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MASTER

GAMMA-GAMMA ANGULAR CORRELATION
IN THE DECAY OF COBALT-60

by
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Submitted in partial fulfillment of
the requirements for the degree of
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This work is accepted as fulfilling
the thesis requirements for the degree of
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Faculty Advisor

Chairman
Department of Physics

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Academic Dean

ABSTRACT

This is a continuation of the work of assembling and testing the equipment necessary to conduct gamma-gamma angular correlation experiments, started by Fort A. Verser, Jr. at the US Naval Postgraduate School (1).

No substantial changes were made in the equipment, but rather a rerun of the Cobalt-60 experiment was made to confirm the results obtained in the previous work. A comparison of the previous work confirms that there is a definite distortion in the shape of the observed correlation function.

The statistical analysis of the data and the solid angle corrections required for evaluation of the results have been programmed for calculation by use of the 1604 Digital Computer. This paper outlines these programs in detail.

The author wishes to express his appreciation for the assistance given him by Professor Harry E. Handler and for his guidance throughout this investigation. Appreciation is expressed to Professor Edmund A. Milne for his advice and comments. Captain T. R. Abernathy, USMC, was very helpful in providing valuable assistance and discussions on various aspects of the computer programing. The cooperation and assistance of Mr. Mervyn C. Brillhart in maintaining and testing the electronic equipment was indispensable.

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CHAPTER I
INTRODUCTION

The decay of Cobalt-60 to an excited state of Nickel-60 and the angular correlation of the resulting gamma-gamma cascade have been studied extensively experimentally (2,6,8,9, and others) and the results of the correlation measurements agree very well with the theoretical correlation for the decay scheme shown in Figure 1. Consequently, the decay of Cobalt-60 is now used as one standard for the testing of correlation equipment.

Angular correlation equipment was assembled at the US Naval Postgraduate School by Verser in 1960 for the investigation of the properties of low-lying excited nuclear states. His testing of the operating characteristics of the equipment by the angular correlation of the cascading gamma rays resulting from the decay of Cobalt-60 yielded an observed correlation curve whose shape was not in agreement with the theoretical curve. This work was initiated in order to attempt to verify Verser's results.

In order to facilitate the statistical analysis of the data, a program has been worked out for the use of the 1604 Digital Computer. The program follows the procedures outlined by M.E. Rose (2) and is contained completely in Appendix I.

An additional program has been written to compute the solid angle corrections, which must be applied to the theoretical curve, by the method of M.E. Rose (2). This progam is outlined in Appendix II.

The results of this work agreed within statistical expectation with those obtained by Verser, indicating that the unexpected shape of the curve is apparently real and not an instrumental effect. These results are given in Chapter VI.

PARTIAL DECAY SCHEME OF COBALT-60

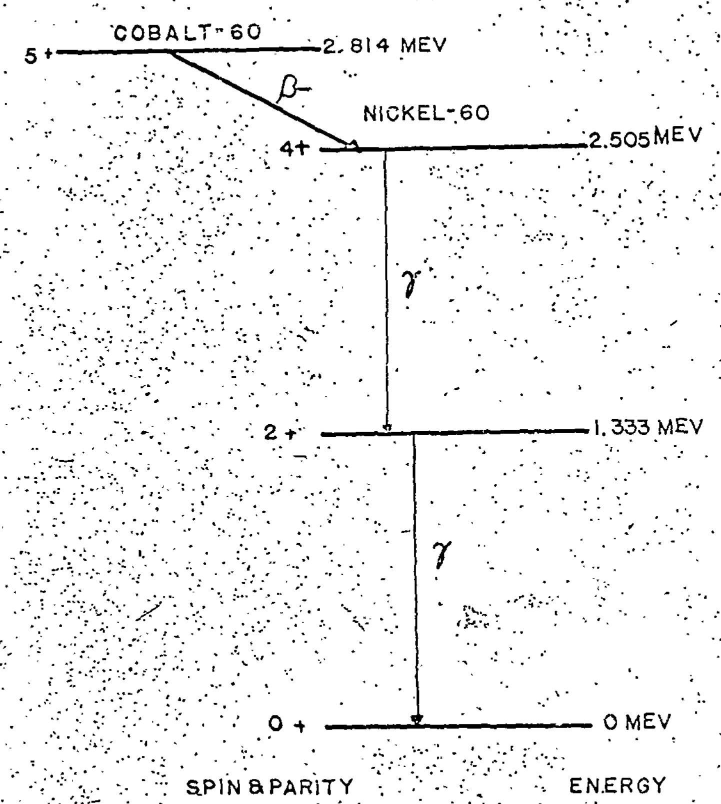


FIGURE 1

CHAPTER II

THEORETICAL CONSIDERATIONS

The determination of the angular momentum quantum numbers, or spins, of low-lying short-lived excited nuclear states by the nuclear spectroscopic tool, known as angular correlation of *successively emitted radiations*, is quite common practice today. Only within recent years, because of the vast advancement of electronics, has practical utilization of this tool become possible.

Since nuclei, under ordinary conditions, are randomly oriented in space, it is not possible to observe a radiation pattern. This is due to the fact that the probability of emission of a radiation by an excited nucleus, depends on the angle between the nuclear spin axis and the direction of the emission. Therefore, in order to observe a radiation pattern, it is first necessary to orient the nuclei.

One method of orienting certain nuclei consists of placing the sample in an electric field gradient or a strong magnetic field at a very low temperature. Another method, the one used in the present consideration, consists of selecting nuclei whose nuclear states have spins lying in preferred directions. This happens to be the case for the intermediate state if a nucleus decays by successive emission of two radiations.

In an angular correlation experiment the first radiation is observed in a fixed direction. This establishes an axis to which the direction of emission of the second radiation, originating from the state formed by the first, can be referred. The second radiation has preferred angles of emission with respect to the direction of the first.

In order that the correlation exhibit maximum anisotropy, the angular momentum vector of the intermediate state must not change direction significantly before the second radiation occurs. The mean life of the intermediate state must be less than about 10^{-8} seconds, the typical precession period of the nuclear spin about local perturbing fields. The angular correlation function is determined by the nature of the radiations and by the spins of the states involved, and thus its measurement may lead to an unambiguous choice of spins for the states.

The theoretical expressions for the correlation functions have been worked out for a large number of cases of interest (7). For the particular case of a gamma-gamma cascade, the correlation function $W(\theta)$ is

$$W(\theta) = \sum_{n=0}^{n_{max}} A_n P_n(\cos\theta) = \sum_{n=0}^{n_{max}} B_n \cos^n\theta \qquad (1)$$

where P_n is the Legendre Polynomial of even order n, n_{max} is the smallest even integer of the set of three numbers consisting of twice the multipole order of each of the two gamma rays, and θ is the angle between the directions of emission of the two gamma rays.

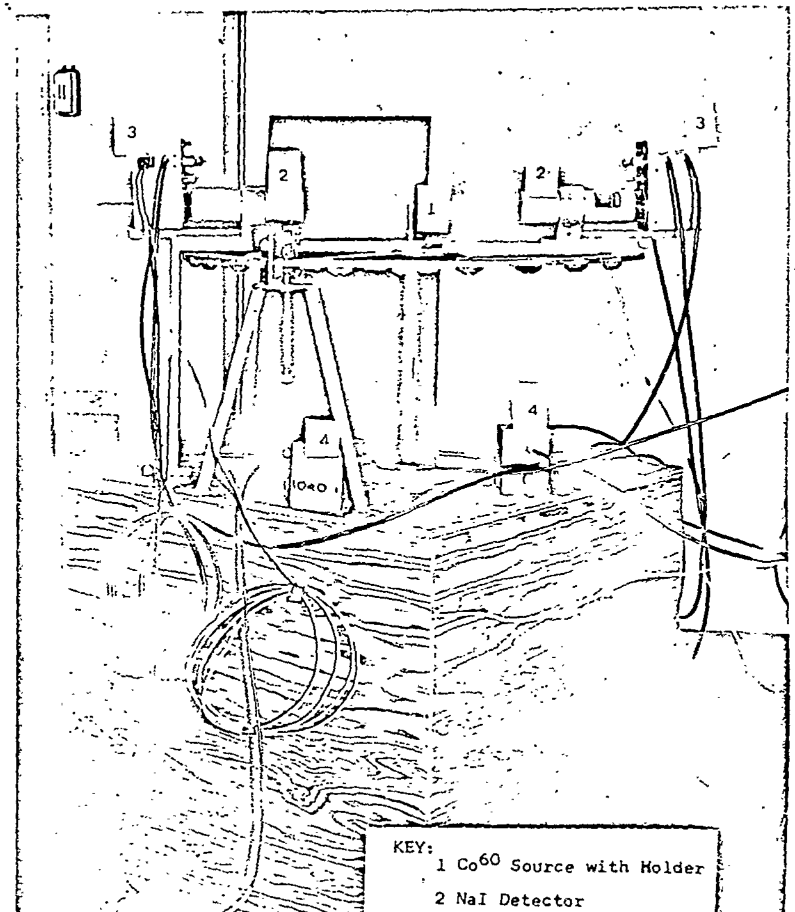
The theoretical correlation function for the cascade in Nickel-60, assuming point detectors and a point source, is

$$W(\theta) = 1 + 0.1020\ P_2(\cos\theta) + 0.0091\ P_4(\cos\theta) \qquad (2)$$

with an anisotropy

$$R = \frac{W(180^\circ) - W(90^\circ)}{W(90^\circ)} = 0.1667 \qquad (3)$$

Many workers, after correcting these theoretical results for the effect of non-point detectors have found good agreement between them and their experimental correlation results.



KEY:
1 Co^{60} Source with Holder
2 NaI Detector
3 Pre-Amplifier
4 Pulse Shaper

ANGULAR CORRELATION TABLE

FIGURE 2

CHAPTER III

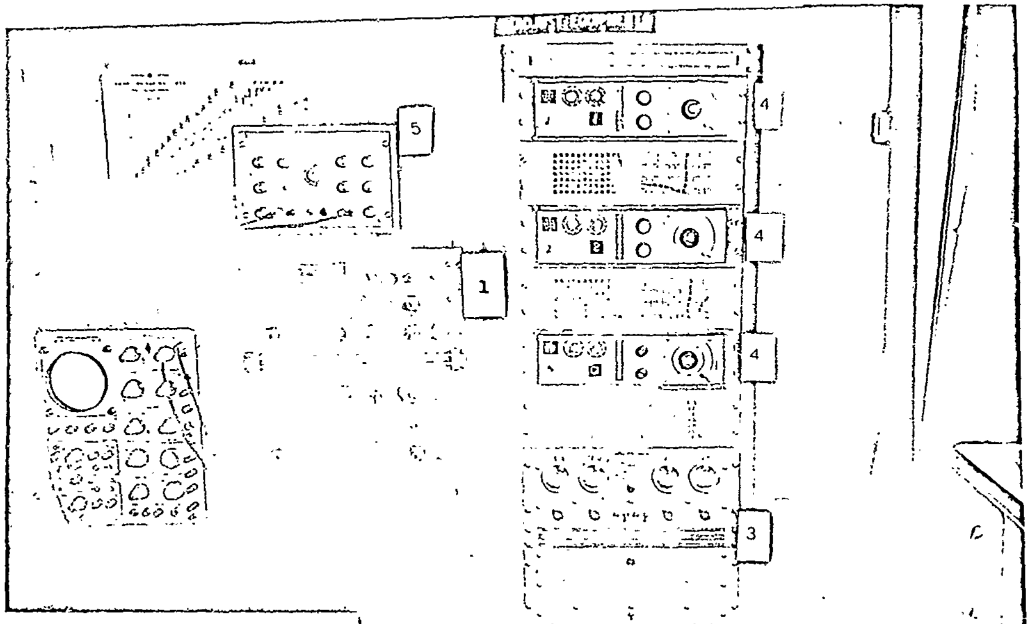
DESCRIPTION OF EQUIPMENT

The equipment needed for the gamma-gamma correlation measurements must furnish means for detecting the radiation, pulse-height amplification with selection or discrimination, coincidence analysis, and adequate recording of the counts in the various counting channels. A mechanical system must also be provided for mounting the detectors and changing their relative positions and for holding and positioning the radioactive source.

The apparatus used for this work was that assembled by Verser and described in detail in his report. Therefore, only a brief description of the equipment and of the minor alterations performed on it will be presented.

Figure 2 is a photograph of the mechanical setup. The original base of the correlation table has been replaced, the new base is of solid brass with a bearing mounted shaft to enable accurate manual detector positioning.

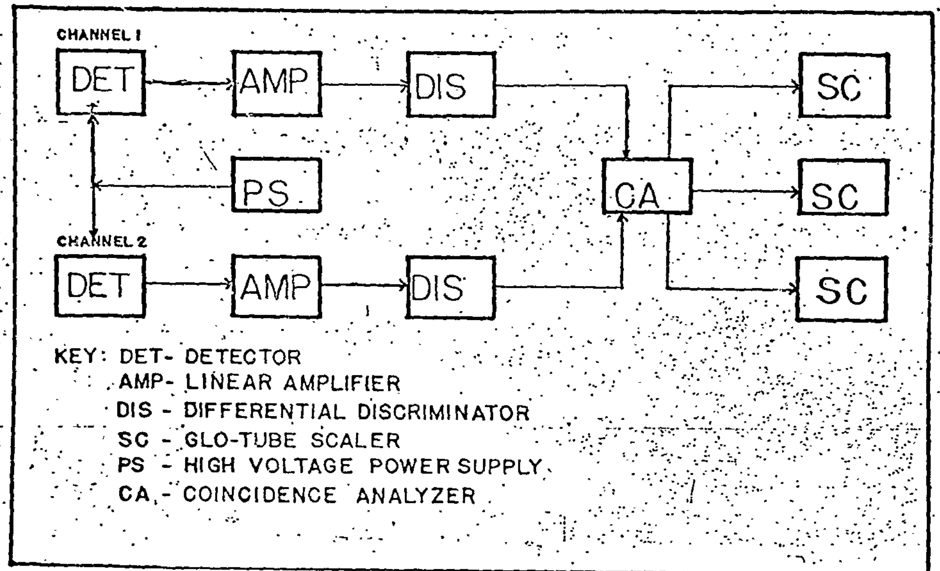
The electronic equipment (Figure 3) has the functions of detection of the radiation, pulse-height amplification and discrimination, coincidence analysis, and recording the number of counts. The only change in the electronic equipment was in the pulse-shaping networks used in the initial calibration of the apparatus. The pulse shapers were rebuilt to give a better simulation between the test pulses and the actual pulses encountered under operating conditions.



KEY:
1. Linear Amplifiers
2. High Voltage Power Supply
3. Coincidence Analyzer
4. Glo-Tube Scaler
Double Pulse Generator

ELECTRONIC SYSTEM

FIGURE 3



SCHEMATIC DIAGRAM OF THE ELECTRONIC SYSTEM

FIGURE 4

CHAPTER IV

EXPERIMENTAL ANALYSIS

The angular correlation function $W(\theta)$ (Equation 1) must be expressed in terms of experimentally-observable quantities. The equipment records the total number of coincidences as a function of the angle between the detectors, and the total number of radiations captured in each channel. C_t, the total number of coincidences in a counting period, is given by

$$C_t = C_g + C_a + C_b \qquad (4)$$

where

C_g = the number of genuine coincidences due to the two cascading radiations,

C_a = the number of accidental coincidences due to the finite resolving time of the electronic equipment, and

C_b = the number of background coincidences.

The half-life of the source is long compared to the time required to collect the necessary data; therefore, equation (4) can be rearranged and rewritten in terms of counting rates:

$$\dot{C}_g = \dot{C}_t - \dot{C}_a - \dot{C}_b \qquad (5)$$

$\dot{C}_g$ can also be expressed in terms of other parameters:

$$\dot{C}_g = (\epsilon_{11}\alpha_{11}\rho_{11}\alpha_{22}\rho_{22} + \epsilon_{12}\alpha_{12}\rho_{12}\epsilon_{21}\alpha_{21}\rho_{21})\Omega_1\Omega_2\phi_{12}\dot{N}_0\bar{W}(\theta_i) \qquad (6)$$

where

$\dot{N}_o$ = the absolute source strength

ϕ_{jk} = the fraction of nuclei decaying by the emission of gamma ray "j" and gamma ray "k" in a cascade

Ω_i = the fractional solid angle subtended by the crystal in Channel "i"

ρ_{ij} = the fraction of gamma rays "j" which leave the source in the right direction to enter crystal "i" that are not absorbed before reaching the crystal

ϵ_{ij} = the total efficiency of the crystal in Channel "i" for gamma ray "j"

α_{ij} = the fraction of the number of gamma rays "j" captured by the crystal in Channel "i" whose pulse heights are accepted by the energy discrimination of Channel "i"

$\bar{W}(\theta_m)$ = the angular correlation function at an angle θ_m averaged over the solid angles used.

$\dot{N}_i$, the counting rate in Channel "i", can also be expressed as a function of certain of these same parameters.

$$\dot{N}_i = \Omega_i \phi_i \dot{N}_o \sum_j \epsilon_{ij}\alpha_{ij}\rho_{ij} + \dot{N}_{ib} \qquad (7)$$

where

ϕ_i = the number of gamma rays "i" per disintegration

$\dot{N}_{ib}$ = the background counting rate in channel "i"

From Equations (5) and (6) we get for the correlation function,

$$\bar{W}(\theta_m) = \left\{\frac{\dot{C}_g}{f\dot{N}_o}\right\}_m = \left\{\frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{f\dot{N}_o}\right\}_m \qquad (8)$$

where f is the appropriate function of the ϵ's, α's, ρ's, and ϕ's.

By combining Equations (7) and (8), we get for the correlation function

$$\overline{W}(\theta_m) = \left\{\frac{(\dot{C}_t-\dot{C}_a-\dot{C}_b)\ \dot{N}_o g}{(\dot{N}_1-\dot{N}_{1b})\ (\dot{N}_2-\dot{N}_{2b})}\right\}_m \tag{9}$$

where g is a function of the ε's, α's, ρ's, Ω's, ϕ's.

In this form $W(\theta_m)$ is relatively insensitive to equipment stability. Therefore, it is only necessary to calculate the modified correlation function given by

$$\overline{W}'(\theta_m) = \frac{\overline{W}(\theta_m)}{g\dot{N}_o} = \left\{\frac{(\dot{C}_t-\dot{C}_a-\dot{C}_b)}{(\dot{N}_1-\dot{N}_{1b})\ (\dot{N}_2-\dot{N}_{2b})}\right\}_m \tag{10}$$

The correlation runs were done with the movable detector at seven angles: 90°, 105°, 120°, 135°, 150°, 165°, and 180°. A minimum of six two-hour counting periods were completed at each angle, and the angular order in which they were taken was varied to minimize any systematic fluctuations. Each run yielded single channel counting rates of approximately 1200 counts per second and a total coincidence rate of approximately 1.1 counts per second.

Before the experimental results can be compared to theory, the data must be checked and corrected, if necessary, for the various deviations from the ideal arrangement, i.e., centered point source, no spurious coincidences due to the coincidence resolving time, no scattering, no background, and perfect stability of the electronic equipment. In addition, the theoretical correlation function must be corrected for non-zero solid angle detectors. The methods for accounting for these effects are discussed in the following paragraphs.

A. SOURCE SIZE AND POSITIONING

As a test of the positioning of the source in the center of the correlation table, the integral counting rate of a portion of the Cobalt-60 spectrum was measured in each channel as a function of the angle between the counters. This was done by Verser and checked again after the base of the correlation table had been changed. Within statistical expectations, the counting rates were constant. The source has a volume of about 0.001 cubic inches and can be regarded as a point source at the distance at which the detectors were placed from it.

B. SCATTERING

Compton scattering occurring outside the detectors can give rise to unwanted coincidences. These in general will tend to smear out the measured correlation function. This problem is minimized by use of scintillation crystals as detectors and accepting only the full-energy peaks of the desired gamma rays. The method for determining the pulse height selection limits has been discussed in detail by Verser.

C. BACKGROUND CORRECTION

With the discriminators at the same settings as were used during the correlation runs, background runs were made before and after the correlation runs. The background coincidence counting rate was negligibly small, and the background rate of each channel was such as to yield total background counts of the order of 0.4 percent of the total counts in each channel during the correlation runs. These background rates were used as corrections to the gross counting rates obtained during correlation runs.

D. DETERMINATION OF GENUINE COINCIDENCE RATE

Since the background coincidence counting rate proved experimentally to be negligible, Equation (5) becomes

$$\dot{C}_g = \dot{C}_t - \dot{C}_a$$

For the total counting time, T, the total number of coincidences is $\dot{C}_t T$ and the standard deviation in the total coincidence rate is

$$\sigma_t = \sqrt{\frac{\dot{C}_t}{T}} \qquad (11)$$

Therefore, the standard deviation of the genuine coincidence rate is

$$\sigma_g^2 = \sigma_t^2 + \sigma_a^2 = \frac{\dot{C}_t}{T} + \frac{\dot{C}_a}{T} \qquad (12)$$

The accidental coincidence rate is given by

$$\dot{C}_a = 2\tau_r \dot{N}_1 \dot{N}_2 \sim 2\tau_r \dot{N}_o^2 \qquad (13)$$

where

τ_r = Coincidence resolving time of the coincidence analyzer.

In order to minimize the accidental coincidence rate, the source strength must be kept as small as possible. However, if the source strength is decreased, the counting time must be increased to obtain a specified precision in the counting rate. Thus, a compromise must be reached between precision and counting time.

The smallest resolving time obtainable with the present equipment is experimentally determined to be

$$\tau_r = (0.1820 \pm 0.0016) \text{ microseconds;}$$

this resulted in an accidental coincidence rate that was about 30% of the

total coincidence rate. The approximate source strength of the water solution of $CoCl_2$ used in this experiment was 0.05 millicuries of Cobalt-60.

E. REFERENCE COUNTING RATE

With the discriminator in each channel adjusted to accept only the full-energy peaks of the desired gamma rays, the integral counting rate of the Cobalt-60 spectrum in each channel was determined. This gave a reference counting rate for each channel. During the course of the correlation runs, either the discriminator settings or the gains of the linear amplifiers were adjusted before each run so that, the integral counting rate agreed within ± 5 cps with these reference rates (Table 1).

TABLE 1

REFERENCE COUNTING RATES

$\dot{N}_1$ = (1085.26 ± 0.57) cps
$\dot{N}_2$ = (1117.32 ± 0.59) cps

As a measure of the gain fluctuations during each counting run, the integral counting rate of each channel was measured after the run using the same discriminator setting that was employed during the run. The difference between this counting rate and the reference counting for that channel was determined. If the variation exceeded ± 20 cps in either channel, the run was discarded.

This procedure resulted in about 30% of the runs being discarded because they fell outside of the maximum acceptable fluctuation. This indicates that the electronic system is not as stable as it should be. A check of the line voltage revealed substantial fluctuations during any 24-hour period. The temperature of the room was not controlled in any manner and varied considerably. These could have been the major causes of the large counting rate fluctuations since the discriminators are highly sensitive to both temperature and voltage variations.

F. SOLID ANGLE CORRECTIONS

The solid angle correction which must be applied to the theoretical correlation function to account for the non-zero solid angle of the detectors and enable a comparison to be made with the measured function is described by Rose (2). The correction for two cylindrical crystals whose axes intersect at the source involves the numerical evaluation of integrals of the form

$$I_{n,i} = \int_0^{\gamma_i} P_n(\cos\phi)\left\{1 - e^{-\Upsilon_i X_i(\phi)}\right\}\sin\phi\, d\phi \qquad (14)$$

where

Υ_i = the full-energy absorption coefficient of the detector in Channel "i" for the gamma ray;

γ_i = the half-angle subtended by the front face of the crystal in Channel "i";

$X_i(\phi) = t_i \sec\phi$ for $0 \le \phi \le \tan^{-1}\dfrac{-r_i}{h_i + t_i}$;

$X_i(\phi) = r_i \csc\phi - h_i \sec\phi$ for $\tan^{-1}\dfrac{r_i}{h_i + t_i} \le \phi \le \gamma_i$;

where

h_i = the distance from the source to the crystal in Channel "i";

t_i = the thickness of the crystal in Channel "i",

r_i = the radius of the crystal in Channel "i".

The attenuation factors, Q_n, are functions of these integrals:

$$Q_n = \left[\frac{I_{n,1}}{I_{o,1}}\right]\left[\frac{I_{n,2}}{I_{o,2}}\right] \qquad (15)$$

The corrected correlation function becomes

$$\bar{W}(\theta) = \sum_{n=0}^{N_{max}} Q_n A_n P_n(\cos\theta)$$

CHAPTER V
EXPERIMENTAL RESULTS

The modified correlation function for the k^{th} run at angle θ_m given by Equation (10) is

$$\bar{W}'_k(\theta_m) = \left\{\frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{(\dot{N}_1 - \dot{N}_{1b})\ (\dot{N}_2 - \dot{N}_{2b})}\right\}_k$$

This means that the seven counting rates $\dot{C}_t$, $\dot{C}_a$, $\dot{C}_b$, $\dot{N}_1$, $\dot{N}_{1b}$, $\dot{N}_2$, and $\dot{N}_{2b}$ must be determined for each run at each angle and the standard deviation of each rate calculated.

The background counting rates $\dot{N}_{1b}$ and $\dot{N}_{2b}$ for each run were experimentally determined. The single-channel counting rates corrected for scaling losses yielded $\dot{N}_1$ and $\dot{N}_2$. The accidental counting rates were calculated for each run from Equation (13). The total coincidence counting rate, $\dot{C}_t$, was experimentally determined. The background coincidence rate, $\dot{C}_b$, was negligible throughout the experiment.

The experimental value of the modified correlation function $\bar{W}'_k(\theta_m)$ and its standard deviation were calculated for each run at each angle. From these the weighted mean $\bar{W}'(\theta_m)$ and its standard deviation were computed for each angle.

The weighted mean of the measurements taken at each angle was determined by using the inverse square of the standard deviation of each measurement as a weighting factor:

$$\bar{W}'(\theta_m) = \frac{\displaystyle\sum_{1}^{N_m} \frac{\bar{W}'_k(\theta_m)}{\sigma_k^2}}{\displaystyle\sum_{1}^{N_m} \frac{1}{\sigma_k^2}} \qquad (18)$$

where N_m = number of runs at the angle θ_m.

The standard deviation of the weighted mean ($\bar{W}'$) was calculated from the individual standard deviations:

$$\frac{1}{\sigma^2(\bar{W}')} = \sum_{1}^{N_m} \frac{1}{\sigma_k^2} \qquad (19)$$

A comparison between the standard deviations of the means calculated from Equation (19) and those calculated from

$$\sigma^2(\bar{W}') = \sum_{1}^{N_m} \frac{\left[\bar{W}'(\theta_m) - \bar{W}(\theta)\right]^2}{N_m(N_m - 1)} \qquad (20)$$

revealed no significant differences. Therefore the standard deviation obtained from Equation (19) were used in subsequent calculations and the method discussed in paragraph E Chapter IV for treating gain instabilities is realistic.

The values of the weighted means and their standard deviations are tabulated in Table 2.

TABLE 2

The Weighted Means $\bar{W}'(\theta_m)$

θ_m (degrees)	Weighted Mean	Standard Deviation
90	5046	45
105	4925	33
120	5109	21
135	5211	36
150	5556	35
165	5667	24
180	5907	43

A curve of the form $\bar{W}'(\theta) = \sum A_n' \; P_n(\cos\theta)$ was fitted to the experimental $\bar{W}'(\theta_m)$ by the method of least squares as outlined by Rose (2). This analysis was programmed to be carried out by the 1604 computer. (See Appendix II for details).

The values of A_n' are given by the matrix equation

$$\|A'\| = \|A^T \omega A\|^{-1} \cdot \|A^T\| \cdot \|\omega\| \cdot \|\mu\| \qquad (21)$$

where

$\|A\|$ = the 7 x 3 matrix consisting of the Legendre Polynomials, P_o, P_2, and P_4, evaluated at the seven angles (Figure 5A).

$\|A^T\|$ = the transposed A matrix

$\|\omega\|$ = a diagonal matrix with elements consisting of the inverse squares of the standard deviations of the experimental $\bar{W}'(\theta_m)$ (Figure 5B)

$\|\mu\|$ = a one column matrix whose elements are the experimental values of $\bar{W}'(\theta_m)$ (Figure 5C)

$\|A'\|$ = the one column matrix whose elements are respectively the least-square coefficients A_o', A_2' and A_4' (Figure 5D)

$\|A^T \omega A\|^{-1}$ = the inverse of the matrix obtained by multiplying the three designated matrices together. The diagonal terms of this matrix are the squares of the standard deviations of the least-square coefficients, A_n'.

The experimental values for the coefficients A_n' and their standard deviations, normalized so that $A_o' = 1$, are listed in Table 3. The corresponding values from Verser's work are included for comparison.

TABLE 3

Least Square Coefficients

	Verser	This Work
A'_o	1.0000 ± 0.0034	1.0000 ± 0.0026
A'_2	0.0961 ± 0.0055	0.0971 ± 0.0057
A'_4	0.0339 ± 0.0071	0.0231 ± 0.0066

MATRIX CONFIGURATIONS

$$\left\| \begin{matrix} P_o(\cos 90^\circ) & P_2(\cos 90^\circ) & P_4(\cos 90^\circ) \\ P_o(\cos 105^\circ) & P_2(\cos 105^\circ) & P_4(\cos 105^\circ) \\ P_o(\cos 120^\circ) & P_2(\cos 120^\circ) & P_4(\cos 120^\circ) \\ P_o(\cos 135^\circ) & P_2(\cos 135^\circ) & P_4(\cos 135^\circ) \\ P_o(\cos 150^\circ) & P_2(\cos 150^\circ) & P_4(\cos 150^\circ) \\ P_o(\cos 165^\circ) & P_2(\cos 165^\circ) & P_4(\cos 165^\circ) \\ P_o(\cos 180^\circ) & P_2(\cos 180^\circ) & P_4(\cos 180^\circ) \end{matrix} \right\|$$

(A)

$$\left\| \begin{matrix} \sigma^{-2}(90^\circ) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sigma^{-2}(105^\circ) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma^{-2}(120^\circ) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma^{-2}(135^\circ) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma^{-2}(150^\circ) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma^{-2}(165^\circ) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma^{-2}(180^\circ) \end{matrix} \right\|$$

(B)

$$\left\| \begin{matrix} \bar{W}'(90^\circ) \\ \bar{W}'(105^\circ) \\ \bar{W}'(120^\circ) \\ \bar{W}'(135^\circ) \\ \bar{W}'(150^\circ) \\ \bar{W}'(165^\circ) \\ \bar{W}'(180^\circ) \end{matrix} \right\|$$

(C)

$$\left\| \begin{matrix} A_o \\ A_2 \\ A_4 \end{matrix} \right\|$$

(D)

FIGURE 5

A. Experimental Anisotropies

The anisotropy is defined:

$$\bar{R} = \frac{\bar{W}(180^{\circ}) - \bar{W}(90^{\circ})}{\bar{W}(90^{\circ})} \quad (22)$$

The anisotropy for the least-square curve was calculated from the experimental correlation function. Since the anisotropy can be determined with much greater precision than can the least-square coefficients themselves, it provides a more sensitive means for comparing the experimental and theoretical functions. The experimental anisotropy is

$$\bar{R} = 0.167 \pm 0.013$$

The standard deviation was calculated by the formula presented by Klema and McGowan (6). The computer program for the calculation of $\bar{R}$ and its standard deviation is outlined in Appendix I.

CHAPTER VI
RESULTS AND CONCLUSIONS

A. COMPARISON BETWEEN EXPERIMENT AND THEORY

The experimental and corrected theoretical functions for this experiment are:

Experimental:

$$\bar{W}'(\theta) = (1.0000 \pm 0.0026) + (0.0971 \pm 0.0057)\ P_2 + (0.0231 \pm 0.0066)\ P_4$$

Theoretical:

$$\bar{W}(\theta) = 1.0000 \pm 0.0996\ P_2 + 0.00838\ P_4$$

The experimental anisotropy was calculated to be $\bar{R} = 0.167 \pm 0.013$ and is compared with Verser's value of $\bar{R} = 0.171 \pm 0.027$ and with the theoretical anisotropy corrected for the solid angle, $\bar{R} = 0.161$.

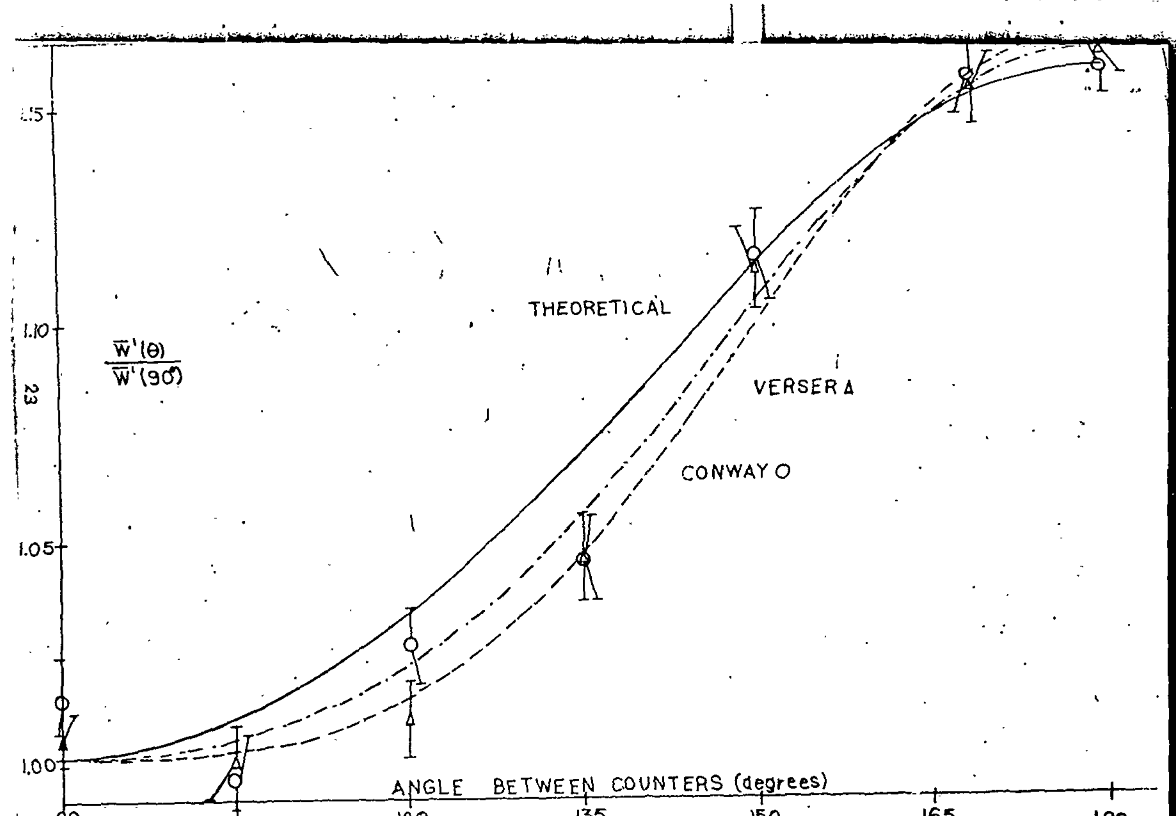
Figure 6 shows the experimental results and their standard deviations for this work and that of Verser. Also shown are the least-square correlation curves for both sets of data and the corrected theoretical correlation curve. All the curves have been normalized to unity at $\theta = 90^{\circ}$.

B. DISCUSSION AND CONCLUSIONS

From Figure 6, it can be seen that the curve obtained in this work agrees with that obtained by Verser. Both of these curves show an apparently real dip in the region from 105° to 135°. It is only a remote possibility that this dip can be attributed to statistical fluctuations, and it is unlikely to be due to instrumental effects.

Two conjectures of possible mechanisms are:

(a) The source may have crystallized resulting in preferential alignment of the nuclei within the crystal due to internal electric fields.



1.15
1.10
1.05
1.00
$\frac{\overline{W}'(\theta)}{\overline{W}'(90^\circ)}$
THEORETICAL
VERSER △
CONWAY ○
ANGLE BETWEEN COUNTERS (degrees)
90
105
120
135
150
165
180

FIGURE 6

(b) The ferromagnetic properties of Cobalt could have led to a preferential alignment of the nuclei in the earth's magnetic field.

The following series of experiments are suggested for future work.

(a) The results for measurements conducted for angles between 180° and 270° should be compared with those already obtained.

(b) In order to check on the possible effects of orientation due to crystalline electric fields, the experiment should be repeated with the present source at various orientations relative to the fixed counter.

(c) In order to check on the possibility of orientation by magnetic effects the source should be placed in a magnetic field of known direction and the measurements repeated.

(d) A correlation curve using a powdered Cobalt-60 source in place of the present source should be obtained for comparison.

These experiments would determine conclusively if any effects causing preferential nuclear orientation are present.

The following instrumentation improvements are suggested in order to improve the stability of the equipment.

(a) A very stable power supply should be purchased to aid in preventing the line voltage fluctuations from interfering with the electronic system.

(b) The effect of temperature variations on the electronic system can be minimized by placing the equipment in a temperature controlled room for conducting future work.

(c) A slow coincidence unit whose resolving time is independent of the counting rate should be obtained.

The precision of the results should be improved by the addition of a fast coincidence channel working in conjunction with the slow coincidence unit to reduce the number of accidental coincidences.

Since the experimental curves using Cobalt-60 have not agreed with the theoretical curve, the experiments on Cobalt-60 should be continued until the source of the distrotion is ascertained. Perhaps the effect can be related to the physical properties of the $CoCl_2$ source.

APPENDIX I

Least-Square Fit of Experimental Results

The comparison of the experimental correlation function to the functional form of the theoretical correlation function given by Equation (1) is accomplished by the method of least-squares, as outlined by Rose (2). The analysis requires the solution of Equation (20) for the values of A'_n.

The computer solution of the matrix equation, like the solid angle calculation, is carried out in floating point format. In addition to the solution for the values of A'_n, the program also calculates the anisotropy by Equation (21), and its standard deviation by the formula presented by Klema and McGowan (6). A flow sheet outline of the program is given in Figure (7). In order to provide a certain amount of flexibility to the program, the angles used have been left as a parameter to be supplied. The program as written is, however, limited to seven different angular positions. The parameters needed for the program may be placed anywhere in the computer and their addresses supplied to the program by placing, them in the B registers in the following order:

B1 = weighted means of the correlation function in ascending angular order.

B2 = the standard deveations of the weighted means in the same order as above.

B3 = the values of the angles used in ascending order.

The program is available for future use on both bioctal tape in machine language, and IBM cards in assembly language. The bioctal tape contains the following:

1. The main program for calculation of A'_n
2. The program of normalization of the A'_n
3. The program for calculation of the resulting correlation function
4. The normalization of the correlation function
5. The calculation of the anisotropy

LEAST-SQUARE FIT FLOW CHART

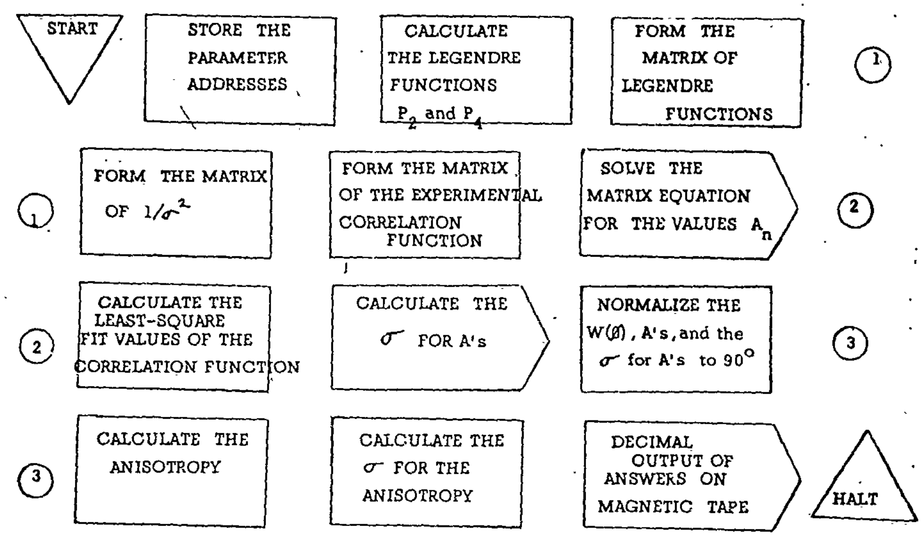


FIGURE 7

6. The calculation of the standard deviation for the anisotropy

7. The subroutines

   a. Floating Point Sine-Cosine

   b. Floating Point Square Root

   c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Lines 1 thru 3	The matrix inverse
Lines 4 thru 6	Check answer; included in the program is a check of the inverse which consists of multiplying the inverse by the original matrix
Line 7	The values of A'_o, A'_2 and A'_4
Line 8	The standard deviations of the A'_n
Line 9 thru 13	The resulting correlation functions
Line 14 and 15	The normalized correlation functions
Line 16	The normalized A'_n
Line 17	The normalized standard deviations of the A'_n
Line 18	The anisotropy
Line 19	The square of the standard deviation of the anisotropy

STATISTICAL ANALYSIS PROGRAM

```
        ORG   12000
        REM   BURTON J CONWAY APRIL 1961
        REM   LEAST SQUARE FIT OF ANGULAR
        REM   CORRELATION DATA.
        REM   MUST BE SUPPLIED WITH
        REM   PARAMETER ADDRESSES AS FOLLOWS.
        REM   B1  CORRELATION FUNCTION.
        REM   B2  SIGMA OF CORRELATION FUNCT. ON.
        REM   B3  ANGLES USED IN DEGREES.
ZEUS    EQU   13000
RHO     EQU   13100
TRANS   EQU   13200
ATW     EQU   13230
ATWA    EQU   13260
INVER   EQU   13500
CHECK   EQU   13520
IAT     EQU   13540
IATW    EQU   13570
ANS     EQU   13620
FINIS   EQU   13630
SINFL   EQU   60000
MATRIX  EQU   10000
```

```
                              ANISO   EQU   13624
12000    56 1 12045                   SIU  1 FORMMU
         50 1 00000                   ENI  1 0
12001    57 2 12032                   SIL  2 SIGMA
         56 2 12033                   SIU  2 SIGMA+1
12002    50 2 00000                   ENI  2 0
         50 0 00000                   ENI  0 0
12003    56 3 12004                   SIU  3 /+1
         50 3 00000                   ENI  3 0
12004    12 1 00000   START           LDA  1 0
         32 0 12512                   FMU  0 CONV
12005    75 4 60001                   SLJ  4 SINFL+1
         50 0 00000                   ENI  0 0
12006    50 0 00000                   ENI  0 0
         50 0 00000                   ENI  0 0
12007    50 0 00000                   ENI  0 0
         50 0 00000                   ENI  0 0
12010    20 1 12463                   STA  1 TEMP
         50 0 00000                   ENI  0 0
12011    54 1 00006                   ISK  1 6
         75 0 12004                   SLJ  0 START
12012    12 1 12463   NEXT            LDA  1 TEMP         STARTS FORMATION
         32 1 12463                   FMU  1 TEMP         OF THE LEG. POL.
```



```
12013    20 0 12461                   STA  0 DON
         32 0 12320                   FMU  0 FLT2
12014    31 0 12316                   FSB  0 FLT
         33 0 12317                   FDV  0 FLT1
12015    20 1 12326                   STA  1 WORK2
         12 0 12461                   LDA  0 DON
12016    32 0 12322                   FMU  0 FLT4
         20 0 12462                   STA  0 DON+1
12017    12 0 12461                   LDA  0 DON
         32 0 12461                   FMU  0 DON
12020    32 0 12323                   FMU  0 FLT5
         31 0 12462                   FSB  0 DON+1
12021    30 0 12320                   FAD  0 FLT2
         33 0 12321                   FDV  0 FLT3
12022    20 1 12335                   STA  1 WORK4
         50 0 00000                   ENI  0 0
12023    54 1 00006                   ISK  1 6
         75 0 12012                   SLJ  0 NEXT
12024    12 0 12325   FORM            LDA  0 WORK1
         20 2 12434                   STA  2 ABLE
12025    51 2 00001                   INI  2 1
         12 1 12326                   LDA  1 WORK2
12026    20 2 12434                   STA  2 ABLE
         51 2 00001                   INI  2 1
```

```
12027   12 1 12335            LDA  1 WORK4
        20 2 12434            STA  2 ABLE
12030   51 2 00001            INI  2 1
        50 0 00000            ENI  0 0
12031   54 1 00006            ISK  1 6
        75 0 12024            SLJ  0 FORM
12032   12 0 12316  SIGMA     LDA  0 FLT
        33 1 00000            FDV  1 0
12033   33 1 00000            FDV  1 0
        20 1 12463            STA  1 TEMP
12034   54 1 00006            ISK  1 6
        75 0 12032            SLJ  0 SIGMA
12035   50 2 00000            ENI  2 0
        50 1 00000            ENI  1 0
12036   12 1 12353  FORMCAD   LDA- 1 CAD
        22 0 12043            AJP  0 /+5
12037   12 2 12463            LDA  2 TEMP
        20 1 12353            STA  1 CAD
12040   51 1 00001            INI  1 1
        50 0 00000            ENI  0 0
12041   54 2 00006            ISK  2 6
        75 0 12036            SLJ  0 FORMCAD
```



```
12042   75 0 12044            SLJ  0 /+2
        50 0 00000            ENI  0 0
12043   51 1 00001            INI  1 1
        75 0 12036            SLJ  0 FORMCAD
12044   50 1 00000            ENI  1 0
        50 2 00000            ENI  2 0
12045   12 1 00000  FORMMU    LDA  1 0
        20 1 12344            STA  1 MU
12046   54 1 00006            ISK  1 6
        75 0 12045            SLJ  0 FORMMU
12047   50 1 00000            ENI  1 0
        50 2 00000            ENI  2 0
12050   75 4 10000            SLJ  4 MATRIX     TRANSPOSE
        50 0 00000            ENI  0 0
12051   50 0 00000            ENI  0 0
        50 0 00000            ENI  0 0
12052   50 0 00000            ENI  0 0
        50 0 00002            ENI  0 2
12053   50 0 00007            ENI  0 7
        50 0 12434            ENI  0 ABLE
12054   50 0 00003            ENI  0 3
        50 0 06626            ENI  0 6626
12055   50 0 00000            ENI  0 0
        50 0 13200            ENI  0 TRANS
```

```
12056   75 4 10000     SLJ  4 MATRIX      ATW
        50 0 00000     ENI  0 0
12057   50 0 00000     ENI  0 0
        50 0 00000     ENI  0 0
12060   50 0 00000     ENI  0 0
        50 0 00004     ENI  0 4
12061   50 0 00003     ENI  0 3
        50 0 13200     ENI  0 TRANS
12062   50 0 00007     ENI  0 7
        50 0 12353     ENI  0 CAD
12063   50 0 00007     ENI  0 7
        50 0 13230     ENI  0 ATW
12064   75 4 10000     SLJ  4 MATRIX      ATWA
        50 0 00000     ENI  0 0
12065   50 0 00000     ENI  0 0
        50 0 00000     ENI  0 0
12066   50 0 00000     ENI  0 0
        50 0 00004     ENI  0 4
12067   50 0 00003     ENI  0 3
        50 0 13230     ENI  0 ATW
12070   50 0 00007     ENI  0 7
        50 0 12434     ENI  0 ABLE
```



```
12071   50 0 00003     ENI  0 3
        50 0 13260     ENI  0 ATWA
12072   75 4 10000     SLJ  4 MATRIX      INVERSE
        50 0 00000     ENI  0 0
12073   50 0 00000     ENI  0 0
        50 0 00000     ENI  0 0
12074   50 0 00000     ENI  0 0
        50 0 00005     ENI  0 5
12075   50 0 00003     ENI  0 3
        50 0 13260     ENI  0 ATWA
12076   50 0 00044     ENI  0 36D
        50 0 13272     ENI  0 ATWA+12
12077   50 0 00000     ENI  0 0
        50 0 13500     ENI  0 INVER
12100   75 4 10000     SLJ  4 MATRIX      CHECK
        50 0 00000     ENI  0 0
12101   50 0 00000     ENI  0 0
        50 0 00000     ENI  0 0
12102   50 0 00000     ENI  0 0
        50 0 00004     ENI  0 4
12103   50 0 00003     ENI  0 3
        50 0 13500     ENI  0 INVER
12104   50 0 00003     ENI  0 3
        50 0 13260     ENI  0 ATWA
```

```
12105   50 0 00003   ENI  0 3
        50 0 13520   ENI  0 CHECK
12106   75 4 10000   SLJ  4 MATRIX     IAT
        50 0 00000   ENI  0 0
12107   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12110   50 0 00000   ENI  0 0
        50 0 00004   ENI  0 4
12111   50 0 00003   ENI  0 3
        50 0 13500   ENI  0 INVER
12112   50 0 00003   ENI  0 3
        50 0 13200   ENI  0 TRANS
12113   50 0 00007   ENI  0 7
        50 0 13540   ENI  0 IAT
12114   75 4 10000   SLJ  4 MATRIX     IATW
        50 0 00000   ENI  0 0
12115   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12116   50 0 00000   ENI  0 0
        50 0 00004   ENI  0 4
12117   50 0 00003   ENI  0 3
        50 0 13540   ENI  0 IAT
```



```
12120   50 0 00007   ENI  0 7
        50 0 12353   ENI  0 CAD
12121   50 0 00007   ENI  0 7
        50 0 13570   ENI  0 IATW
12122   75 4 10000   SLJ  4 MATRIX     ANS
        50 0 00000   ENI  0 0
12123   50 0 00000   ENI  0 0
        50 0 00000   ENI  0 0
12124   50 0 00000   ENI  0 0
        50 0 00004   ENI  0 4
12125   50 0 00003   ENI  0 3
        50 0 13570   ENI  0 IATW
12126   50 0 00007   ENI  0 7
        50 0 12344   ENI  0 MU
12127   50 0 00001   ENI -0 1
        50 0 13620   ENI  0 ANS
12130   50 4 00000   ENI  4 0
        50 5 00000   ENI  5 0
12131   50 6 00000   ENI  6 0
        50 1 00000   ENI  1 0
12132   50 2 00000   ENI  2 0
        50 3 00000   ENI  3 0
12133   54 1 77777   ISK  1 77777
        75 0 12133   SLJ  0 /
```

```
12134   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12135   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12136   01 0 13500           01  0 INVER
        04 0 00001           04  0 1
12137   12 0 12315          LDA  0 MIKE
        70 0 12136          RAD  0 /-1
12140   54 4 00002          ISK  4 2
        75 0 12135          SLJ  0 /-3
12141   54 1 77777          ISK  1 77777
        75 0 12141          SLJ  0 /
12142   54 1 77777          ISK  1 77777
        75 0 12142          SLJ  0 /
12143   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12144   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12145   01 0 13520           01  0 CHECK
        04 0 00004           04  0 4
12146   12 0 12315          LDA  0 MIKE
        70 0 12145          RAD  0 /-1
```



```
12147   54 4 00002          ISK  4 2
        75 0 12144          SLJ  0 /-3
12150   54 1 77777          ISK  1 77777
        75 0 12150          SLJ  0 /
12151   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12152   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12153   01 0 13620           01  0 ANS
        04 0 00007           04  0 7
                            REM  STARTS FORMATION OF THE
                            REM  CORRELATION FUNCTION
12154   12 0 13620  DUMP    LDA  0 ANS
        32 4 12434          FMU  4 ABLE
12155   20 0 13100          STA  0 RHO          A0P0 IN STORAGE
        51 4 00001          INI  4 1
12156   12 0 13621          LDA  0 ANS+1
        32 4 12434          FMU  4 ABLE         A2P2 IN A REG
12157   30 0 13100          FAD  0 RHO          A0P0+A2P2 IN THE
        20 0 13100          STA  0 RHO          A REGISTER
12160   12 0 13622          LDA  0 ANS+2
        51 4 00001          INI  4 1
12161   32 4 12434          FMU  4 ABLE         A4P4 IN A REG
        30 0 13100          FAD  0 RHO          SUM IN A REG
```

```
12162   20 6 13000    STA  6 ZEUS    ANS TO STORAGE
        51 6 00003    INI  6 3
12163   54 4 00024    ISK  4 24
        75 0 12154    SLJ  0 DUMP
12164   12 2 13500    LDA  2 INVER
        75 4 12527    SLJ  4 SQRFL
12165   50 0 00000    ENI  0 0
        50 0 00000    ENI  0 0
12166   20 1 12501    STA  1 TTA
        51 2 00004    INI  2 4
12167   54 1 00002    ISK  1 2
        75 0 12164    SLJ  0 /-3
12170   50 1 00000    ENI  1 0
        50 2 00000    ENI  2 0
12171   50 3 00000    ENI -3 0
        50 4 00000    ENI  4 0
12172   54 1 77777    ISK  1 77777
        75 0 12172    SLJ  0 /
12173   50 0 00000    ENI  0 0
        74 7 42040    EXF  7 42040
12174   75 4 71000    SLJ  4 71000
        50 0 00000    ENI  0 0
```



```
12175   01 0 12501    01  0 TTA
        04 0 00010    04  0 10
12176   54 1 77777    ISK 1 77777
        75 0 12176    SLJ 0 /
12177   50 0 00000    ENI 0 0
        74 7 42040    EXF 7 42040
12200   75 4 71000    SLJ 4 71000
        50 0 00000    ENI 0 0
12201   01 0 13000    01  0 ZEUS
        04 0 00011    04  0 11
12202   12 0 12315    LDA 0 MIKE
        70 0 12201    RAD 0 /-1
12203   54 5 00004    ISK 5 4
        75 0 12200    SLJ 0 /-3
12204   12 1 13000    LDA 1 ZEUS    NORMALIZES THE
        33 0 13000    FDV 0 ZEUS    CORRELATION
12205   20 2 12472    STA 2 NORM  - FUNCTION
        51 1 00003    INI 1 3
12206   54 2 00006    ISK 2 6
        75 0 12204    SLJ 0 /-2
12207   54 1 77777    ISK 1 77777
        75 0 12207    SLJ 0 /
12210   50 0 00000    ENI 0 0
        74 7 42040    EXF 7 42040
```

```
12211   75 4 71000      SLJ  4 71000    DUMPS THE
        50 0 00000      ENI  0 0        NORMALIZED
12212   01 0 12472       01  0 NORM     CORRELATION
        04 0 00016       04  0 16       FUNCTION
12213   12 0 12315      LDA  0 MIKE
        70 0 12212      RAD  0 /-1
12214   54 2 00001      ISK  2 1
        75 0 12211      SLJ  0 /-3
12215   50 1 00000      ENI  1 0
        50 0 00000      ENI  0 0
12216   12 1 13620      LDA  1 ANS
        33 0 13620      FDV  0 ANS
12217   20 1 12507      STA  1 AN
        50 0 00000      ENI  0 0
12220   54 1 00002      ISK  1 2
        75 0 12216      SLJ  0 /-2
12221   54 1 77777      ISK  1 77777
        75 0 12221      SLJ  0 /
12222   50 0 00000      ENI  0 0
        74 7 42040      EXF  7 42040
12223   75 4 71000      SLJ  4 71000
        50 0 00000      ENI  0 0
```



```
12240   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12241   01 0 13624           01  0 ANISO
        04 0 00022           04  0 22
12242   12 0 12314          LDA  0 ZRO
        20 0 12514          STA  0 ROB
12243   12 1 12344   AVG    LDA  1 MU
        31 2 13000          FSB  2 ZEUS
12244   20 0 12513          STA  0 EBSIL
        32 0 12513          FMU  0 EBSIL
12245   32 3 12353          FMU  3 CAD
        30 0 12514          FAD  0 ROB
12246   20 0 12514          STA  0 ROB
        51 2 00003          INI  2 3
12247   51 3 00010          INI  3 10
        50 0 00000          ENI  0 0
12250   54 1 00006          ISK  1 6
        75 0 12243          SLJ  0 AVG
12251   12 0 12514          LDA  0 ROB
        33 0 12324          FDV  0 FLT6
12252   20 0 12514          STA  0 ROB
        50 2 00000          ENI  2 0
```

```
12224   01 0 12507    01  0 AN
        04 0 00020    04  0 20
12225   12 1 12501    LDA 1 TTA       NORMALIZES THE
        33 0 13000    FDV 0 ZEUS      SIGMAS FOR A
12226   20 1 12504    STA 1 TTAN
        50 0 00000    ENI 0 0
12227   54 1 00002    ISK 1 2
        75 0 12225    SLJ 0 /-2
12230   54 1 77777    ISK 1 77777
        75 0 12230    SLJ 0 /
12231   50 0 00000    ENI 0 0
        74 7 42040    EXF 7 42040
12232   75 4 71000    SLJ 4 71000
        50 0 00000    ENI 0 0
12233   01 0 12504    01  0 TTAN
        04 0 00021    04  0 21
12234   12 0 13022    LDA 0 ZEUS+22
        31 0 13000    FSB 0 ZEUS
12235   33 0 13000    FDV 0 ZEUS
        20 0 13624    STA 0 ANISO
12236   54 1 77777    ISK 1 77777
        75 0 12236    SLJ 0 /
12237   50 0 00000    ENI 0 0
        74 7 42040    EXF 7 42040
```



```
12253   50 3 00000    ENI 3 0
        50 1 00000    ENI 1 0
12254   12 0 12514    LDA 0 ROB
        32 1 13500    FMU 1 INVER
12255   20 2 12515    STA 2 AXE
        51 1 00004    INI 1 4
12256   54 2 00002    ISK 2 2
        75 0 12254    SLJ 0 /-2
12257   12 0 12514    LDA 0 ROB
        32 0 13501    FMU 0 INVER+1
12260   20 0 12520    STA 0 COV02
        12 0 12514    LDA 0 ROB
12261   32 0 13505    FMU 0 INVER+5
        20 0 12521    STA 0 COV24
12262   12 0 13621    LDA 0 ANS+1
        30 0 13622    FAD 0 ANS+2
12263   20 0 12522    STA 0 A24
        32 0 12522    FMU 0 A24
12264   20 0 12523    STA 0 A242
        12 0 12522    LDA 0 A24
12265   33 0 13620    FDV 0 ANS
        20 0 12524    STA 0 GET
12266   32 0 12524    FMU 0 GET
        20 0 12524    STA 0 GET
```

```
12267   12 0 12522     LDA  0 A24
        32 0 13620     FMU  0 ANS
12270   20 0 12522     STA  0 A24
        50 0 00000     ENI  0 0
12271   12 0 12521     LDA  0 COV24
        32 0 12317     FMU  0 FLT1
12272   30 0 12516     FAD  0 AXE+1
        30 0 12517     FAD  0 AXE+2
12273   33 0 12523     FDV  0 A242
        20 0 12525     STA  0 WIT
12274   12 0 12515     LDA  0 AXE
        33 0 13620     FDV  0 ANS
12275   33 0 13620     FDV  0 ANS
        30 0 12525     FAD  0 WIT
12276   20 0 12525     STA  0 WIT
        12 0 12520     LDA  0 COV02
12277   30 0 12521     FAD  0 COV24
        33 0 12522     FDV  0 A24
12300   32 0 12317     FMU  0 FLT1
        20 0 12526     STA  0 WIT+1
12301   12 0 12525     LDA  0 WIT
        31 0 12526     FSB  0 WIT+1
```



```
12302   32 0 12524           FMU  0 GET
        20 0 13630           STA  0 FINIS
12303   54 1 77777           ISK  1 77777
        75 0 12303           SLJ  0 /
12304   50 0 00000           ENI  0 0
        74 7 42040           EXF  7 42040
12305   75 4 71000           SLJ  4 71000
        50 0 00000           ENI  0 0
12306-  01 0 13630           01   0 FINIS
        04 0 00025           04   0 25
12307   54 1 77777           ISK  1 77777
        75 0 12307           SLJ  0 /
12310   54 1 77777           ISK  1 77777
        75 0 12310           SLJ  0 /
12311   50 0 00000           ENI  0 0
        74 7 42040           EXF  7 42040
12312   74 0 42003           EXF  0 42003
        50 0 00000           ENI  0 0
12313   76 0 12000           SLS  0 12000
        50 0 00000           ENI  0 0
12314   00 0 00000     ZRO   OCT  0
        00 0 00000
12315   00 0 00004     MIKE  0 0 4
        00 0 00001           0 0 1
```

```
12316   20 0 14000   FLT     DEC   1.0
        00 0 00000
12317   20 0 24000   FLT1    DEC   2.0
        00 0 00000
12320   20 0 26000   FLT2    DEC   3.0
        00 0 00000
12321   20 0 44000   FLT3    DEC   8.0
        00 0 00000
12322   20 0 57400   FLT4    DEC   30.0
        00 0 00000
12323   20 0 64300   FLT5    DEC   35.0
        00 0 00000
12324   20 0 34000   FLT6    DEC   4.0
        00 0 00000
12325   20 0 14000   WORK1   DEC   1.0
        00 0 00000
12326   00 0 00000   WORK2   BSS   7
        00 0 00000
12335   00 0 00000   WORK4   BSS   7
        00 0 00000
12344   17 5 34167   MU      DEC   .5046D-6
        17 3 10477
```



```
12345   17 5 34103           DEC   .4925D-6
        21 2 75007
12346   17 5 34222           DEC   .5109D-6
        23 0 76631
12347   17 5 34276           DEC   .5211D-6
        06 7 01135
12350   17 5 34522           DEC   .5556D-6
        22 1 24417
12351   17 5 34601           DEC   .5667D-6
        75 2 36515
12352   17 5 34751           DEC   .5907D-6
        02 3 02276
12353   20 7 07231   CAD     DEC   .6574621D+17
        17 2 43106
12354   00 0 00000           OCT   0
        00 0 00000
12355   00 0 00000           OCT   0
        00 0 00000
12356   00 0 00000           OCT   0
        00 0 00000
12357   00 0 00000           OCT   0
        00 0 00000
12360   00 0 00000           OCT   0
        00 0 00000
```

```
12361   00 0 00000      OCT  0
        00 0 00000
12362   00 0 00000      OCT  0
        00 0 00000
12363   20 7 05367      DEC  .4938271D+17
        05 2 01171
12364   00 0 00000      OCT  0
        00 0 00000
12365   00 0 00000      OCT  0
        00 0 00000
12366   00 0 00000      OCT  0
        00 0 00000
12367   00 0 00000      OCT  0
        00 0 00000
12370   00 0 00000      OCT  0
        00 0 00000
12371   00 0 00000      OCT  0
        00 0 00000
12372   00 0 00000      OCT  0
        00 0 00000
12373   20 7 05015      DEC  .4526935D+17
        20 7 37137
```



```
12374   00 0 00000      OCT  0
        00 0 00000
12375   00 0 00000      OCT  0
        00 0 00000
12376   00 0 00000      OCT  0
        00 0 00000
12377   00 0 00000      OCT  0
        00 0 00000
12400   00 0 00000      OCT  0
        00 0 00000
12401   00 0 00000      OCT  0
        00 0 00000
12402   00 0 00000      OCT  0
        00 0 00000
12403   20 7 05176      DEC  .4725897D+17
        27 1 03164
12404   00 0 00000      OCT  0
        00 0 00000
12405   00 0 00000      OCT  0
        00 0 00000
12406   00 0 00000      OCT  0
        00 0 00000
12407   00 0 00000      OCT  0
        00 0 00000
```

12410	00 0 00000	OCT	0
	00 0 00000		
12411	00 0 00000	OCT	0
	00 0 00000		
12412	00 0 00000	OCT	0
	00 0 00000		
12413	20 7 04477	DEC	.4164931D+17
	37 2 35173		
12414	00 0 00000	OCT	0
	00 0 00000		
12415	00 0 00000	OCT	0
	00 0 00000		
12416	00 0 00000	OCT	0
	00 0 00000		
12417	00 0 00000	OCT	0
	00 0 00000		
12420	00 0 00000	OCT	0
	00 0 00000		
12421	00 0 00000	OCT	0
	00 0 00000		
12422	00 0 00000	OCT	0
	00 0 00000		

12423	20 7 15041		DEC	.9124087D+17
	16 1 31752			
12424	00 0 00000		OCT	0
	00 0 00000			
12425	00 0 00000		OCT	0
	00 0 00000			
12426	00 0 00000		OCT	0
	00 0 00000			
12427	00 0 00000		OCT	0
	00 0 00000			
12430	00 0 00000		OCT	0
	00 0 00000			
12431	00 0 00000		OCT	0
	00 0 00000			
12432	00 0 00000		OCT	0
	00 0 00000			
12433	20 7 05367		DEC	.4938271D+17
	05 2 01171			
12434	20 0 14000	ABLE	DEC	1.0
	00 0 00000			
12435	57 7 73777		DEC	-.5
	77 7 77777			
12436	17 7 66000		DEC	.375
	00 0 00000			

```
12437   20 0 14000        DEC   1.0
        00 0 00000
12440   60 0 11466        DEC   -.3995454
        73 1 10267
12441   17 7 54455        DEC   .1434268
        71 7 14727
12442   20 0 14000        DEC   1.0
        00 0 00000
12443   60 0 23777        DEC   -.125
        77 7 77777
12444   60 0 13277        DEC   -.289065
        76 5 40722
12445   20 0 14000        DEC   1.0
        00 0 00000
12446   17 7 64000        DEC   .250017
        10 7 23316
12447   60 0 11400        DEC   -.40624
        05 1 74265
12450   20 0 14000        DEC   1.0
        00 0 00000
12451   20 0 05000        DEC   .625
        00 0 00000
```



```
12452   17 7 26004          DEC   .023471
        31 0 11317
12453   20 0 14000          DEC   1.0
        00 0 00000
12454   20 0 07144          DEC   .8995
        26 4 16254
12455   20 0 05364          DEC   .684614
        13 3 47506
12456   20 0 14000          DEC   1.0
        00 0 00000
12457   20 0 14000          DEC   1.0
        00 0 00000
12460   20 0 14000          DEC   1.0
        00 0 00000
12461   00 0 00000   DCN    BSS   2
        00 0 00000
12463   00 0 00000   TEMP   BSS   7
        00 0 00000
12472   00 0 00000   NORM   BSS   7
        00 0 00000
12501   00 0 00000   TTA    BSS   3
        00 0 00000
12504   00 0 00000   TTAN   BSS   3
        00 0 00000
```

```
12507   00 0 00000   AN      BSS   3
        00 0 00000
12512   17 7 24357   CONV    DEC   .01745329252
        50 6 50451
12513   00 0 00000   EBSIL   BSS   1
        00 0 00000
12514   00 0 00000   ROB     BSS   1
        00 0 00000
12515   00 0 00000   AXE     BSS   3
        00 0 00000
12520   00 0 00000   COV02   BSS   1
        00 0 00000
12521   00 0 00000   COV24   BSS   1
        00 0 00000
12522   00 0 00000   A24     BSS   1
        00 0 00000
12523   00 0 00000   A242    BSS   1
        00 0 00000
12524   00 0 00000   GET     BSS   1
        00 0 00000
12525   00 0 00000   WIT     BSS   2
        00 0 00000
```



```
                             REM   FLOATING POINT SQUARE ROOT
12527   75 0 00000   SQRFL   SLJ   0 0            ALARM EXIT
        56 1 12552           SIU   1 SQFEXIT      STORE B1
12530   22 0 12550           AJP   0 SQFEXIT-2    TEST 0 ARGUMENT
        22 3 12527           AJP   3 SQRFL        TEST - ARGUMENT
12531   50 0 00000           ENI   0 0
        42 0 12556           SCM   0 SQMASK1      SET CORRECT
12532   05 0 00001           ALS   0 1            SIGN FOR
        03 0 00045           LRS   0 37D          EXPONENT
12533   22 3 12534           AJP   3 /+1          COMPUTE
        11 0 00002           INA   0 2            EXPONENT
12534   11 0 03777           INA   0 3777         FOR ROOT
        03 0 00001           LRS   0 1
12535   05 0 00044           ALS   0 36D          SHIFT EXPONENT
        20 0 12561           STA   0-SQERAS       AND SIGN
12536   44 0 12557           LDL   0 SQMASK2
        01 0 00004           ARS   0 4
12537   23 3 12540           QJP   3 /+1
        01 0 00001           ARS   0 1
12540   20 0 12562           STA   0 SQERAS+1
        14 0 12555           ADD   0 SQFCON3
12541   20 0 12563           STA   0 SQERAS+2
        12 0 12554           LDA   0 SQFCON2
```

```
12542   27 0 12563            DVF  0 SQERAS+2
        14 0 12553            ADD  0 SQFCON1
12543   50 1 00001            ENI  1 1
        04 0 00000            ENQ  0 0
12544   20 0 12563            STA  0 SQERAS+2
        12 0 12562            LDA  0 SQERAS+1
12545   27 0 12563            DVF  0 SQERAS+2
        14 0 12563            ADD  0 SQERAS+2
12546   01 0 00001            ARS  0 1
        55 1 12544            IJP  1 /-2
12547   01 0 00011            ARS  0 11
        42 0 12561            SCM  0 SQERAS
12550   32 0 12560            FMU  0 SQMASK3
        52 1 12527            LIU  1 SQRFL
12551   51 1 00001            INI  1 1
        57 1 12552            SIL  1 /+1
12552   50 1 00000  SQFEXIT   ENI  1 0
        75 0 00000            SLJ  0 0
12553   21 3 66405  SQFCON1   DEC  218518306D-8B45
        01 4 47436
12554   76 3 72106  SQFCON2   DEC  -302289917l4D-10B41
        43 6 47567
12555   03 0 56173  SQFCON3   DEC  154515776D-8B43
        52 7 71341
```



```
12556   20 0 00000  SQMASK1   OCT  2000000000000000
        00 0 00000
12557   37 7 77777  SQMASK2   OCT  3777777777774000
        77 7 74000
12560   20 0 14000  SQMASK3   OCT  2001400000000000
        00 0 00000
12561   00 0 00000  SQERAS    BSS  3
        00 0 00000
                              END
```

APPENDIX II

Solid Angle Correction

The solid angle correction, which must be applied to the theoretical correlation function to enable a comparison to be made with the experimental correlation function, is described by Rose (1). The correction involves the numerical evaluation of the integrals given by Equation (14):

$$I_{ni} = \int_{o}^{\gamma} P_n(\cos\phi)\ (1-e^{-T_i X_i(\phi)})\ \sin\phi\ d\phi$$

and the subsequent solutions of Equations (15) and (16).

The computer solution for this correction was carried out in floating point format. The numerical integration was computed using an interval of 0.001 radians. A flow sheet outline of the program is given in Figure (8). The program must be supplied with the parameters Υ, h, r, and t same in both channels (see Table 4) thus enabling solid angle corrections to be made for any experimental set-up to which these corrections may be applicable. These parameters may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order

B1 = r (address of the crystal radius in centimeters)

B2 = t (address of the crystal thickness in centimeters)

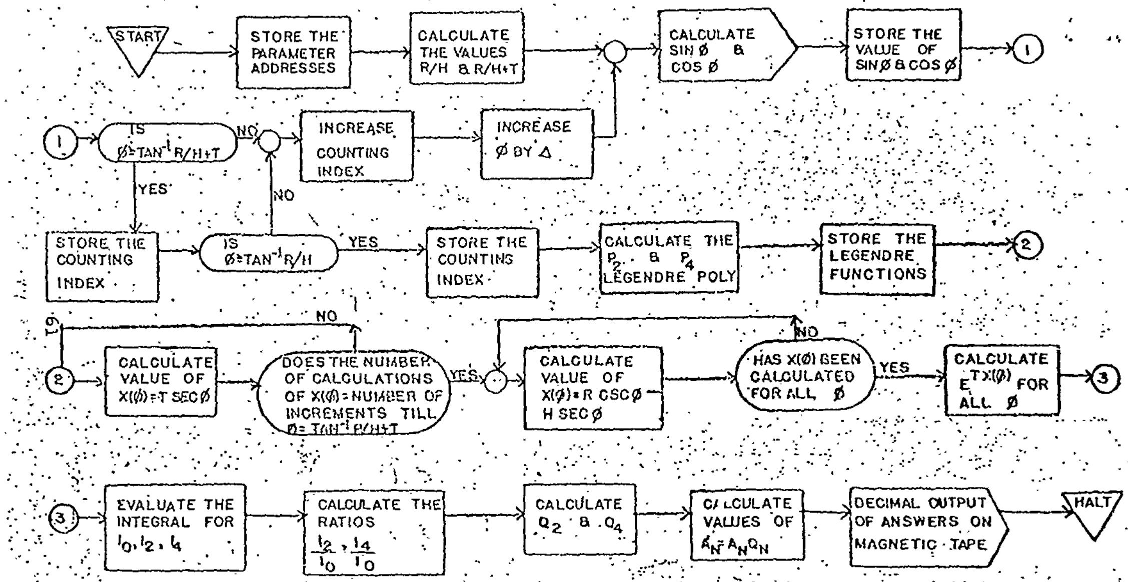
B3 = h (address of the crystal to source distance in centimeters)

B4 = Υ (the value of the full-energy absorption coefficient of the detector for the gamma ray in centimeters^{-1})

The values of the parameters used in the calculation of the corrected angular correlation coefficients for the theoretical correlation function and the results of the calculations are listed in Table 4.

The program is available for future use on bioctal tape in machine language and on IBM cards in assembly language. The bioctal tape contains all the necessary subroutines to enable a complete computation, i.e.

1. The main program for solution of Equation (14),
2. The subroutines



SOLID ANGLE CORRECTION FLOW CHART

FIGURE 8

a. Floating Point Sine-Cosine

b. Floating Point Exponential

c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Line 1	I_0
Line 2	I_2
Line 3	I_4
Line 4	I_2/I_0
Line 5	I_4/I_0
Line 6	Q_2
Line 7	A_2Q_2
Line 8	Q_4
Line 9	A_4Q_4

TABLE 4

SOLID ANGLE CORRECTION PARAMETERS

h (cm)	18.0
ť (cm)	2.54
r (cm)	2.54
T (cm^{-1})	0.098
I_0	0.0079
I_2	0.0078
I_4	0.0076
$\frac{I_2}{I_0}$	0.9882
$\frac{I_4}{I_0}$	0.9609
Q_2	0.9765
Q_4	0.9234
Q_2A_2	0.0996
Q_4A_4	0.0084

SOLID ANGLE CORRECTION PROGRAM

```
              ORG   12000
              REM   BURTON J CONWAY APRIL 1961
              REM   SOLID ANGLE CORRECTIONS
              REM   OF THE THEORETICAL CORRELATION
              REM   CURVE.  MUST BE SUPPLIED
              REM   WITH PARAMETER ADDRESSES AS
              REM   FOLLOWS.
              REM   B1 ADDRESS OF XTAL RADIUS.
              REM   B2 ADDRESS OF XTAL THICKNESS.
              REM   B3 ADDRESS OF CRYSTAL TO
              REM   SOURCE DISTANCE.
              REM   B4 ADDRESS OF PARAMETER TAU.
        HOLD  EQU   5500
        TEMP  EQU   6500
        WORK2 EQU   7500
        WORK4 EQU   10500
        HANS  EQU   11500
        SOLD  EQU   12500
        JAYO  EQU   13500
        JAY2  EQU   13504
        JAY4  EQU   13510
        JAY20 EQU   13514
```



```
                          JAY40   EQU   13520
                          EXPFL   EQU   60600
                          SINFL   EQU   60000
12000   12 1 00000                LDA   1 0
        20 0 12163                STA   0 RAD
12001   12 2 00000                LDA   2 0
        20 0 12164                STA   0 THK
12002   12 3 00000                LDA   3 0
        20 0 12165                STA   0 HGT
12003   12 4 00000                LDA   4 0
        20 0 12166                STA   0 TAU
12004   12 0 12171                LDA   0 ZRO
        20 5 13500                STA   5 JAYO
12005   54 5 00030                ISK   5 30
        75 0 12004                SLJ   0 /-1
12006   12 0 12171                LDA   0 ZRO
        20 0 12151                STA   0 DELTA
12007   50 1 00000                ENI   1 0
        50 2 00000                ENI   2 0
12010   50 3 00000                ENI   3 0
        50 4 00000                ENI   4 0
12011   50 5 00000                ENI   5 0
        50 6 00000                ENI   6 0
```

```
12012   12 0 12163   START   LDA  0 RAD        FORMATION OF R/H
        33 0 12165           FDV  0 HGT
12013   20 0 12172           STA  0 PLEAS
        50 0 00000           ENI  0 0
12014   12 0 12165           LDA  0 HGT        FORMATION OF R/H+T
        30 0 12164           FAD  0 THK
12015   20 0 12175           STA  0 ONCE
        12 0 12163           LDA  0 RAD
12016   33 0 12175           FDV  0 ONCE
        20 0 12175           STA  0 ONCE
12017   12 0 12151   BGN     LDA  0 DELTA      SINE AND COSINE
        50 0 00000           ENI  0 0          FORMATION
12020   75 4 60001           SLJ  4 SINFL+1    COSINE
        50 0 00000           ENI  0 0
12021   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12022   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12023   20 1 06500           STA  1 TEMP       COSINE TO STORAGE
        12 0 12151           LDA  0 DELTA
12024   75 4 60000           SLJ  4 SINFL      SINE ROUTINE
        50 0 00000           ENI  0 0
12025   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
```



```
12026   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12027   20 1 05500           STA  1 HOLD       SINE TO STORAGE
        33 1 06500           FDV  1 TEMP       SINE/COSINE
12030   31 0 12175   REPL    FSB  0 ONCE       SINE/COSINE-R/H+T
        22 0 12141           AJP  0 FIRST      JUMPS IF A IS 0
12031   22 2 12141           AJP  2 FIRST      JUMPS IF A IS +
        51 1 00001           INI  1 1
12032   12 0 12152           LDA  0 DELTA+1
        30 0 12151           FAD  0 DELTA
12033   20 0 12151           STA  0 DELTA
        75 0 12017           SLJ  0 BGN
12034   56 1 12105   NEXT    SIU  1 JAY+3      STARTS FORMATION OF
        56 1 12073           SIU  1 INCL+5     THE LEGENDRE POL.
12035   56 1 12111           SIU  1 JAYTO+3
        56 1 12051           SIU  1 RMK
12036   56 1 12074           SIU  1 INCL+6
        56 1 12101           SIU  1 JAY-1
12037   56 1 12115           SIU  1 JAYFR+3
        50 1 00000           ENI  1 0
12040   12 1 06500           LDA  1 TEMP       COSB IN A REG.
        32 1 06500           FMU  1 TEMP
```

```
12041   20 0 12173            STA  0 DON
        32 0 12157            FMU  0 FLT2
12042   31 0 12155            FSB  0 FLT
        33 0 12156            FDV  0 FLT1      P2 IN A REG.
12043   20 1 07500            STA  1 WORK2
        12 0 12173            LDA  0 DON
12044   32 0 12161            FMU  0 FLT4
        20 0 12174            STA  0 DON+1
12045   12 0 12173            LDA  0 DON
        32 0 12173            FMU  0 DON
12046   32 0 12162            FMU  0 FLT5
        31 0 12174            FSB  0 DON+1
12047   30 0 12157            FAD  0 FLT2      P4 IN THE A REG.
        33 0 12160            FDV  0 FLT3
12050   20 1 10500            STA  1 WORK4
        50 0 00000            ENI  0 0
12051   54 1 00000   RMK      ISK  1 0         NUMBER OF ANGLES
        75 0 12040            SLJ  0 NEXT+4    INSERTED BY PROGRAM
12052   12 0 12164   HALF     LDA  0 THK       FORMATION OF XB
        33 1 06500            FDV  1 TEMP
12053   20 1 11500            STA  1 HANS
        50 0 00000            ENI  0 0
12054   54 1 00000            ISK  1 0         NUMBER INSERTED
        75 0 12052            SLJ  0 HALF      BY PROGRAM
```

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```
12055   12 1 11500            LDA  1 HANS
        32 0 12166            FMU  0 TAU
12056   20 1 11500            STA  1 HANS
        50 0 00000            ENI  0 0
12057   54 1 00000            ISK  1 0         NUMBER ENTERED
        75 0 12055            SLJ  0 /-2       BY PROGRAM
12060   12 1 11500   POWER    LDA  1 HANS      STARTS FORMATION
        75 4 60600            SLJ  4 EXPFL     OF E TO THE TAU X
12061   50 0 00000            ENI  0 0
        50 0 00000            ENI  0 0
12062   20 1 12500            STA  1 SOLD
        50 0 00000            ENI  0 0
12063   54 1 00000            ISK  1 0
        75 0 12060            SLJ  0 POWER
12064   54 2 00001            ISK  2 1
        75 0 12066            SLJ  0 /+2
12065   75 0 12076            SLJ  0 HANG
        50 0 00000            ENI  0 0
12066   50 1 00000   INCL     ENI  1 0
        51 1 00001            INI  1 1
12067   12 0 12165            LDA  0 HGT       STARTS CALCULATION
        33 1 06500            FDV  1 TEMP      R CSCB-SECB
```

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```
12070   20 1 12500          STA  1 SOLD
        12 0 12163          LDA  0 RAD
12071   33 1 05500          FDV  1 HOLD
        31 1 12500          FSB  1 SOLD
12072   32 0 12166          FMU  0 TAU
        20 1 11500          STA  1 HANS
12073   54 1 00000          ISK  1 0
        75 0 12057          SLJ  0 /-4
12074   50 1 00000          ENI  1 0
        56 1 12063          SIU  1 POWER+3
12075   50 1 00000          ENI  1 0
        75 0 12060          SLJ  0 POWER
12076   12 0 12155   HANG   LDA  0 FLT
        33 1 12500          FDV  1 SOLD
12077   20 1 12500          STA  1 SOLD
        12 0 12155          LDA  0 FLT
12100   31 1 12500          FSB  1 SOLD
        20 1 12500          STA  1 SOLD
12101   54 1 00000          ISK  1 0
        75 0 12076          SLJ  0 HANG
12102   12 0 12153   JAY    LDA  0 WORK      STARTS CALCULATION
        32 1 12500          FMU  1 SOLD      OF THE INTERGAL
12103   32 1 05500          FMU  1 HOLD
        32 0 12152          FMU  0 DELTA+1
```



```
12104   30 0 13500          FAD  0 JAYO
        20 0 13500          STA  0 JAYO
12105   54 1 00000          ISK  1 0
        75 0 12102          SLJ  0 /-3
12106   12 1 07500   JAYTO  LDA  1 WORK2
        32 1 12500          FMU  1 SOLD
12107   32 1 05500          FMU  1 HOLD
        32 0 12152          FMU  0 DELTA+1
12110   30 0 13504          FAD  0 JAY2
        20 0 13504          STA  0 JAY2
12111   54 1 00000          ISK  1 0         NUMBER OF TIMES
        75 0 12106          SLJ  0 /-3       TILL R/H
12112   12 1 10500   JAYFR  LDA  1 WORK4
        32 1 12500          FMU  1 SOLD
12113   32 1 05500          FMU  1 HOLD
        32 0 12152          FMU  0 DELTA+1
12114   30 0 13510          FAD  0 JAY4
        20 0 13510          STA  0 JAY4
12115   54 1 00000          ISK  1 0         NUMBER OF TIMES
        75 0 12112          SLJ  0 /-3       TILL R/H
12116   12 0 13504          LDA  0 JAY2
        33 0 13500          FDV  0 JAYO
```

```
12117   20 0 13514           STA  0 JAY20
        12 0 13510           LDA  0 JAY4
12120   33 0 13500           FDV  0 JAY0
        20 0 13520           STA  0 JAY40
12121   12 0 13514           LDA  0 JAY20
        32 0 13514           FMU  0 JAY20
12122   20 0 13524           STA  0 JAY40+4
        32 0 12167           FMU  0 THEOR
12123   20 0 13530           STA  0 JAY40+10
        12 0 13520           LDA  0 JAY40
12124   32 0 13520           FMU  0 JAY40
        20 0 13534           STA  0 JAY40+14
12125   32 0 12170           FMU  0 THEOR+1
        20 0 13540           STA  0 JAY40+20
12126   54 1 77777           ISK  1 77777
        75 0 12126           SLJ  0 /
12127   50 0 00000           ENI  0 0
        74 7 42040           EXF  7 42040
12130   75 4 71000           SLJ  4 71000
        50 0 00000           ENI  0 0
12131   01 0 13500            01  0 JAY0
        04 0 00001            04  0 1
12132   12 0 12154           LDA  0 MIKE
        70 0 12131           RAD  0 /-1
```



```
12133   54 5 00010           ISK  5 10
        75 0 12130           SLJ  0 /-3
12134   54 1 77777           ISK  1 77777
        75 0 12134           SLJ  0 /
12135   54 2 77777           ISK  2 77777
        75 0 12135           SLJ  0 /
12136   50 0 00000           ENI  0 0
        74 7 42040           EXF  7 42040
12137   74 0 42003           EXF  0 42003
        50 0 00000           ENI  0 0
12140   76 0 05000           SLS  0 5000
        50 0 00000           ENI  0 0
12141   12 0 12147   FIRST   LDA  0 SEC        MODIFIES THE PROGRAM
        20 0 12030           STA  0 REPL       WHEN THE VALUE OF
12142   12 0 12150           LDA  0 SEC+1      B  CHANGES
        20 0 12031           STA  0 REPL+1
12143   56 1 12054           SIU  1 HALF+2
        56 1 12057           SIU  1 HALF+5
12144   56 1 12063           SIU  1 POWER+3
        56 1 12075           SIU  1 INCL+7
12145   56 1 12066           SIU  1 INCL
        51 1 00001           INI  1 1
```

```
12146   75 0 12017          SLJ  0 BGN
        50 0 00000          ENI  0 0
12147   31 0 12172   SEC    FSB  0 PLEAS     PARAMETER TO MODIFY
        22 0 12034          AJP  0 NEXT      PROGRAM FOR B
12150   22 2 12034          AJP  2 NEXT      GREATER THAN R/H+T
        51 1 00001          INI  1 1
12151   00 0 00000   DELTA  OCT   0
        00 0 00000
12152   17 6 64061          DEC   .001
        11 5 64570
12153   20 0 14000   WORK   DEC   1.0
        00 0 00000
12154   00 0 00004   MIKE    0 0 4
        00 0 00001           0 0 1
12155   20 0 14000   FLT    DEC   1.0
        00 0 00000
12156   20 0 24000   FLT1   DEC   2.0
        00 0 00000
12157   20 0 26000   FLT2   DEC   3.0
        00 0 00000
12160   20 0 44000   FLT3   DEC   8.0
        00 0 00000
12161   20 0 57400   FLT4   DEC   30.0
        00 0 00000
```



```
12162   20 0 64300   FLT5   DEC   35.0
        00 0 00000
12163   20 0 25050   RAD    DEC   2.54
        75 3 41217
12164   20 0 25050   THK    DEC   2.54
        75 3 41217
12165   20 0 54400   HGT    DEC   18.0
        00 0 00000
12166   17 7 46213   TAU    DEC   .098
        20 7 12601
12167   17 7 46416   THEOR  DEC   .1020
        25 4 02030
12170   17 7 14511          DEC   .00907
        51 2 62577
12171   00 0 00000   ZRO    OCT   -0
        00 0 00000
12172   00 0 00000   PLEAS  BSS   1
        00 0 00000
12173   00 0 00000   DON    BSS   2
        00 0 00000
12175   00 0 00000   ONCE   BSS   1
        00 0 00000
                            END
```

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END