K40 Correlation HDC 82-18

A MEASUREMENT OF THE TWO PHOTON CORRELATION OF THE CERENKOV LIGHT FROM POTASSIUM-FORTY IN WATER SOLUTION

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October 14, 1982

ABSTRACT

This describes the experimental measurement of the two photon correlation of the Cerenkov light from K40 in water solution and gives the measured results in tabular and graphic form.

1.0 Statement of Problem

Potassium Forty will present Cerenkov light to the DUMAND sensors that will cause coincidences. Will these coincidences be isotropic or depend upon the angular separation between the detectors? The problem is to measure the angular correlation of cerenkov photons from the decay of potassium-40 in water solution. In DUMAND that is important because it affects the probability of a single sensor detecting more than one photoelectron from a single K40 decay.

2.0 Description of Apparatus

The apparatus was adapted from the equipment used in the experiment of Physics 480L to study the gamma-ray coincidences produced by the annihilation of a Na22 positron and an electron in copper. {1}

2.1 Electronics

This being an experiment to detect light, we used bare PMT's in place of the scintillator-covered PMT's of the sodium-22 exp. The PMT's were 20cm diameter EMI hemispherical-cathode tubes. The PMT bases were constructed as part of this experiment. Two HP model 520L scalers and two EGG model T101 discriminators and an EGG C104 coincidence detector were used to obtain the numbers of coincidence pulses. Separate Fluke 415B High Voltage power supplies were used to power the PMT's. The LED pulser was typically operated at a rate of 2566 pulses/sec. Figure 2.1.1 shows the connections for this equipment.

2.2 Source

The source consisted of 225.71 grams of potassium as hydroxide in 500ml of distilled water. This solution was contained in a 500ml glass stoppered reagent bottle of 4cm radius. In a similar reagent bottle we placed distilled water to be used as the control.

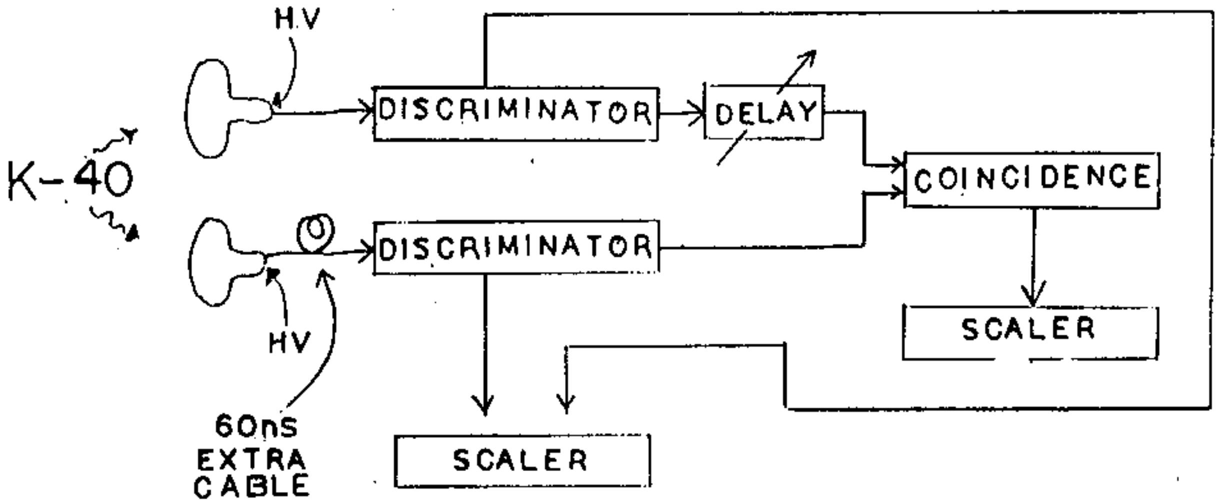

Figure 2.1.1
ELECTRONICS SET-UP

The potassium forty was positioned to be viewed by both tubes. We only had access to two scalers so we used one to count the coincidences and the other to alternate counting the singles rates.

2.3 Physical Arrangement

The experiment was set-up in two adjacent rooms with the detection equipment in one 'dark' room and the electronic instrumentation in the other room. Black plastic plant pots were used as PMT holders. We used a milling machine #2 standard rotary table attachment to hold and move one adjustable PMT. The other PMT was fixed. The glass reagent bottles are placed on the axis of the rotating arm of the milling machine to present the same geometry to the movable PMT at all angles. See Figure 2.3.1.

3.0 Determination of Operating Points

3.1 Noise Curve

We verified the operation of the electronics with the Na22 source and detectors from the Modern Physics Lab. Then we replaced the gamma-ray detectors with our 20cm bare faced EMI tubes and obtained the noise rate as a function of the HV applied to the tubes. This measurement was preformed under the same conditions as section 4.0 except for the K40 source bottle and the control bottle both being absent from the PMT room. Figure 3.1.1 gives the noise curves.

3.2 Single Photoelectron Plateau

We configured the test set-up as shown in Figure 3.2.1 to obtain the single photoelectron plateau. We attenuated the LED pulser with scotch tape until the ratio of PMT pulse rate to the LED flash rate was very small (~0.02). Since the probability of getting zero photoelectron is 0.98, {2} the probability of getting more than one photoelectron in a single flash of a photon source is vanishingly small. We used this value of light intensity to run a plateau curve by varying the H.V.. The the operating voltages we used are indicated on the curves. Figure 3.2.2 shows the curves.

3.3 Setting the proper delays

Once we had determined the best operating point for the tubes we inserted a variable delay box into tube I's signal line and a fixed (~15meter~60ns) line in tube II's signal circuit. See Figure 3.3.1. Using the LED attenuation) and with both tubes positioned to view the LED pulser, we obtained a coincidence delay curve (Figure 3.3.2) by stepping the delay box through a range of delays. From this we obtained the point where the coincidence detector gave the most counts for coincidences from the LED pulser. The distribution has a full width at half maximum of 85ns, which is consistant with the discriminator output pulse width of 50ns. With the equipment thus calibrated, we were ready to start taking data.

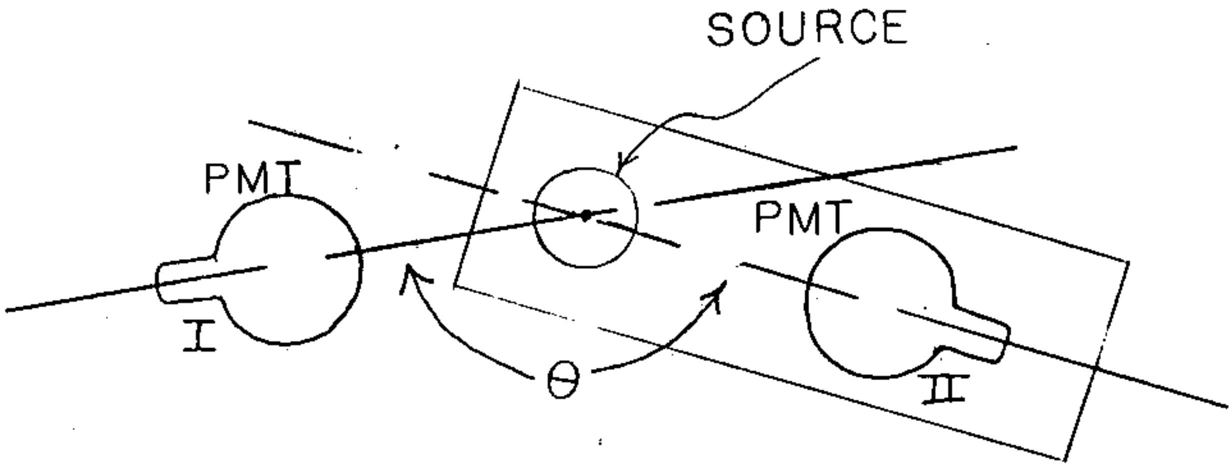

Figure 2.3.1
PMT PHYSICAL ARRANGEMENT

PMT I was stationary and the other PMT was movable through 260 degrees in the primary set-up and 300 degrees in the secondary set-up. See section 4.2.

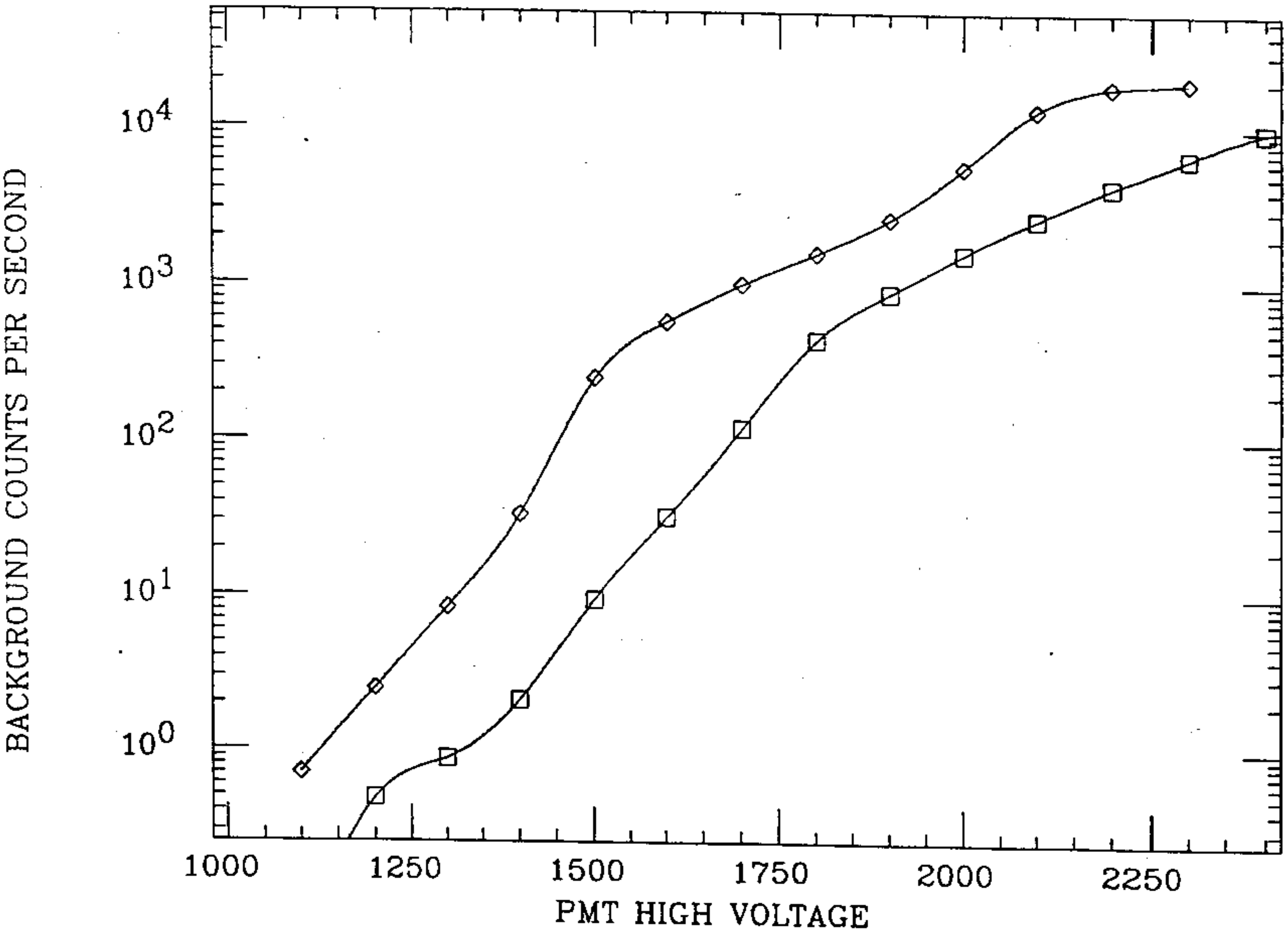

Figure 3.1.1
PMT NOISE CURVES

These curves show the noise counting rates of the PMT's as a function of the High Voltage. The conditions for this measurement are the same as the actual K-40 measurements except for having no water or K-40 source in the PMT room.

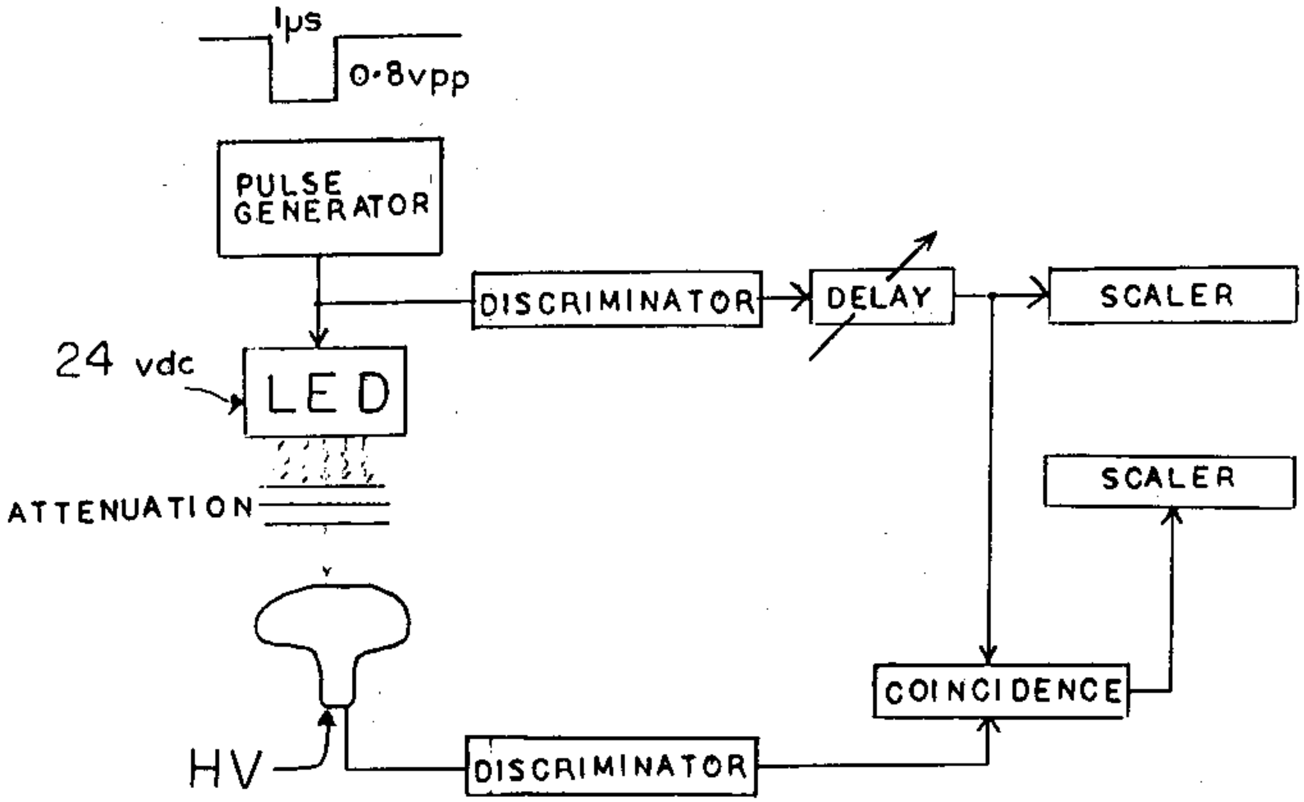

Figure 3.2.1
SINGLE PHOTOELECTRON PLATEAU SET-UP

This shows the configuration we used to measure the Plateau Curves.

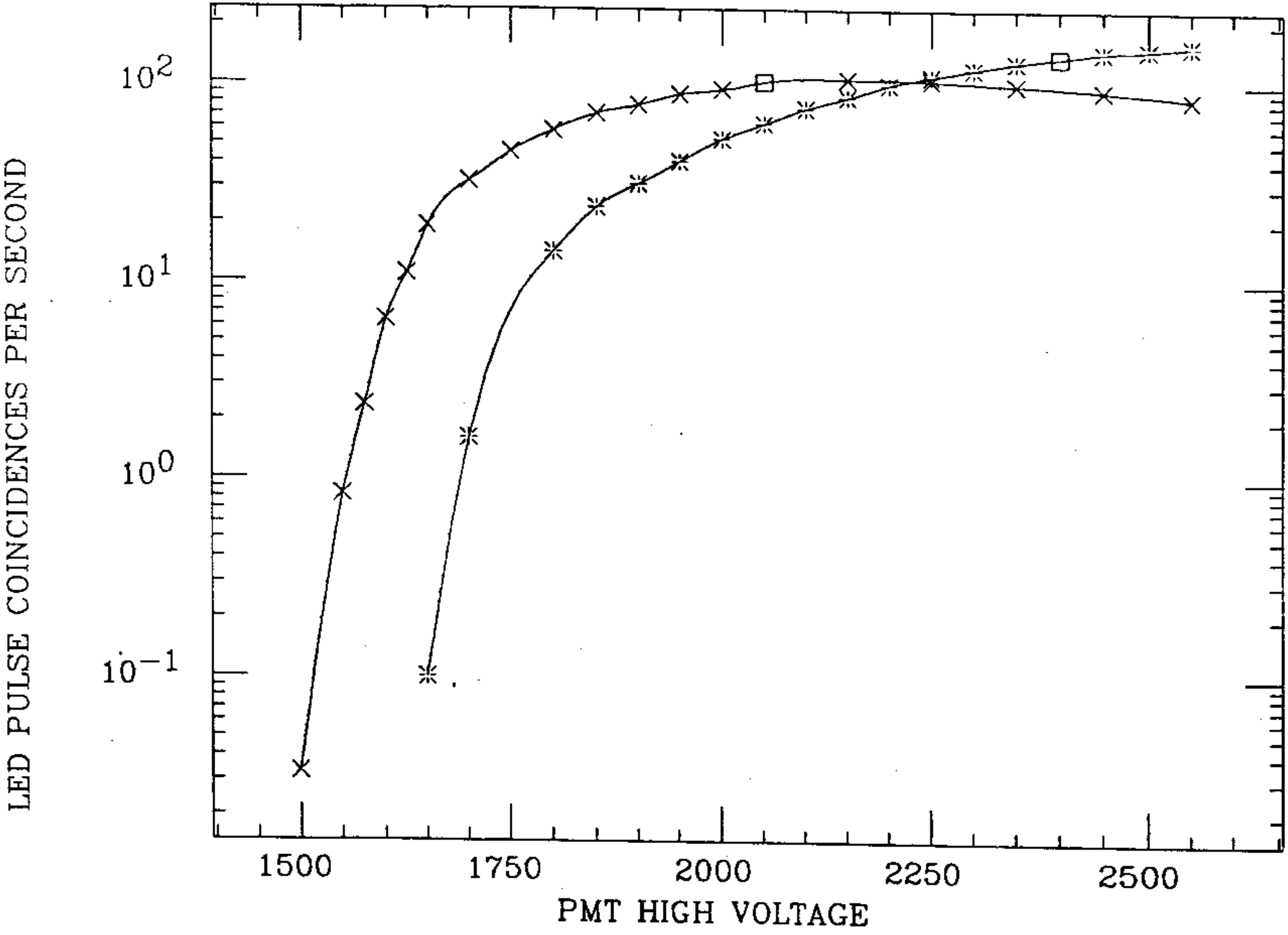

Figure 3.2.2
SINGLE PHOTELECTRON PLATEAU

These curves were obtained by attenuating a LED source until we reached a level where the probability of getting more than one photoelectron in a single flash is vanishingly small. The squares show the operating points that we choose for the PMT's.

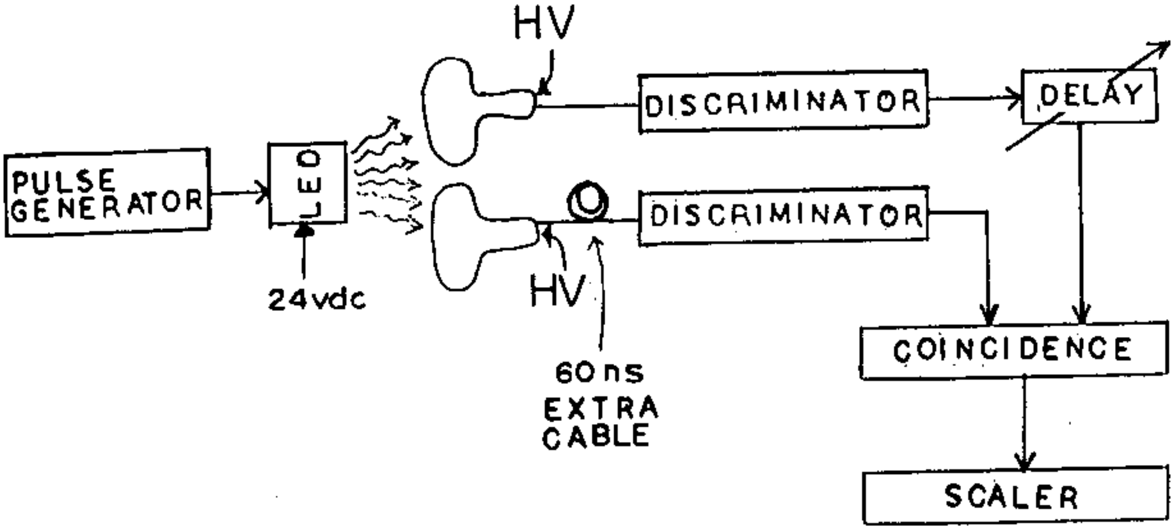

Figure 3.3.1
DELAY CURVE SET-UP

This shows the configuration we used to measure the Plateau Curves.

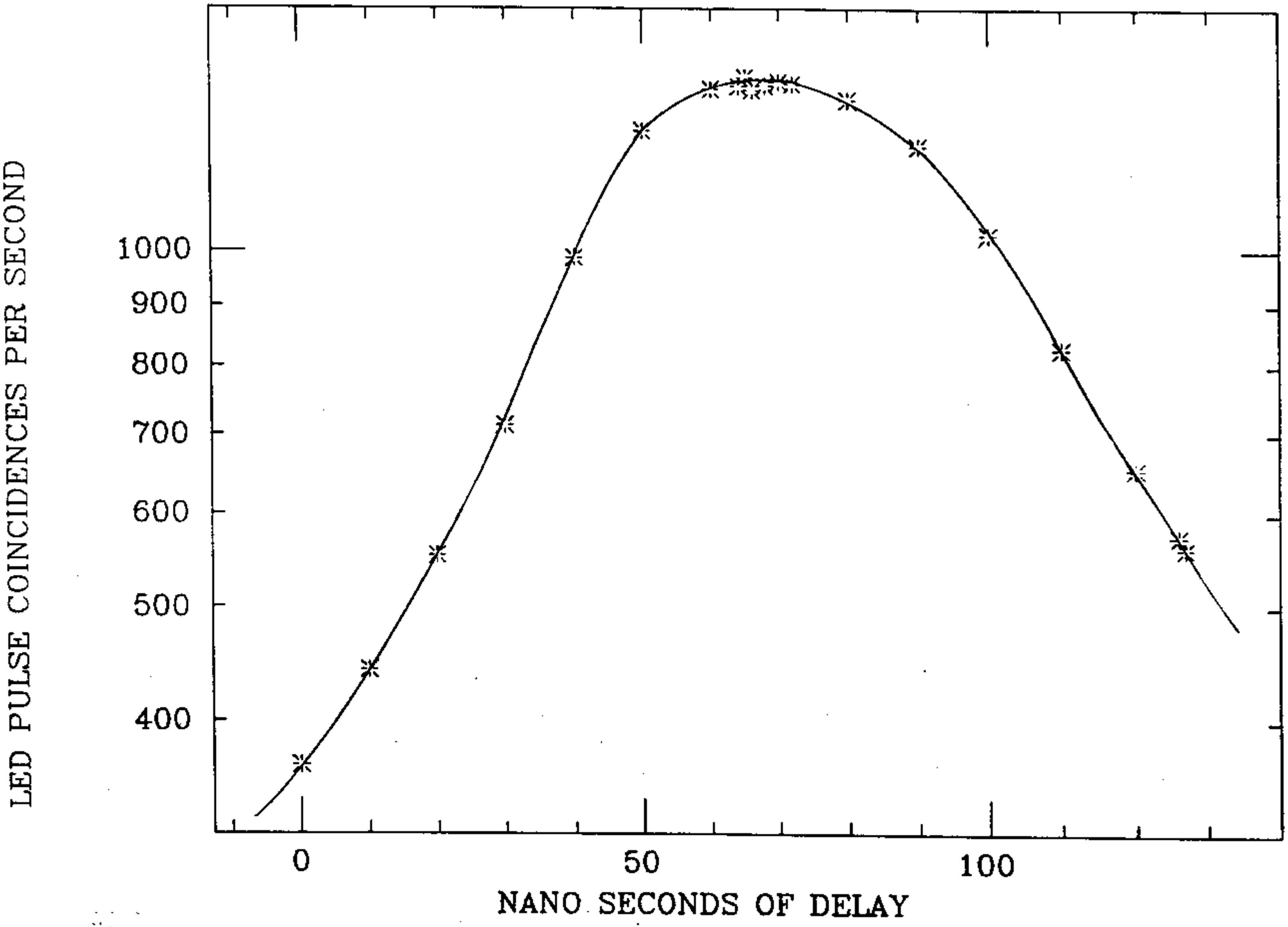

Figure 3.3.2
DELAY CURVE

This shows the delay curve for our experimental set-up. We operated the K-40 measurements at 67ns.

4.0 Data Runs

4.1 Verification of Cerenkov Light

The first check we did was to verify we were seeing cerenkov light and not gammas. We placed a light baffle between the PMT's and the source. The light baffle consisted of a black paper sheet 50cmX50cmX0.5mm. and in each case the coincidence rates dropped to the same low base rate of ~1.5c/s This low base rate is most likely due to a combination of the following:

1. Compton scattered gammas
2. Cosmic ray Coincidences
3. Random coincidences

We calculated the random coincidence rate Rc = N1 * N2 * 2T, where N1 & N2 are the individual singles rates of the PMT's and T is the pulse width of the signals into the coincidence circuit. N1 = 2442c/s, N2 = 3486c/s and T = 50ns; these numbers give Rc = 0.86c/s. The residue 0.64 is due to 1 and 2 above.

4.2 Data Collection

In all the measurements we took we measured both the coincidences from a water sample (for background) and the sample of Potassium Hydroxide at each angle. In the first set of data we measured the coincidence rates from the minimum angle (for the set up) of 50 degrees to 180 degrees to see if there was indeed an anisotropy in the distribution of photons giving coincidences. The preliminary graph of this data showed there was a change in the number of coincidence counts by a factor of three.

We reconfigured the set-up by doubling the initial separation between the PMT's and the sample bottle. This enabled us to go to a smaller PMT separation angle. The minimum angle here was 30 degrees but the maximum number of coicidences for the potasssium-40 sample dropped from ~36c/s to ~5c/s. We only measured angles 50, 40, and 30 to extend the range of measurements toward 0.0 degrees. By scaling from the common angle of 50 degrees we calculated a value of ~49c/s for the angle of 30 and 40 degrees at the original PMT distance of 26cm. Then we reconfigured the system to the original set-up where the tubes subtend a solid angle of 0.06 and obtained a set of data points at ten degree intervals from 50 degrees to 310 degrees.

5.0 Results

5.1 Measured

We measured a singles rate of 350 counts per second. The beta coincidence rate was a maximum of ~49 counts per second at 30 and 330 degrees and a minimum of ~17 counts per second at 180 degrees as shown by Figure 5.1.1. Table 1 shows the data.

5.2 Calculated

We estimated the singles rate to be 432 counts per sec., by the following relationship:

$$Rs = gK * D * a * e * n * x$$

Where;

Rs	is the theoretical singles rate,	
gK	is the number of grams of K in our sample	(225g)
D	is the number of decays per sec-gram	(31.3d/s-g) {3}
a	is the effective solid angle	(0.019sr)
e	is the tube efficiency	(~0.15%)
n	is the number of quanta per decay	(~43) {4}
x	is an assumed absorption factor	(0.5%)

We calculated the effective solid angle subtended by the tubes by taking the ratio of the effective frontal area of a PMT to the surface area of a sphere of radius R equal to the separation of the tubes and the sample bottle. The effective frontal area of the PMT in the vertical direction was determined by considering the two cases shown in Figure 5.2.1. Case one is without the KOH/Glass/Air interface, this is used to determine the angle subtended by the radius of our PMT. This angle is carried over to case two, where KOH/Glass/Air interface is included is included and becomes theta 2. Theta 2 is used to solve for theta 1. Once theta 1 is known, we apply the inverse tangent on theta 1 to obtain the effective radius of the PMT. The effective radius is used in the calculation of the effective solid angle. We assumed that the horizontal off axis effect is approximently the same as the vertical effect.

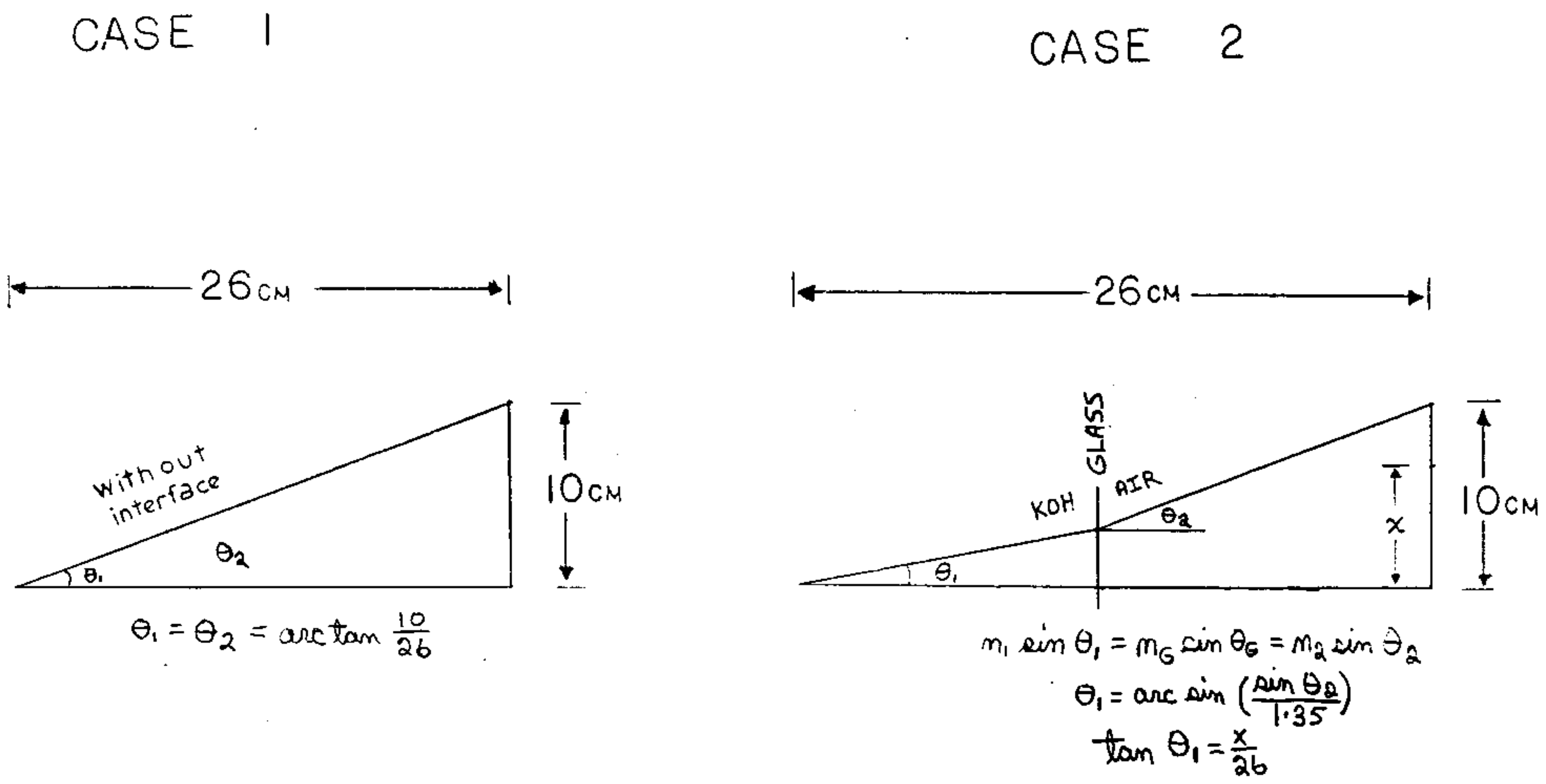

Figure 5.2.1
EFFECTIVE PMT RADIUS

This shows case one and case two that were used to determine the effective radius (x) of the PMT. Theta 2 in case one is equal to theta 2 in case two.

Table 1
Single & Coincidence Rates vs Angular Separation

PMT Separation	Coincidence Rate		Singles Rate	
Angle	K40	H2O	K40	H2O
30	49.4c/s	3.7c/s	3940c/s	
40	43.0	3.5	3972	
50	37.7	3.5	3486	3192
60	33.8	3.2	3470	3120
70	31.2	3.2	3540	3087
80	28.8	3.3	3459	3122
90	25.5	3.0	3406	3132
100	23.1	3.2	3534	3226
110	21.4	2.9	3526	3261
120	20.1	3.1	3581	3233
130	19.0	2.9	3548	3351
140	17.9	2.9	3678	3362
150	17.9	2.9	3861	3513
160	17.6	2.8	3830	3537
170	16.8	2.7	3880	3535
180	17.2	2.6	4084	3541
-170 (190)	17.6	2.6	3896	3623
-160 (200)	17.3	2.7	4077	3616
-150 (210)	17.7	3.2	3994	3696
-140 (220)	19.0	2.9	4093	3754
-130 (230)	19.3	2.9	4066	3753
-120 (240)	20.4	2.9	4074	3608
-110 (250)	21.6	2.7	4100	3704
-100 (260)	23.5	2.8	4081	3662
-90 (270)	25.5	2.8	4011	3683
-80 (280)	28.3	2.6	3991	3595
-70 (290)	30.7	2.8	3981	3745
-60 (300)	33.4	2.8	4043	3755
-50 (310)	37.2	2.8	4334	3764
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		Singles avg	3837	3487

These results are plotted in Figure 5.2.1.

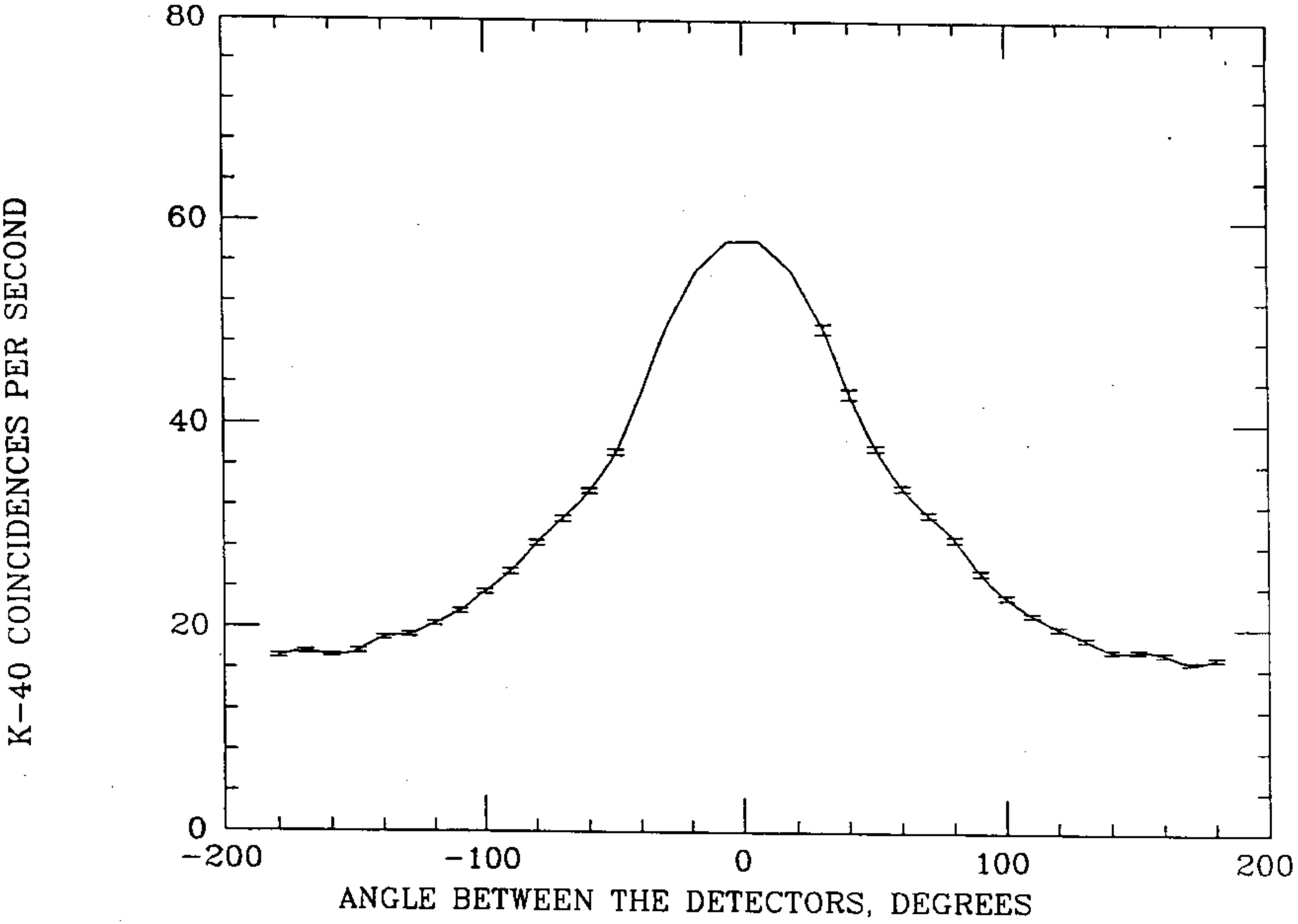

Figure 5.1.1
THE RESULTS

This plot of the experimental data shows the angular correlation of cerenkov photons from the decay of potassium forty in water solution. The peak is centered about 0.0 degrees and is about one cerenkov cone wide on either side of 0.0 degrees. The coincidences do not go to 0 at 180 degrees due to scattering of the Beta.

6.0 Discussion

Using the relationship Rc = Rd * P {4}, where;

Rc is the number of coincidences expected,
Rd is the number of decays the tubes see,
P is the probability of getting a count from a single K-40 decay = (1-exp(-nea)),
n is the number of photons per decay,
a is the fractional solid angle,
e is the photocathode efficiency.

We calculated a theoretical coincidence rate of 113.9c/s. This is the rate that would be expected from an isotropic distribution of photons from individual K-40 decays. The difference between our estimated singles rate (Section 5.2) and our measured singles rate (section 5.1) could be due to fewer effective photons per decay and/or lower quantum efficiencies for the tubes, that what we assumed in our calculations.

As is shown by Figure 5.2.1 we measured an angular dependence, of a factor of ~3 over the range 0 to 180 degrees, in the two photon correlation. There is a visual change in the slope of our data that is centered about the cone width of the average beta decay. This 'bump' is symmetric about 0.0 degrees. Naively, without considering scattering, we would expect to see peaks at these 'bumps' with the number of coicidences going to a minimum everywhere else. The shape we measured must be due to scattering of the low energy electron and the decrease in the cerenkov angle as the electron energy goes below Cerenkov threshold. The statistical error in our measurements were 2% for the coincidences and 5% for the singles rates. The difference is due to our making fewer measurements at each point for the singles data. Prelimanary Monti Carlo results, written in Applesoft Basic, show a distribution similar to what was measured in the lab. The simulation just considers the plane of the PMT's and the source KOH. I plan to convert the simulation over to UCSD PASCAL (runs faster than basic on the Apple II) and have it consider a three dimensional model. The Applesoft program generated 86 decays per run by stepping through the beta spectrum formula in Geelhood {3} in .1 MeV steps and each run lasted about 35 hours. This simulation was done as a project for one of my non-physics courses at UH Manoa. I plan to submit the results of the 3-D Pascal Monti Carlo as a future DUMAND report.

Acknowledgements

1. A. Roberts for direction and guidance.
Mahalo Nui

2. P.P. Crooker for loaning the Modern Physics Lab equipment. Mahalo

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4. A. Roberts, DUMAND Note 81-21.