLE IX. The variation with energy of the shape factor in each case is small, and also depends on the value of u and x. It is unlikely that an experimentally determined value of the shape factor could distinguish between these configurations. It could, however, with the angular correlation data, limit the acceptable range of values of u and x. A third experiment, for example, on the beta circularly-polarized gamma ray directional correlation would be required to decide between these configurations.

3. <u>Conclusion</u>

The values of the parameters V, Y, u and x are all non-zero for this decay. It is impossible to distinguish between the different nuclear configurations on the basis of the angular correlation data alone. The configurations possible for the shell model are $(f_{5/2})^{\pi}(g_{9/2})^4$, $(f_{5/2})^{\pi}(g_{9/2})^2$ and $(f_{5/2})^2(g_{9/2})^{\nu}$. The collective excitation for the first excited state of Germanium is also possible. To determine whether indeed a selection rule is present, and to distinguish between these cases, other data, such as shape factor, beta-circularly polarized gamma ray directional correlation, are required.

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UCRL - 5451, University of California Lawrence Radiation Laboratory, Livermore, California, Contract No. W-7405-eng-48
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