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THE HALF-LIVES OF SOME SHORT LIVED LOW Z NUCLEI FORMED BY PHOTONUCLEAR REACTIONS

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ABSTRACT

The half-lives of several members of the "mirror" nuclei series have been measured, using improved scintillation counter detectors and a cycling apparatus which programs the synchrotron beam and several subsequent gated detectors in sequence repetitively. By the use of beta-ray energy discrimination, least squares fitting of decay curves, and by careful correction for background activities, the improved values listed in Table A were found.

Table A

Summary of Half-lives Measured

Mg^{23}	10.7 ± 0.7 seconds
S^{31}	2.40 ± 0.07
K^{37}	0.98 ± 0.02
Si^{27}	4.05 ± 0.10
Na^{21}	22.9 ± 0.4

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INTRODUCTION AND PROBLEM

The problem of studying short lived activities whose half lives are in the range of one second to several minutes is a challenging one because such activities are detectable by conventional methods and yet are too short lived to examine accurately by means of a stopwatch and scaler. The problem may be divided into three parts:

1. The problem of transportation of the radioactive isotope to a place and in a suitable form to be analyzed by some counting technique.

2. The problem of recording the data to determine accurately the half life of the short lived activity.

3. Somewhat related to 2 is the difficulty of getting enough data for accurate measurement of the half life. This may be due to transportation difficulties, interfering activities, too low a bombardment intensity to give good activation, or poor analyzing equipment. The latter includes bad geometry of the detecting device (photomultiplier tube and the scintillation crystal, Geiger Mueller counter, or electroscope).

There have been many methods designed to overcome these difficulties since 1935, and especially in more recent years. Considerable use has been made of the cathode ray oscilloscope in conjunction with a camera. Schelberg (1) has displayed pulses from a photomultiplier tube together with a "time marker" pulse on an oscilloscope and photographed the result. Boley and Zaffarano (2), by using compressed air to fire a target between bombarding position and counting position, were able to measure many of the short half lives and energy spectra of the mirror nuclei. The events from the detector were displayed on an oscilloscope screen as dots whose displacements were proportional to the energy of the particles

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[1] This report is based on a Master of Science thesis by Philip Phipps submitted December, 1953, to Iowa State College, Ames, Iowa. This work was done under contract with the Atomic Energy Commission.

causing the pulse. These dots were photographed with 35 mm film and later analyzed. Martin and Breckon (3) used a similar method.

Various instruments such as an electroscope (4) or the lights on a scaler together with a stop watch (5) have been photographed on rapidly moving film; the data can be analyzed at one's leisure. Pulses from a detector, such as a G. M. counter or photomultiplier and scintillation crystal, can be recorded on the moving paper tape of a Brush oscillograph (6, 7). Another method used by Crane, DeBasso, Fowler, and Lauritsen (8) in 1935 consisted of monitoring a rotating target whose activity varied with the angular displacement from the bombarding position. Still another method employs a set of micro switches operated by a cam to control pulses from a detector to a set of scalers (9). One of the fastest methods is the use of electronic "gates" of fixed width but of variable time delay after the bombardment time (10, 11, 12). In this method a set of scalers is allowed to count during the period of their respective "gates". Activities of a few milliseconds duration can then be measured.

METHOD USED

The method used for analyzing the short half lives discussed in this thesis consists of the use of a set of relays which automatically turn on the Iowa State College 70 Mev synchrotron beam for a specified length of time. The beam is then turned off, and after a preset delay nine scalers are allowed to count in consecutive order. The counting time of each scaler is one of two periods. The bombardment time and the counting times of each of the first five scalers is approximately equal to the half life to be studied. The rest of the nine scalers use the second time period which is set for periods of two to five times the half life to be studied, and thus an accurate measurement of the background may be obtained. After the last scaler has finished its counting period, the programming circuit switches the scaler off, turns on the synchrotron beam, and the entire cycle commences again. A large number of complete cycles like this produce a histogram with each interval represented by a scaler, and the magnitude in the interval is represented by the total counts recorded by the scaler.

A photomultiplier tube, with an anthracene crystal mounted on the photo sensitive end, is set about one foot behind a 5" thick lead shield. The target is hung immediately above the crystal and directly in the path of the synchrotron X-ray beam as shown in Figure 1. The pulses from the photomultiplier tube are sent a distance of about 40 feet to a Nuclear Linear Amplifier Model 204-C. The amplified pulses (5 to 70 volts) are displayed on a Dumont 303 oscilloscope and are also fed into a single channel differential analyzer. This is shown in the diagram of Figures 2

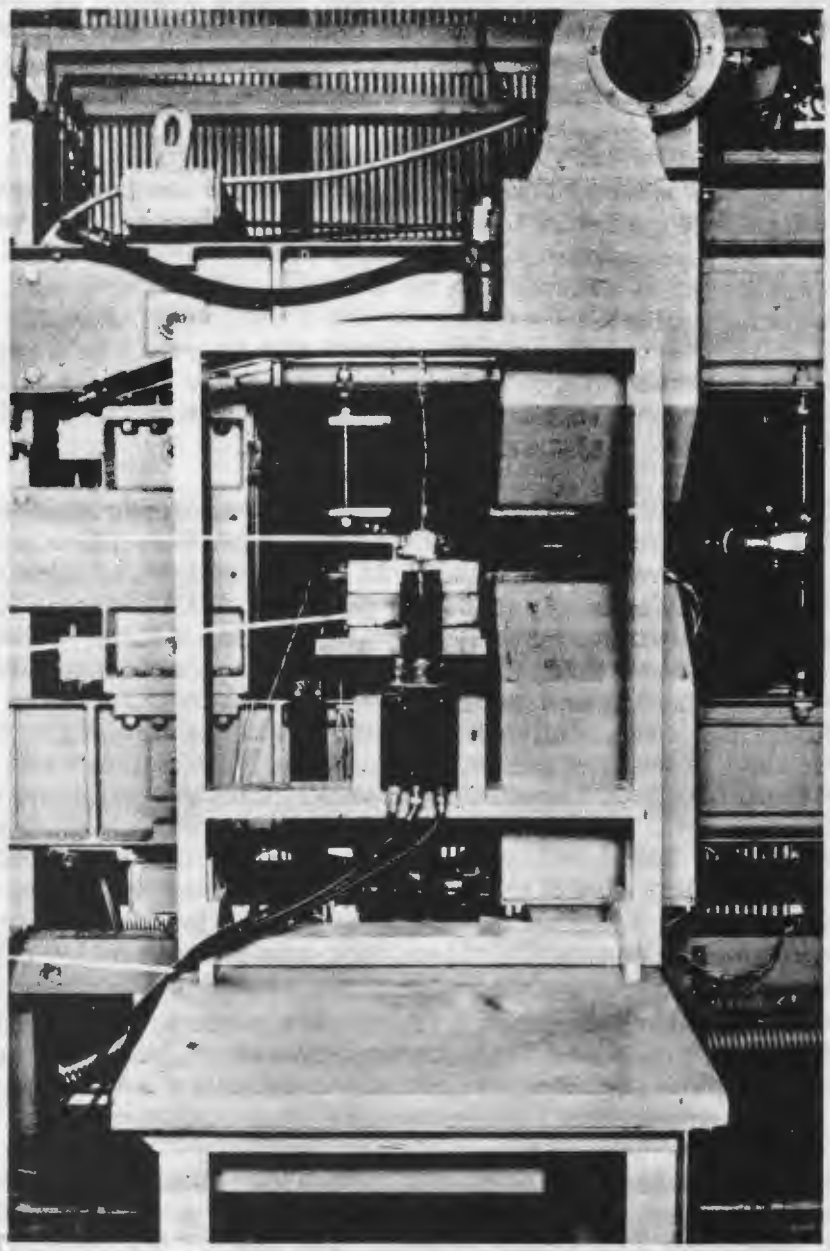

Fig. 1--Bombardment arrangement.

and 3. The differential analyzer discriminates against all incoming pulses except for those within a narrow preset energy range or against all pulses below a certain pulse height. All acceptable pulses then pass into a Schmitt trigger circuit whose output signal has a constant amplitude of about 20 volts. Another cathode follower sends these pulses into the programming circuit where they are distributed to the nine scalers, when there is no bombardment taking place. A basic timing pulse once each second is produced by the pendulum of a clock as it swings and interrupts a beam of light shining on a photo cell. This pulse is sent to the programming circuit's frequency divider.

The two middle left hand switches in Figure 4 adjust the frequency divider for the desired bombarding and first counting periods. The lower left hand switch controls the frequency divider for the second counting period. The right hand dial switch is the delay selector and has a range of from 1/10th of a second to 54 seconds. The total time the first scaler is registering pulses is equal to the first time interval minus the delay. This delay in the first scaler allows one to avoid picking up any unwanted activity in the second and millisecond ranges. Further information and details may be found in the Physics Department Master's thesis to be submitted by Raymond M. Kline.

The photomultiplier tube and scintillation crystal require special consideration. For this discussion see Figure 5. The anthracene crystal used was a solid cylinder 1-1/2" in diameter by 1" thick and had one end formed concave in order to fit an R. C. A. 5819 Photomultiplier tube face. The optical contact was obtained with the use of Dow-Corning 1,000,000 centipoise Silicone "200" Fluid. A magnesium oxide coated aluminum reflector was used on the sides and top. Black Vinylite electrical tape was wrapped around the tube and aluminum reflector, making the whole tube light tight. It was found from experience that improved resolution was obtained if the reflector did not touch the crystal, but was a few millimeters from it. The thin MgO coating seemed to improve resolution somewhat, because of its greater light reflecting quality than the usual polished aluminum. It was found that the 3.1 mg per sq. cm. Al end had very negligible effect on electrons of 0.5 Mev or greater. The resolution of the anthracene crystal and photomultiplier tube was consistently 16% when measured with the internally converted electron energy of 624 kilovolts from Cs^{137}. The resolution was measured by first subtracting the Compton spectrum, then dividing the half width of the conversion peak by the energy of the conversion line. The half width and conversion line energy were in arbitrary units proportional to energy as shown in Figure 6.

On all occasions except one, the above described anthracene crystal was used. In the one exception a commercially mounted "Larco" sodium iodide (thallium activated) crystal was used. The crystal was enclosed in an aluminum cylinder 1-1/2" in diameter by 1" deep with a thin glass

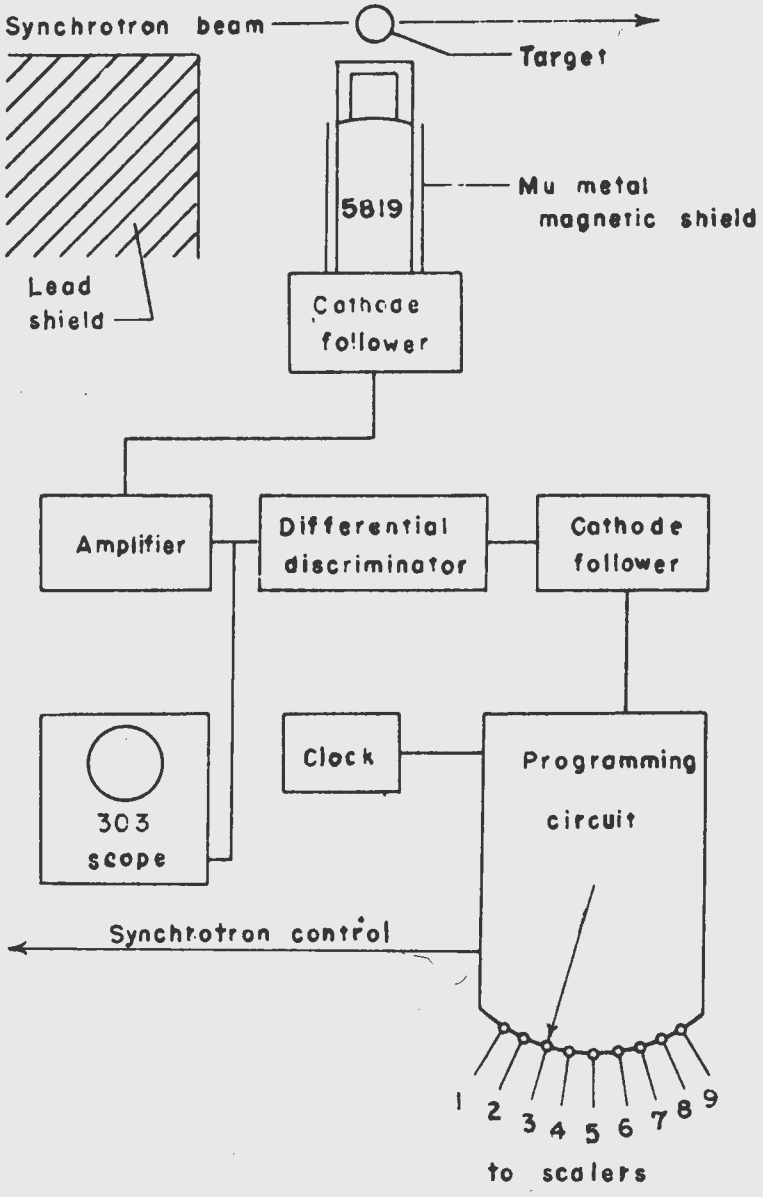

Fig. 2--Block diagram of equipment.

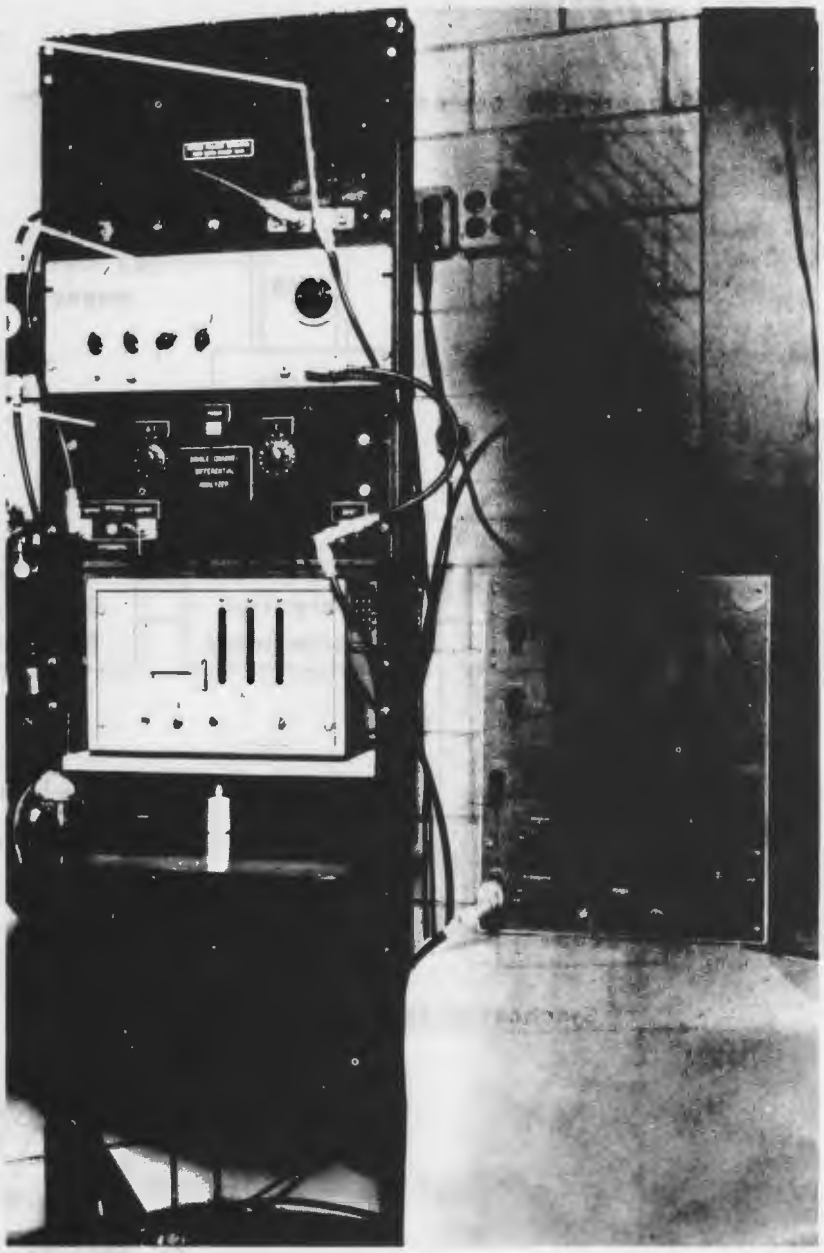

Fig. 3--Amplifying and analyzing rack.

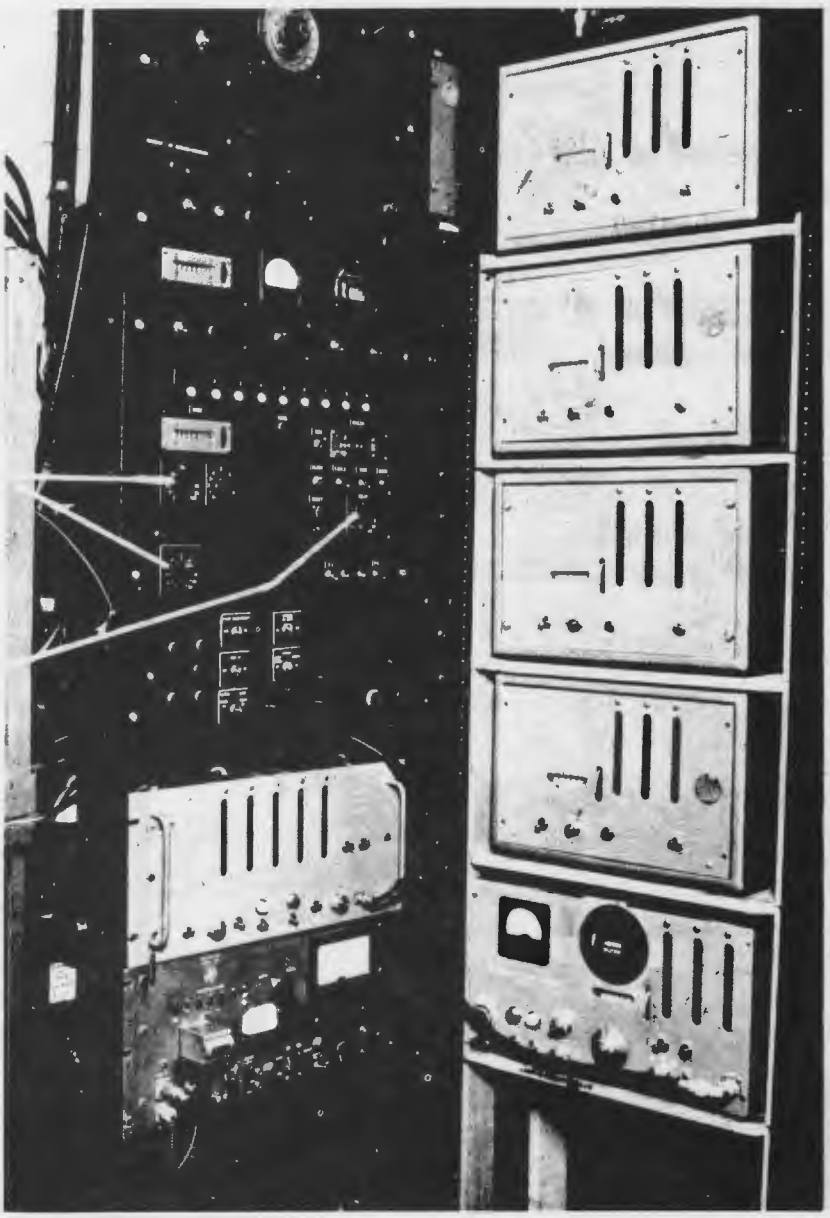

Fig. 4--Programming circuit and scaler racks.

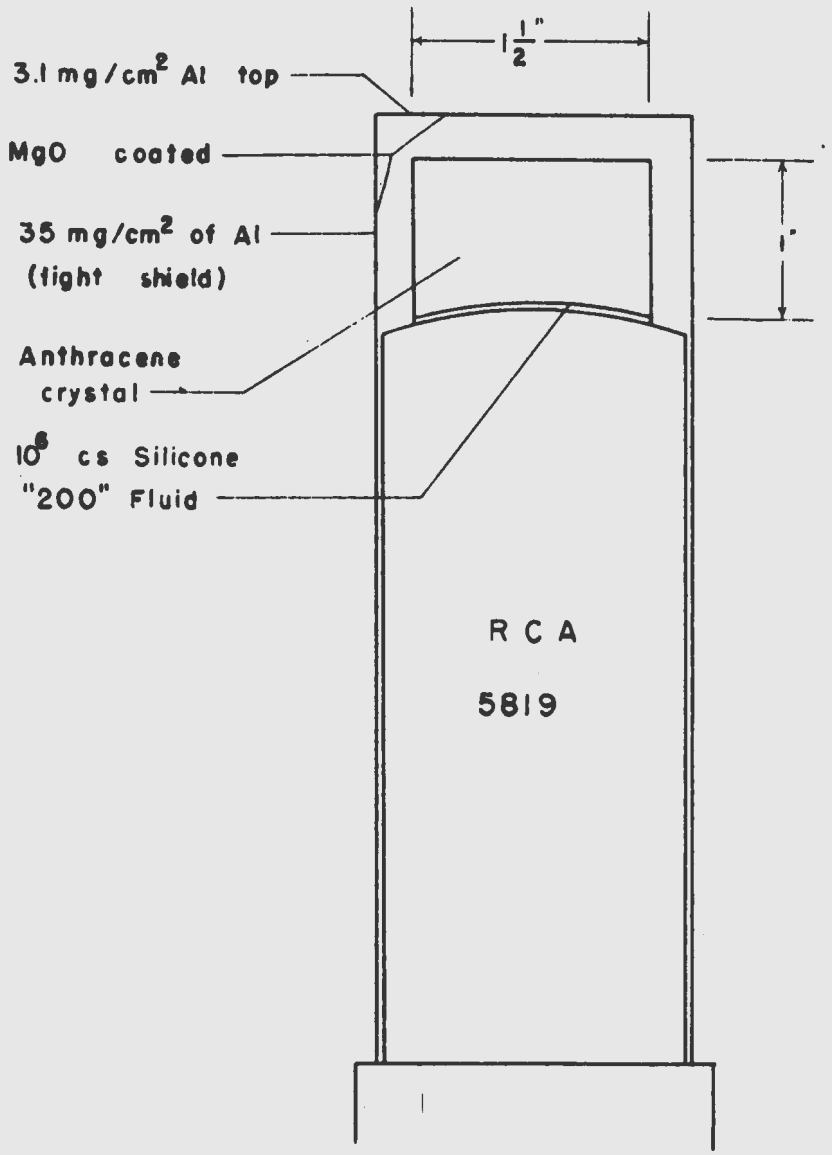

Fig. 5--Photomultiplier tube and crystal mounting.

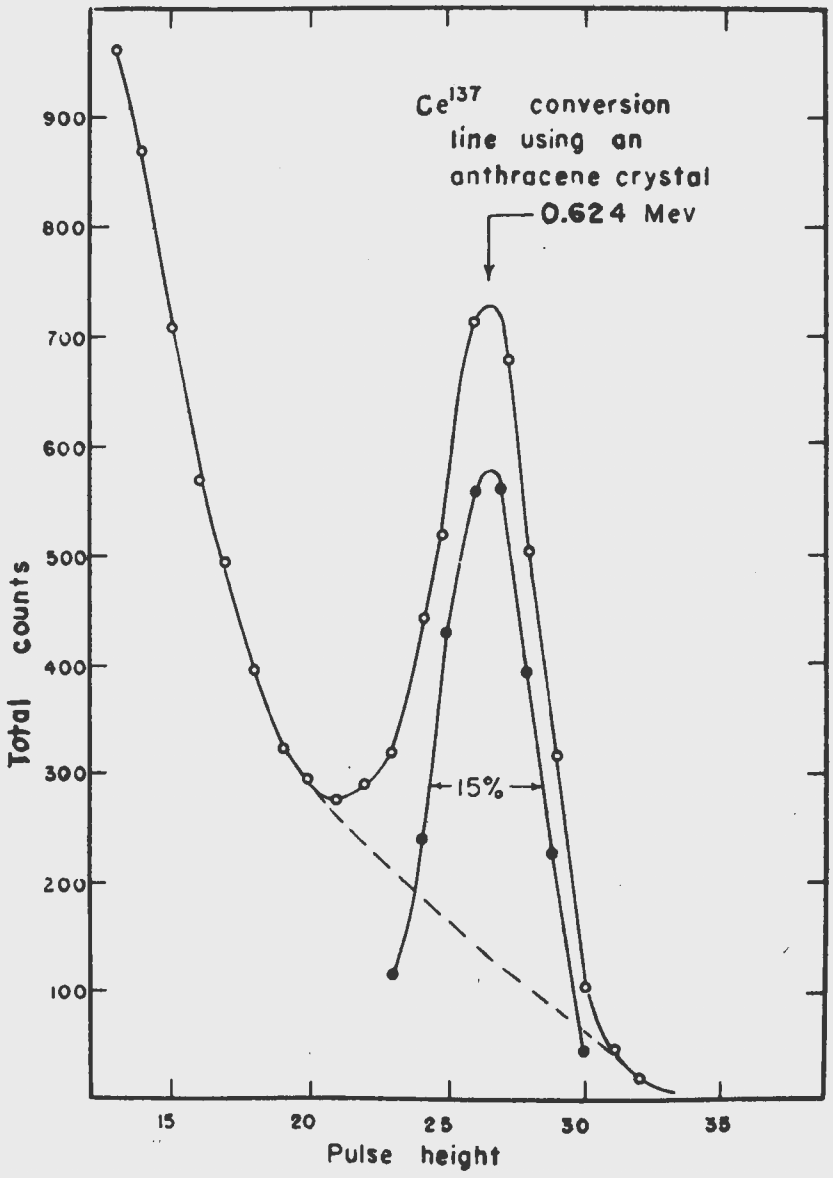

Fig. 6--Typical resolution curve for anthracene.

light pipe sealed into one end. The light pipe was concave to fit the face of the photomultiplier tube. Additional optical contact was made with the 1,000,000 centipoise silicone oil and the whole tube and crystal were wrapped in black Vinylite electrical tape to insure light tightness. The sodium iodide crystal gave a resolution of 12% with the 661 kilovolt γ-ray line from Cs^{137}.

EQUIPMENT TESTS AND CALIBRATIONS

For linearity of the equipment two checking methods were used. The first involved a linear step attenuator and a pulse generator. Pulses were sent through the step attenuator into the cathode follower of the photomultiplier tube. The pulse height after amplification was located with the differential discriminator. The result is a series of equally spaced points through which a line was passed and was observed to go through the origin.

The second method made use of the sodium iodide crystal and a number of radioactive gamma ray sources as listed in Table 1 and Figure 7.

The equipment was also checked using an anthracene crystal and the Compton edges* of the gamma rays in Table 1. Essentially the same results were found, i.e., the system was linear and the calibration line passed through the origin.

The voltage at which the photomultiplier cathode follower saturatres was measured to be about 30 volts. The anthracene crystal and photomultiplier combination used in this thesis gave a 4.5 volt pulse with 660 volts on the photomultiplier. The 4.5 volt pulse corresponded to the Compton edge of Th-C'' gamma ray of 2.62 Mev. The Compton edge was calculated to be 2.4 Mev. The NaI crystal and tube gave pulses of about 2 volts for the Th-C'' gamma ray.

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* The Compton edge (magnitude of the kinetic energy of electron suffering head-on collision with quantum of energy $E\gamma$) was calculated for each gamma-ray from the formula (13)

$$E_{max} = \frac{E\gamma}{1 + \frac{m_o c^2}{2E\gamma}}$$

computed for relativistic Compton scattering.

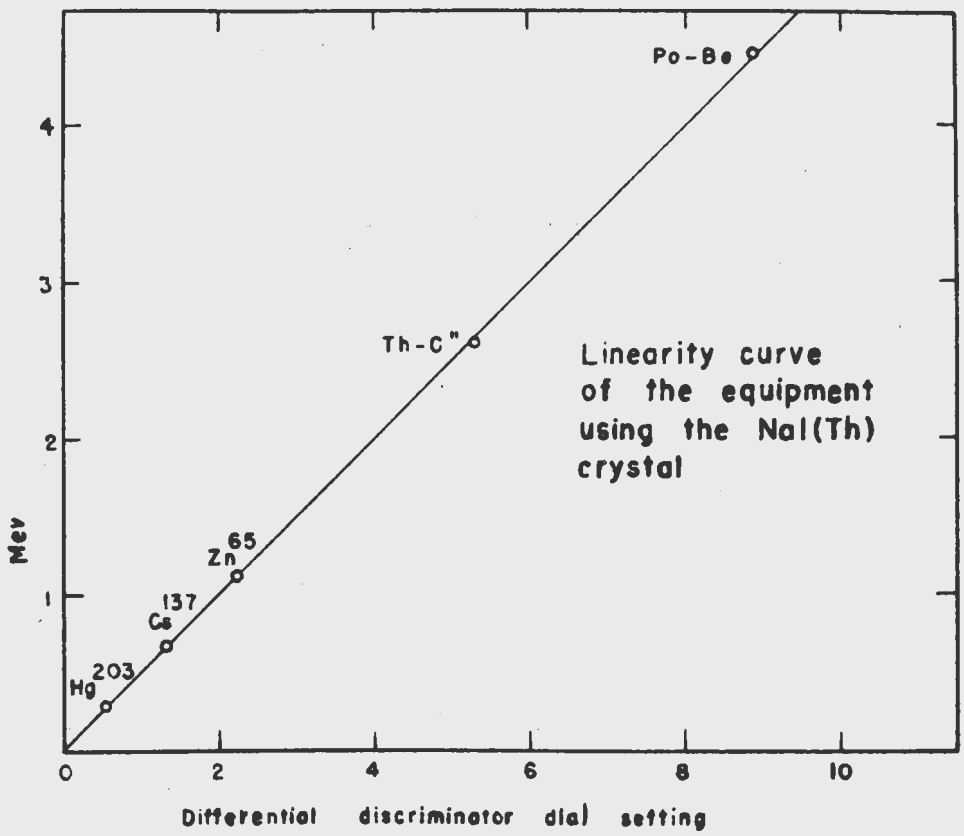

Fig. 7--Linearity test with NaI(Th) crystal.

Table 1

Radioactive gamma ray sources used for calibration with the NaI crystal

Source	Gamma ray energy
Po-Be*	4.45 Mev
Th-C''	2.62 "
Zn^{65}	1.12 "
Cs^{137}	0.661 "
Hg^{203}	0.280 "
C^{11} (annihilation radiation)	0.511 "

*The alpha particle from the decay of Polonium causes the reaction $Be^{9}(\alpha, n)C^{12}$. The C^{12} is sometimes left in the first excited state 4.45 Mev.

As long as the anthracene crystal was not exposed directly in the beam, no increased background was noted. This was not the case with NaI. Even though the crystal was shielded with lead and placed outside of the synchrotron beam, a background build up was noted. A cadnium shield was placed around the tube and crystal, and this served to cut the induced background in half. This suggested that the NaI crystal was being activated by neutrons. The crystal and photomultiplier tube were finally placed about 20 feet from the beam with good results. The use of this arrangement is discussed in the section describing the results obtained with Na^{21}.

The check on the reliability of the programming circuit consisted of putting a signal generator at the input of the amplifier and allowing the programming device to operate as if it were actually controlling a bombardment and collecting counts on the nine scalers. The pulse totals recorded on each of the scalers were found to check one another to within one half per cent. A Cesium 137 source and the photomultiplier tube and crystal were also used to provide a source of randomly distributed pulses. The totals on the scalers again checked to within one half per cent.

The delay in the first scaler was measured in several ways, all of which agreed. The ratio of the counts in the first scaler to those in the second was taken, and knowing the counting time of the second scaler per cycle, the delay was calculated to be 0.10 seconds. Another method

involves using an oscillator, coincidence circuit and differentialdiscriminator. This method will be described in more detail in the Master's thesis to be submitted by Raymond M. Kline.

It should be mentioned that the 0.10 second delay is obtained from a special relay that requires this amount of time to build up its magnetic field. The other delays, none of which was used with any of the half lives discussed in this thesis, made use of the timing pulse from the clock pendulum and a frequency divider. The clock was checked with station WWV several times a week and was found to vary only a few seconds per day.

Since many of the activations had to be run at a low synchrotron energy to avoid higher order reactions, the synchrotron maximum energy meter itself had to be checked. This meter is known to be linear and to read accurately at the maximum beam energy of 69 Mev. Therefore, an activation curve was made on 10.5 minute Cu^{62} (7) to determine its threshold energy. The threshold of the reaction $Cu^{63}(\gamma,n)\ Cu^{62}$ is known to be 10.6 Mev (23). The value measured was 10.5 ± 0.2 Mev which agrees reasonably well. Thus, within this error the calibration of the synchrotron maximum energy meter passes through the origin.

Actual trial runs were made using the known radioactive decays of He^6 and Li^8 to test the equipment. These isotopes were formed from the reactions, $Li^7(\gamma,p)He^6$ and $Be^9(\gamma,p)\ Li^8$ respectively. The lithium was in the form of LiF; the beryllium was in the form of a metal block. The differential discriminator was set to stop all signals below a pulse height corresponding to 0.62 Mev in the case of He^6, and 3.5 Mev in the case of Li^8. In the latter case the discriminator was set at this high level so as to avoid all pulses from the reaction $Be^9(\gamma,2pn)He^6$. The synchrotron was run at 69 Mev maximum energy for both reactions. The results are as follows:

Table 2

Comparison of He^6 and Li^8 half life values with other reported values

Isotope	Half life reported here	Other values
He^6	0.825 ± 0.022 seconds (0.017 external error)	0.823 ± 0.004 (14)
$Li^7(\gamma,p)He^6$		0.823 ± 0.013 (15)
		0.85 ± 0.05 (16)
		0.83 ± 0.03 (34)

Table 2 continued

Isotope	Half life reported here	Other values
Li^8	0.842 ± 0.004 seconds (0.010 external error)	0.85 ± 0.03 (17)
$Be^9(\gamma,p)Li^8$		0.825 ± 0.02 (18)
		0.88 (19, 20, 21)
		0.89 ± 0.01 (33)

About five times as many events were collected for Li^8 as for He^6. The He^6 activity also had more background to subtract, thus giving it considerably more error. Both values reported here are seen to agree fairly well with other reported values. The discussion of internal and external errors may be found at the end of this section.

Since the delay immediately following the bombardment is part of the first scaler's counting time, a correction must be made to those counts. Assuming no background, this correction factor is the ratio of the counts that would have occurred, had there been no delay, to the counts actually observed. This fraction is

$$\frac{1 - e^{\lambda t_2}}{1 - e^{\lambda (t_2 - t_1)}}$$

where t_2 is the total counting period available, t_1 is the delay, and λ is the decay constant of the activity observed. With a background which is long lived compared to t_2, the net corrected counts in the first scaler is given by

$$\left[N - \frac{t_2 - t_1}{t_2} B \right] \left[\frac{1 - e^{\lambda t_2}}{1 - e^{\lambda (t_2 - t_1)}} \right]$$

where N is the gross uncorrected counts, and B is the background.

All the half lives reported here were calculated by means of weighted least squares according to the formulas given by Worthing and Geffner (24). The errors quoted on the data of this thesis are the internal errors, unless otherwise stated. The internal error of

a half life is calculated from the probable error in each observed point, whereas the external error is based on the standard deviation of the residuals of the observed points from the calculated line. Essentially the external error is a measure of the scattering of the points about the least squares line provided there are no systematic errors or incorrect background subtractions. The ratio of the external to the internal error should fluctuate statistically about a mean of unity (25). If the ratio is much larger than one, there is reason to believe that either too much or not enough background* was subtracted.

The line that is to be fitted to the data has the form

$$y = \mathrm{Ln}N = A + \lambda t$$

where N is the net counts, t the time in seconds, and A and λ are the parameters (λ is the decay constant). The constants are calculated thus:

$$A = \frac{\sum w_i t_i^2 \sum w_i y_i - \sum w_i t_i \sum w_i t_i y_i}{D}$$

$$\lambda = \frac{\sum w_i \sum w_i t_i y_i - \sum w_i t_i \sum w_i y_i}{D}$$

where $D = \sum w_i \sum w_i t_i^2 - (\sum w_i t_i)^2$. The weighting factor w is equal to the reciprocal of the probable error squared.

From the propagation of errors relation the internal probable error in λ is

$$P_{int} = 0.6745 \sqrt{\sum (B' t_i - B)^2 w_i}$$

where $$B' = \frac{\sum w_i}{D}$$

and $$B = \frac{\sum w_i t_i}{D}.$$

The external probable error is

$$P_{ext} = P_y \sqrt{B'}$$

*Background as used here includes all activity, constant and decaying, other than the activity one wants to study.

where $$P_y = 0.6745 \sqrt{\frac{\sum (y_i - A - \Sigma t_i)^2 w_i}{n - 2}}$$

and n is the number of points used.

APPLICATION TO FIVE SHORT LIVED LOW Z ISOTOPES

In nearly all the activities studied there was present, in addition to a constant background, a long decaying background. The constant background was subtracted from the decaying background and a least squares line was put through the result. This line was extrapolated to the initial activity, and the total background, both decaying and constant, was subtracted. The result again had a least squares line passed through it and the slope determined, hence, the half life.

Four of the five isotopes were treated in a similar manner; the fifth, Na^{21}, was treated in a different way. The activity of each of the first four isotopes was observed with the aid of an anthracene crystal and photomultiplier tube set up as shown in Figure 1. The differential discriminator was set to exclude all signals below an equivalent energy of 0.62 Mev for these first four isotopes. The conversion peak of Cs^{137} was used for the calibration.

Magnesium 23

Magnesium 23 may be produced from the reaction $Mg^{24}(\gamma,n)Mg^{23}$. In this experiment a fairly pure block of magnesium was bombarded for periods of 10 seconds per cycle with a beam energy of 27.5 Mev. This is just below the calculated threshold of $Mg^{24}(\gamma,2n)Mg^{22}$ which is 29.5 Mev.* The estimated error in such a calculation is about 1/2 Mev thus the synchrotron was set at 2 Mev lower than the calculated threshold. The first five scalers counted for 10 seconds each per cycle; the last four scalers counted for 30 seconds each per cycle. After the run was completed, the background was carefully recorded for some ten minutes until it seemed to level out into the constant background as shown in Figure 8. The entire procedure was repeated again with essentially the same results, and therefore the total events at similar times in the two runs were added together. The decaying background had a half life of 64 seconds and is very likely from the reaction $Mg^{26}(\gamma,p)Na^{25}$. Na^{25} has a half life of about 62 seconds (26, 7).

*All threshold calculations are based on the mass values as given by C. W. Li (26, 37) and A. G. W. Cameron (38).

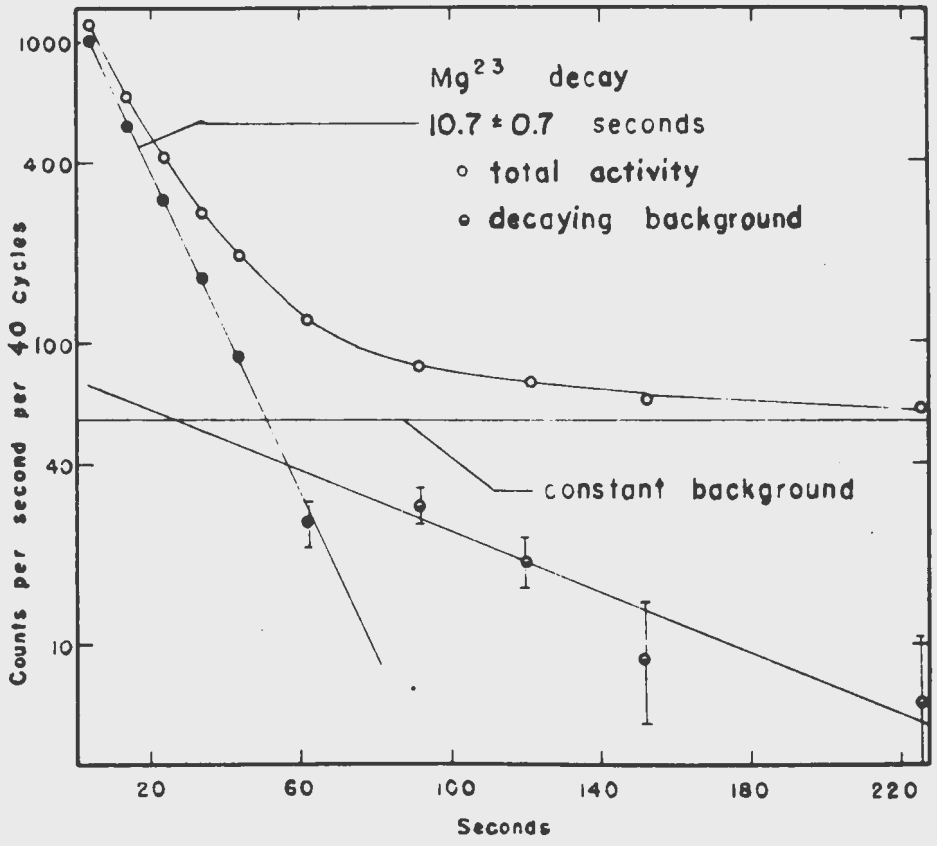

Fig. 8--Decay curve of Mg^{23}.

The largest discrepancy is found with Boley's (2) value. This is apparently due to unsubtracted background, since his decay curve was recorded only long enough to identify the isotope and to measure its energy spectrum. The external error given here indicates further investigation would be justified such as using a NaI crystal as was done in the case of Na^{21}. The same maximum beam energy should be used, 27.5 Mev. to avoid $Mg^{24}(\gamma,2n)Mg^{22}$ and $Mg^{24}(\gamma,dn)Na^{21}$. In view of the ratio of nearly unity between the external error and the internal error there is little reason to suspect a bad background subtraction. In any event, it will be interesting to see what values will be obtained in the near future with this equipment for Mg^{23}.

Table 3

Comparison of values for the half life of Mg^{23}.

Value reported here	Other values
10.7 ± 0.2 seconds (0.2 external error)	12.3 ± 0.4 (2)
	11.9 ± 0.3 (26)
	11.6 ± 0.5 (4)

Sulphur 31

The sulphur used was in a compressed "flowers" of sulphur form. In order to avoid the reaction $S^{32}(\gamma,2n)S^{30}$ when producing $S^{32}(\gamma,n)S^{31}$ the beam energy was set at 25.5 Mev. The threshold calculation gives a value of 27.3 Mev for the production of S^{30}. The first five scalers were on a 3 second time period per cycle, while the last four scalers counted for 12 seconds each per cycle. After the run was completed, the background decay was recorded. The background points were badly scattered as can be seen in Figure 9, but it definitely decayed; the half life was approximately 33 seconds. This does not correspond to any known photonuclear reaction; it perhaps could be due to the activity from $S^{36}(\gamma,p)p^{35}$.

The most recent values (27, 35) are more in agreement than the others with the one reported here. The ratio of external error to internal error is very nearly unity. This would suggest that the data is at least consistent with itself.

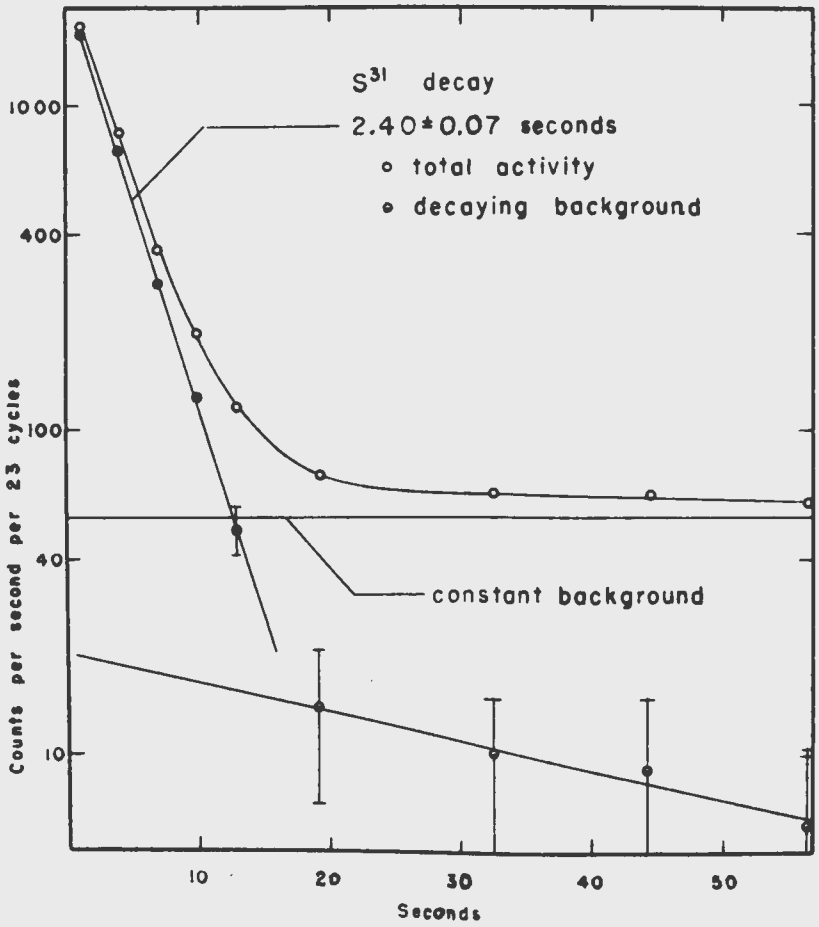

Fig. 9--Decay curve of S31.

Table 4

Comparison of values for the half life of S^{31}.

Value reported here	Other reported values	
2.40 ± 0.07 seconds (0.07 external error)	2.6 ± 0.2	(27)
	2.66 ± 0.03	(35)
	3.18 ± 0.04	(5)
	3.2 ± 0.2	(4)
	2.9	(28)
	3.2 ± 0.3	(2)

Potassium 37

This isotope was produced from the reaction $K39(\gamma,2n)K37$. Potassium iodide powder was pressed into a cylinder 1-1/2 inches in diameter and 3 inches long. In this form it was bombarded with a maximum beam energy of 39 Mev for one second per cycle. The programming circuit was set to allow the first five scalers to count for one second per cycle, while the last four scalers counted for four seconds each per cycle.

The background appeared very constant in the last three scalers (Figure 10), and therefore their registered counts were averaged together, subtracted from the initial activity, and a least squares plot of this was made. The activity built up in the background most probably was due to the K^{38} 7.7 minute isotope. This has an end point of 2.8 Mev, whereas K^{37} has an endpoint of 4.6 Mev. Another possibility is I^{128} from neutron activation of I^{127}. This would result in an activity whose maximum beta energy end point is 2.02 Mev and whose half life is 25 minutes. It would seem that setting the discriminator at 2.8 Mev would eliminate this background. It was found, however, that this reduced the statistical accuracy on K^{37} so much that it was impractical with the low synchrotron beam intensity at the time.

Langmuir's value (29) is considerably higher, yet he used the same $(\gamma,2n)$ reaction. No mention of his background was made. Boley's value (2) also from an identical reaction here at Iowa State College is barely

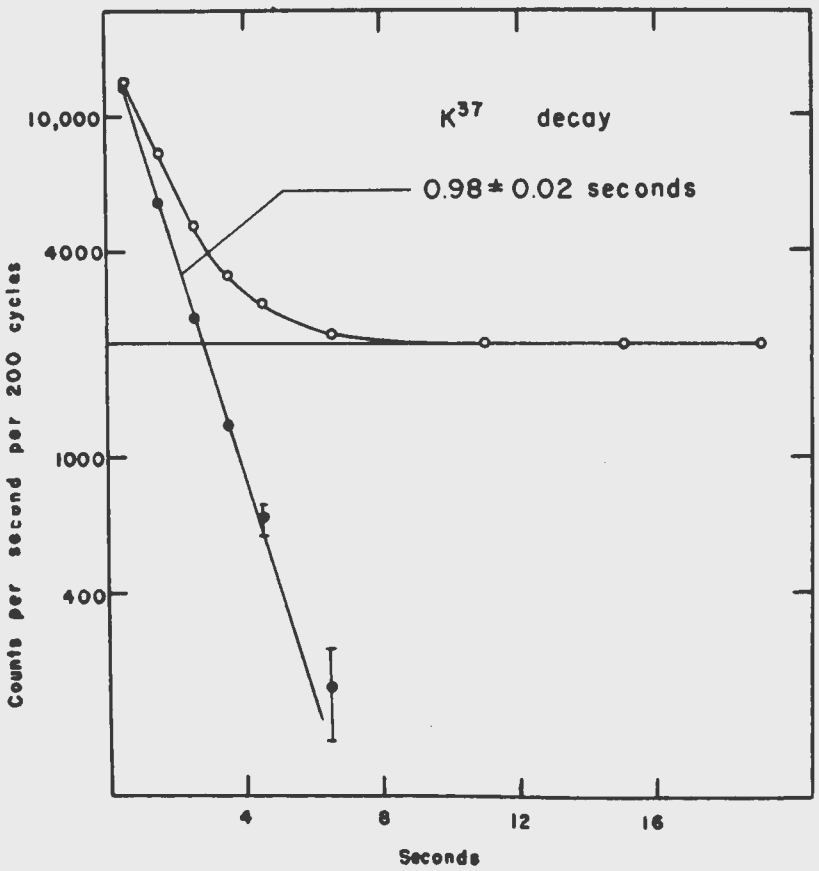

Fig. 10--Decay curve of K^{37}.

within agreement with the value reported here. But again, Boley followed the activity only long enough to identify it and find the end point of its beta spectrum. Apparently no background was subtracted. Had it been subtracted it might have lowered his value enough to agree with that reported here.

Table 5

Comparison of values for the half life of K^{37}.

Values reported here	Other reported values
0.98 ± 0.02 seconds (0.04 external error)	1.3 ± 0.1 seconds (29)
	1.2 ± 0.2 seconds (2)

On the other hand, the background for the value reported here is not well defined, i.e., it has not been recorded long enough after the decay of K^{37} to identify it. There is a possibility of a short lived isomeric state in K^{38} which could shorten the value given here. This latter suggestion is made in view of the recent discovery of such a state in Cl^{34} (23).

Silicon 27

Silicon oxide (silica gel), packaged in a very thin rubber hydrochloride plastic bag, was bombarded with a maximum synchrotron beam energy of 27.5 Mev to produce the reaction $Si^{28}(\gamma,n)Si^{27}$. This low energy was chosen to avoid the reaction $Si^{28}(\gamma,2n)Si^{26}$ which has a threshold of 29.9 Mev. The bombarding time and the first five scalers were on for five seconds each cycle, while the last four scalers counted for eighteen seconds each cycle. After the run was completed, the background was recorded, and still later the constant background was counted. The half life of the decaying background was 164 seconds, which is probably due to the $Si^{29}(\gamma,p)Al^{28}$ (2.3 minutes) and the $O^{16}(\gamma,n)O^{15}$ (2.1 minutes).

The value reported here is within statistical error of all except Boley's (2). Again, Boley had little idea of his background and therefore could not subtract it.

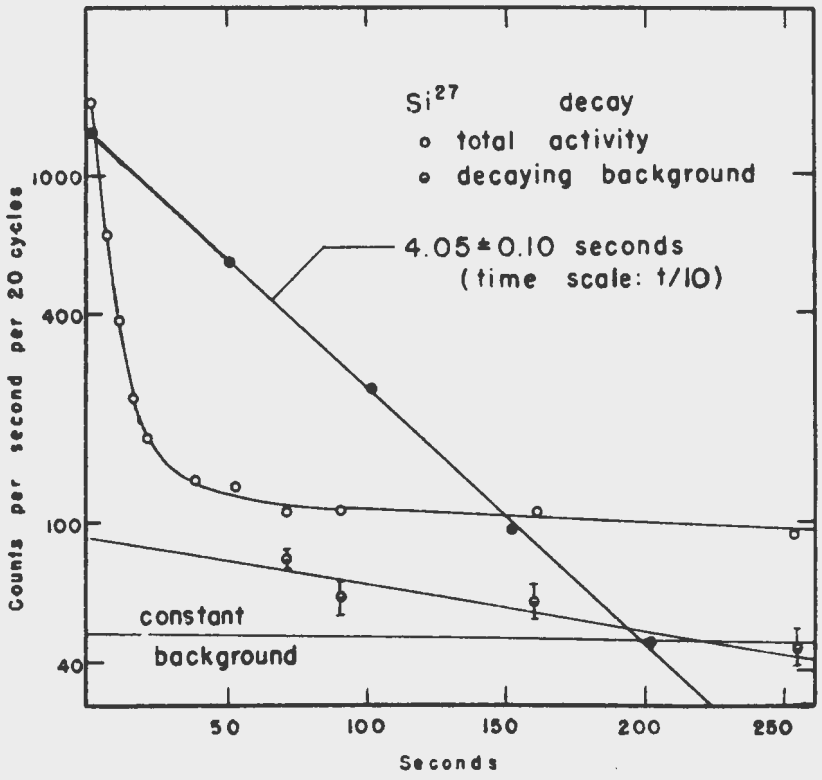

Fig. 11--Decay curve of Si^{27}.

Table 6

Comparison of values for the half life of Si^{27}

Value reported here	Other reported values	
4.05 ± 0.10 seconds (0.05 external error)	5.4 ± 0.4	(2)
	4.5	(28)
	4.92 ± 1	(5)
	4.9 ± 1	(30, 31)

Sodium 21

The longest of the half lives studied was that of Sodium 21. A block of sodium metal was wrapped in a thin rubber hydrochloride bag and bombarded at 69 Mev maximum energy for an interval of 20 seconds to induce the reaction $Na^{23}(\gamma,2n)Na^{21}$. A delay of fourteen seconds each cycle ensued before the programming circuit was put into operation. During this delay the sodium was manually transported about 20 feet from the bombarding position to a NaI crystal and photomultiplier tube. The crystal and photomultiplier tube were placed in this position to avoid background build up. A 2.6 gm/cm^2 aluminum absorber was placed between the crystal and the sodium. This was for the purpose of absorbing the beta particles from the reaction $Na^{23}(\gamma,2pn)F^{20}$. After each 5,000 counts in the first scaler, a background run was made to make sure there was no change. This type of set up was used primarily to mask out the activity of F^{20} and F^{21} which are not positron emitters. The delay of 14 seconds insured against Na^{20} activity of 0.23 seconds.

The first counting period per cycle was 20 seconds for scalers one to four; the second counting period per cycle was 108 seconds for scalers five to nine. The annihilation radiation from the positrons of C^{11} was used as a calibration of the differential discriminator. The discriminator was then set to pass pulses corresponding to the energy range 0.47 to 0.55 Mev.

As will be noted from Figure 12, there is still a long lived background which is attributed to nitrogen contamination. The nitrogen from Na_3N will give the reaction $N^{14}(\gamma,n)N^{13}$ whose half life is 10.1 minutes.

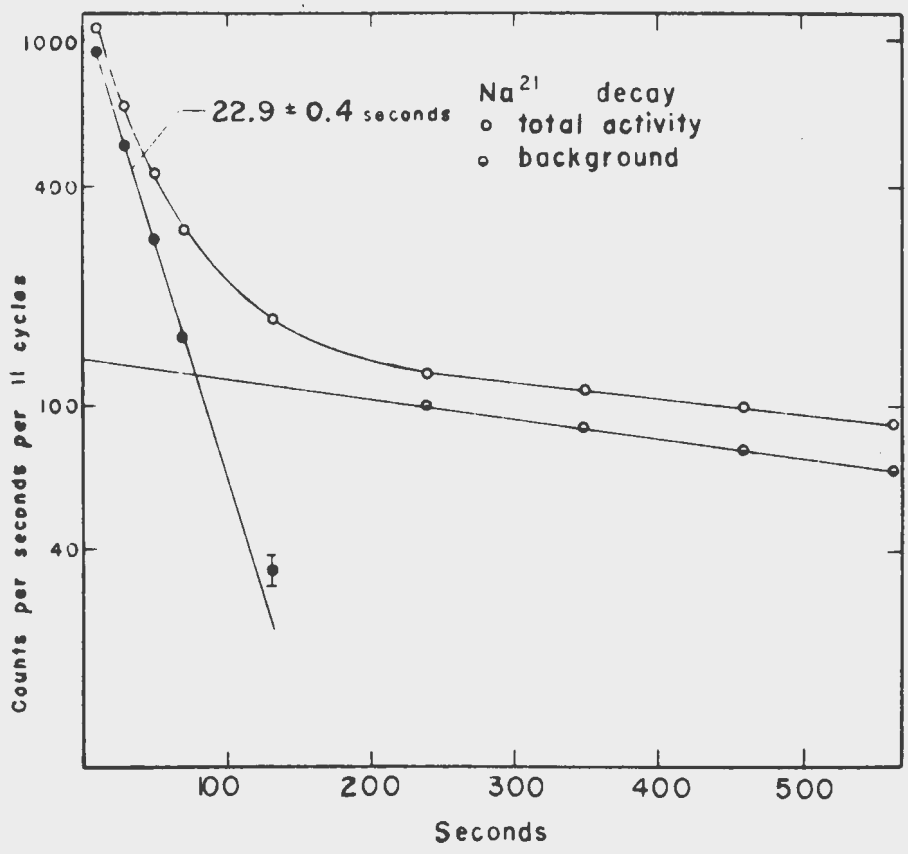

Fig. 12--Decay curve of Na^{21}.

The external error in this case indicates that the scattering of the points is less than one would expect. Very favorable agreement is seen with both Schrank and Richardson's (32) value and with Fox, Croutz, and Sullon's (30) value. This measurement of Na^{21} could also be considered a good check on the equipment in the longer half life range.

Table 7

Comparison of values for the half life of Na^{21}

Value reported here	Other reported values	
22.9 ± 0.4 seconds (0.2 external error)	22.8 ± 0.5	(32)
	23 ± 2	(30)

CONCLUSION

One of the purposes of this thesis has been to demonstrate the practicality of this short half life equipment by applying it to five of the mirror nuclei, Z - N = 1. It is hoped that greater accuracy will be attained in the future using this method. More accurate half lives of the mirror nuclei will be especially valuable in the theory of beta decay. In the second column of Table 7 the approximate half lives were calculated by averaging the background and subtracting that average from the initial activity. The results are higher than those in column 3 except for K^{37} which had an almost constant background anyway. The fact that Na^{21} agrees so well with the literature values is a good test of the equipment on the longer counting periods. The first four half lives, according to a more accurate background analysis by least squares (Table 7, column 3), are somewhat lower than those published in the literature. However, more work on these isotopes is being planned.

The data reported here can be further checked by observing the positron annihilation with a NaI crystal with the synchrotron maximum beam energy below the threshold of higher order reactions (the (γ, 2n), (γ,2p), etc.). The NaI crystal should be used to test for gamma rays in the mirror nuclei. It has been found in this work that the values of the half lives are quite sensitive to the amount of background being subtracted. As new and more accurate values of half lives are being reported, it is becoming increasingly important to account for all

background when making new measurements. Failure to do this is the cause of much discrepancy in reporting short half lives today.

Table 8

A summary of the activities studied in this thesis

Isotope	Half life with crude background subtraction	Half life with least squares background subtraction
Mg^{23}	12 sec.	10.7 ± 0.7 seconds (external error)
S^{31}	2.6	2.40 ± 0.07
K^{37}	1	0.98 ± 0.02
Si^{27}	5	4.05 ± 0.10
Na^{21}	27	22.9 ± 0.4

These criticisms have been suggested during the course of this work and are offered in the hope that they will be of value in the future work with this equipment.

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