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STUDIES IN β - AND γ -RAY SPECTROSCOPY

Harry Tyson Easterday
(Thesis)

March, 1953

Berkeley, California

STUDIES IN β - AND γ -RAY SPECTROSCOPY

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ABSTRACT

Energy determinations have been made using the conversion and photoelectron spectra and scintillation crystal pulse height analysis for twelve γ -rays associated with the Rb^{82} decay (6.3 hours, β^+ , K-capture). The β^+ spectrum is found to contain four allowed components of maximum energies 1080, 890, 610 and 300 kev. A tentative decay scheme is suggested.

The decay of Cu^{67} (61 hours, β^-) has been fitted into the known decay scheme of Zn^{67} . The β -spectrum contains three components of upper energies 577, 484, and 395 kev and conversion electrons from 92 and 182 kev transitions. The multipole orders of transitions between levels in Zn^{67} have been measured and level configurations postulated on the basis of the Shell model of the nucleus, which are consistent with the decay schemes of Cu^{67} and Ga^{67} .

Multipole order measurements have been made for two transitions involved in the Se^{73} decay (7.1 hours, β^+ , K-capture). The 67 kev isomeric transition in Se^{73} is shown to be E3 and the 360 kev transition between the first excited and ground states of As^{73} is found to be M2. Neither of these transitions can be reconciled with the Shell model if the decay scheme as it now stands is correct.

Details are given as to the design of the photo-converter and as to methods used in multipole order measurements. An apparatus used for NaI-Th crystal pulse height analysis is described.

STUDIES IN β - AND γ -RAY SPECTROSCOPY

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SECTION I

Radioactivity of Rb^{82}

Mass assignments and half lives of the radioactive Rb isotopes $A = 81$ to 84 have been made by Karraker, Reynolds and Templeton.¹ The mass assignments were found by using a mass spectrograph instead of the more usual procedure of excitation functions. More detailed investigations have been made recently on Rb^{82} (6.3 hour, β^+ K) and Rb^{84} (34 day, β^+ , K, β^-) by C. M. Huddlestons and A. C. G. Mitchell² who measured the β^+ -spectrum and determined γ -ray energies with a β -spectrometer. The work reported here is primarily concerned with Rb^{82} . In addition to measuring the β^+ -spectrum, γ -ray energies have been found in the present experiments from their conversion and photoelectrons and by scintillation crystal pulse-height analysis. The results reported in Reference 2 and those given here agree except for one line in the γ -ray measurements but do not agree in the β -spectrum. Attempts to explain the discrepancies will be made later.

The Rb activity is produced by bombarding CuBr powder with α -particles. The chemical procedure is to remove the copper by precipitation as a sulfide then scavenge with SrCO_3 and La(OH)_3 . As an added precaution, Ga is extracted with ether. Ammonium compounds are driven off by heating, and Rb remains as a chloride. Since Br consists of two stable isotopes of roughly equal abundance, $A = 79$ and 81 , Rb^{82} and Rb^{84} are produced with (α, n) reactions on Br and Rb^{81} (4.7 hour) by $(\alpha, 2n)$. It was found that by reducing the beam energy to 12-14 Mev only Rb^{82} and Rb^{84} were formed. The half life

of the activity produced with 14 Mev α 's is shown in Figure 1. γ -ray measurements made by the three methods, conversion electrons, photoelectrons and pulse height analysis are shown in Figures 2 to 4, and the results are given in Table I.

TABLE I
 γ -Ray Energies (in kev) of Rb⁸²

Conversion Electrons	Photoelectrons		NaI Crystal Pulse Height Analysis	Estimate of Relative Intensity
	Au Converter	U Converter		
188	187		195	strong
268	260		250	strong
320	325		315	weak
390	395		380	weak
454	465		475	strong
620	630		610	fairly strong
685	695		685	weak
780	775		770	strong
828	833		835	fairly strong
		1020	1030	weak
		1315	1305	weak
		1460	1440	weak

The spectra were scanned continuously over an extended period of time in order to be able to check the half lives of the individual lines. The main discrepancy between these results and the values given in Reference 2 is that a 558 kev line listed as Rb⁸² was found to have a half life much longer than 6.3 hours and is probably connected with the 34 day Rb⁸⁴ decay.

The β^+ -spectrum and Fermi analysis are shown in Figures 5 and 6. Energies, branching percentages and log ft values are given in Table II.

TABLE II
Positrons from Rb⁸²

Maximum Energy (kev)	Branching Percentage	Log ft 10
1080 $\pm$ 10	40	5.25
890 $\pm$ 15	38	4.95
610 $\pm$ 20	12	4.70
300 $\pm$ 50	10	3.80

These values disagree with those given in Reference 2. The spectrometer used by Huddleston and Mitchell was not equipped to distinguish between electrons and positrons. Since Compton and conversion electrons from the 1020 and 1314 kev transitions occur in the region of the upper energy limit of the positrons, it is felt that the difference could be caused by uncertainty in choosing the background counting rate for the positron spectrum. These authors also mentioned that they corrected the spectrum for Rb⁸⁴ positrons. Several bombardments were made in the present experiments at various beam intensities, and the half life of the activity was followed in each case to insure that an (α , 2n) reaction indicated by the presence of Rb⁸¹ did not occur due to foil damage in the target. When the activity was decaying with a 34 day half life, the β^+ -spectrum was measured for Rb⁸⁴. In each case the Rb⁸⁴ activity was close enough to background to make corrections to the Rb⁸² spectrum unnecessary.

The great number of transitions associated with the decay prevents accurate measurements of relative γ -ray intensities. Any decay scheme postulated without knowing intensities has to be tentative because the levels can be oriented in several ways. The most consistent

scheme that can be postulated from the rough γ -ray intensity estimates and the allowed nature of the four positron groups is shown in Figure 7. The 775 kev transition appears to be the most intense followed by the 187 kev. Refer to Figure 4. The multipole order of the 187 kev line was measured to be E2 which is a characteristic transition between low lying levels in even-even nuclei. Details of the method of determining γ -ray multipole orders are given in Appendix I. The spin and parity of the ground state of Rb^{82} can be postulated by using a general rule given by Nordheim³ for combining configurations in odd-odd nuclei:

1. The individual configurations of neutrons and protons in odd-odd nuclei are the same as in odd A nuclei with the same number of nucleons in the odd particle group.
2. If the odd neutron and odd proton groups belong to different Schmidt groups, then their resultant spins will subtract.
3. If the odd neutron and proton groups belong to the same Schmidt group, their spins will couple to a larger than minimum resultant.

Referring to Figure 13 of Section II, the ground state configuration of $_{37}\text{Rb}^{82}_{45}$ is expected to be:*

$$\left[(\phi_{5/2})^5_{5/2} (g_{9/2})^4 (p_{1/2})^1_{1/2} \right] \quad 3+$$

The proton and neutron spins couple according to Nordheim's third rule. Transitions to the ground state of Kr^{82} are second forbidden whereas those to the first and second excited states are allowed in agreement with the decay scheme.

* Greek letters indicate proton states; Roman letters indicate neutrons.

SECTION II

Energy Levels of Zn^{67} - Radioactivity of Cu^{67}

The radioactivity of Ga^{67} was originally used by Alvarez to show the existence of the K-capture process⁴ and has been investigated in the past by Helmholtz and others.⁵ More recently, two groups^{6,7} using scintillation spectrometers have found γ -rays from weaker transitions and the energy level scheme of Zn^{67} , shown in Figure 8, has been satisfactorily established. It was thought worthwhile to attempt to fit the scheme into the levels allowed in this region of nucleon numbers by the Shell model of the nucleus.⁸ In order to do this, the spins and parities of the levels must be determined by investigating the degree of forbiddingness of β - or K-capture decay and the spin and parity changes of transitions between energy states of the daughter nucleus which lead to γ -ray or conversion electron emission.

In order to obtain information about the Zn^{67} levels, the β -decay of Cu^{67} has been investigated in detail. The activity was produced by two reactions, (α, p) on Ni using 40 Mev α 's and $(d, 2p)$ on Zn using 195 Mev deuterons. The half-life was found to be 61 ± 1 hours followed over ten half lives (Figure 9). Since thin samples are essential for the analysis of β -spectra, chemical separations are made carrier free using ion-exchange columns. Pd carrier is added to the dissolved targets and both Cu and Pd are extracted by precipitation as sulfides. The Cu is then separated from Pd by washing the activity from a Dowex A2 ion-exchange column with 3N-HCl. Samples were mounted on thin Tygon foils (approximately 0.1 mg/cm^2) and were of negligible thickness. The β -spectrometer⁹ used was a thick lens type of two percent transmission and four percent resolution and was equipped with a helical baffle which permitted either electrons or positrons to be transmitted. By checking the samples for traces of a β^+ -spectrum, the presence of 12.8 hour Cu^{64} could be detected which would not be observed from the gross activity. Since Cu^{64} emits both electrons and positrons of greater energy than Cu^{67} , a slight amount of the short life activity seriously distorts the Cu^{67} β -spectrum, especially near the upper energy limit. Figure 10 shows

the β^- and conversion electron spectra and Figure 11 is the Fermi analysis. Table III gives the end point energies, relative intensities and ft-values of the β -spectra and the γ -ray energies.

TABLE III
Beta and Gamma-rays of Cu⁶⁷

Transition energy (kev)		Relative Intensity (percent)	log ft 10
Beta	577	20	6.3 (1-forbidden)
	484	35	5.7
	395	45	5.35
Gamma	92		
	182		

In order to verify the lack of β -transitions to the uppermost level, a careful search was made for conversion electrons with the β -spectrometer and γ -rays with the scintillation spectrometer (Apparatus is described in Appendix II) from the 296 kev transitions, but none were found to occur. As a further check on the correctness of the Fermi analysis, the activity was studied for the presence of γ - γ coincidences. The only way γ - γ coincidences can occur is through branching to higher levels since the 92 and 182 kev transitions are not in cascade. Although the 92 kev level has a lifetime longer than the resolving time of the coincidence apparatus, a branching of greater than five percent to the highest level would produce observable coincidences. Results of the experiments indicate that when the data is corrected for background counts and chance coincidences, no γ - γ coincidences occur.

More complete information as to spin values can be obtained if the multipole orders are known of the γ -rays emitted by transitions between states. Ga⁶⁷ activity for the conversion coefficient measurements was made by (d, n) on Zn. Fe carrier is added to the dissolved

target and Ga and Fe extracted with di-isopropyl ketone. Fe is removed from a Dowex A2 column with 3N-HCl and the Ga activity is washed down with water. Figure 12 shows the conversion and photoelectron spectra. Table IV gives the results of the measurements along with theoretical values from Rose's Tables.¹⁰

TABLE IV
Zn⁶⁷ - Experimental and Theoretical Values of
K-Shell Conversion Coefficients

γ-Ray Ener- gy (kev)	Theoretical Conversion Coefficients						Ex- peri- mental	Mul- ti- pole Order
	E1	E2	E3	M1	M2	M3		
92	6.8×10^{-2}	7.5×10^{-1}	7.0	5.5×10^{-2}	6.6×10^{-1}	6.7	0.5 ± 0.2	E2
182	8.8×10^{-3}	6.0×10^{-2}	3.9×10^{-1}	1.1×10^{-2}	7.3×10^{-2}	4.1×10^{-1}	$1.2 \pm 0.2 \times 10^{-2}$	M1
298	2.1×10^{-3}	9.5×10^{-3}	3.8×10^{-2}	3.3×10^{-3}	1.5×10^{-2}	6.0×10^{-2}	$3.9 \pm 0.6 \times 10^{-3}$	M1
388	1.0×10^{-3}	3.9×10^{-3}	1.4×10^{-2}	1.8×10^{-3}	6.7×10^{-3}	2.4×10^{-2}	$1.0 \pm 0.9 \times 10^{-2}$	M1 or E1

A mixture of M1 and E2 in the 92 kev transition is permissible¹¹ but the possibility can be ruled out due to the half life of 8.5×10^{-6} seconds for the first excited level. According to the Weisskopf formula,¹¹ an M1 transition of this energy for A = 67 would have a half life of roughly 5×10^{-10} seconds whereas an E2 would have $\tau_{1/2} = 2.5 \times 10^{-6}$ seconds. An M1 transition of 80 kev in Xe¹³¹ is known to have a half life of 5×10^{-10} seconds.¹² The intensity of the two high energy transitions is so low that a choice between E1 and M1 cannot be made from the data.

According to the Shell model, the energy levels in the region 28-50 nucleons are filled as shown in Figure 13. The sequence is the same for both neutrons and protons.

In the region of nucleon numbers 29-37, the ground states of all odd-A nuclei with two exceptions have $p_{3/2}$ spins. The reason for this is that as nucleons are added beyond 32, where the $p_{3/2}$ level is

expected to be complete, nucleons tend to fill the available $f_{5/2}$ states in pairs leaving a vacancy in the $p_{3/2}$ state. This coupling effect is due to the large pairing energy of f-nucleons. The only exceptions are Rb^{87} and Zn^{67} which have $f_{5/2}$ ground states. Thus, the ground state configurations beyond 28 nucleons of the nuclei involved and the basis for the choice are as follows (Greek letters indicate proton states and Roman letters neutrons):

$${}_{29}Cu^{67} (\pi_{3/2})^1 {}_{3/2} (f_{5/2})^6 (p_{3/2})^4$$

$${}_{30}Zn^{67} (\pi_{3/2})^2 (f_{5/2})^5 {}_{5/2} (p_{3/2})^4$$

$${}_{31}Ga^{67} (\pi_{3/2})^3 (f_{5/2})^6 (p_{3/2})^2$$

Cu^{63} and Cu^{65} have $I=3/2$, μ -value closest to the $\ell + 1/2$ Schmidt line, and $Q < 0$ indicating closed shell plus one nucleon.

Zn^{67} has a measured $I=5/2$, μ -value closest to $\ell - 1/2$ Schmidt line, and $Q > 0$ indicating closed shell minus one nucleon.

Ga^{69} and Ga^{71} have $I=3/2$, μ -value closest to $\ell + 1/2$ Schmidt line, $Q > 0$.

β -transitions to the ground state ($E_{max} = 577$ kev) involve $f_{5/2} \rightarrow \pi_{3/2}$ configuration changes which are 1-forbidden in agreement with the log ft value of 6.3.³ Transitions to the ground state from Ga^{67} require a two particle change which is forbidden and do not occur in the decay.⁶

From the γ -ray multipole order measurements, spin values of $1/2$ - and $P_{3/2}$ can be assigned to the first and second excited states, respectively. If a $p_{3/2}$ neutron is excited to a $f_{5/2}$ state to form a completed f-shell and the two protons couple to give zero spin as expected from the Shell model, a $p_{3/2}$ state results from the closed shell minus one particle configuration of the neutrons. Since both protons and neutrons exist in incomplete p-shells, it is possible that they can interact so the two $\pi_{3/2}$ protons can couple to give spin two (spin one is excluded) with a $1/2$ -spin and parity resulting for the level. The first two excited states then have the configuration:

$$\left\{ (\pi_{3/2})^2_{0,2} (p_{3/2})^3_{3/2} \right\} {}_{3/2,1/2-} (f_{5/2})^6$$

K-capture and β -transitions would then involve $3/2- \rightarrow 3/2-$ or $1/2-$ changes which are allowed in agreement with the decay scheme.

It seems clear that this is a case where the single particle model is not sufficient to explain the low excited states, and one must consider interactions of several nucleons.

SECTION III

The Radioactivity of Se^{73}

The suggested decay scheme for the Se^{73} activity¹³ is shown in Figure 14.

The purpose of the study was to measure the internal conversion coefficients of the 67 and 360 kev γ -rays. The 67 kev transition would be expected to be isomeric and the spin change of the 360 kev is of interest in explaining the forbiddingness of the β^+ -decay to the ground state ($\log ft = 7.7$)

The activity was made with an (α, n) reaction by bombarding GeO_2 powder with 40 Mev α 's. Due to the low energy of the 67 kev transition, it was necessary to use a fairly low Z photoelectron converter, Ag. The photoelectron energy equals the γ -ray energy minus the K-shell binding energy of the converter, so more efficient standard converters such as Au or U which have binding energies greater than 67 kev could not be used. The conversion coefficient and K/L values are given in Table V.

TABLE V

Theoretical and Experimental Conversion Coefficients
and K/L Values for Se^{73} - As^{73} Transitions

γ -Ray Ener- gy	$\frac{K}{L}$	Theoretical Conversion Coefficients					Experimental	Multi- pole Order
		E2	E3	M2	M3	M4		
67	7.6		10		~ 100	∞	4.5 ± 2.0	E3
360	8.6	7.9×10^{-3}	3.2×10^{-2}	1.4×10^{-2}	5.6×10^{-2}		$1.3 \pm 0.2 \times 10^{-2}$	M2

The relatively large error in the measurement for the 67 kev transition is due to the low energy. Counter end window corrections are necessary and it is difficult to calibrate the photo-converter in the low energy region.

The half life of the excited state of Se^{73} for γ -emission is calculated to be 1.25×10^5 seconds from the branching ratio between γ , β^+ , and K-capture decays.¹³ The half life of a 67 kev level in $A = 73$ for various multipole orders are given by the Weisskopf formula¹¹ as follows:

Multipole Order	Half Life (Seconds)
E3	9×10^2
M3	5×10^4
M4	8×10^{12}

In choosing the 67 kev transition as E3 instead of M3, the conversion coefficient determination is considered more accurate than the half life calculation because of the uncertainty in the branching. The assignment of the 360 kev transition as M2 is fairly certain because of the close agreement between the measured and theoretical values of the conversion coefficient and the small probable error.

It does not appear possible to assign spins to the states according to the Shell model and still be in agreement with the suggested decay scheme. The odd A Se isotopes are in the region of isomerism with neutron numbers around 40 where the $p_{1/2}$ and $g_{9/2}$ levels are filling (Rf. Figure 13). Se^{79} and Se^{81} are known to have E3 isomeric transitions involving $7/2+$ and $p_{1/2}$ levels.¹⁴ The $7/2+$ level is formed by the coupling of three or more $g_{9/2}$ neutrons. The ground state configuration of Se^{73} is expected to be:

$$(\phi_{5/2})^2 (f_{5/2})^6 \left\{ \begin{array}{l} (p_{1/2})^1_{1/2} \\ \text{or} \\ (g_{9/2})^1_{9/2} \end{array} \right.$$

With a single neutron beyond the filled $(f_{5/2})$ level, the ground and excited states are either $p_{1/2}$ or $g_{9/2}$. Thus, according to the Shell model, the isomeric transition must be an M4 which can be ruled out because of the half life of 8×10^{12} seconds. There is no way of getting a parity change with a transition between neighboring levels in the region of 32 to 38 nucleons. The 360 kev transition is supposedly between the first excited and ground states of As^{73} and the measured

multipole order involves a parity change (M2 is $\Delta I = 2$ (yes)). Therefore, it is not possible to fit the decay as it now stands into a true one particle model, i. e., without assuming some excitation of the inner core of the nucleus.

The author wishes to express his thanks to Professor A. C. Helmholtz for continual guidance during the course of the studies.

APPENDIX I A Method of Determining Transition Multipole Orders.

Extensive tables have been published¹⁰ giving theoretical K-shell internal conversion coefficients ($\alpha_k = N_k/N_\gamma$) for γ -rays of various energies, Z-values, and multipole orders. Since the agreement between theoretically calculated and experimentally measured values of conversion coefficients has proven quite good, measurement of these coefficients is the best means of determining spin values of excited energy states and the technique will be described in detail in this report.

The internal conversion coefficient of a transition is found from the area under the K-internal conversion electron peak and the number of γ -rays, N_γ , measured indirectly from the number of photoelectrons produced in a converting material. The main inaccuracy is caused by insufficient source intensity to give measurable photoelectron peaks. This is especially true in experiments with isomeric transitions where internal conversion electrons are favored over γ -ray emission. A photo-converter which has proven successful for conversion coefficient measurements¹⁵ is shown in Figure 15. The source is surrounded by enough brass to absorb any β -rays emitted in the decay. The function of the aluminum cap is to absorb Compton electrons made in the brass while aluminum being a low Z material, will not act to produce secondaries. The high Z photo-converting material surrounds the source on three sides. Since most of the photoelectrons are emitted perpendicular to the direction of the γ -ray, the lateral faces of the converter are most effective in contributing to the photoelectron line. The absolute efficiency of the converters at several energies is determined from transitions whose internal conversion coefficients are known. Variation of converter efficiency with energy can also be correlated with the published photoelectric absorption coefficients.¹⁶

The determination of the multipole order of the 187 kev transition of Rb^{82} given in Section I will be used as an illustrative example of the method. Referring to Figure 16 which gives the photoelectron, pe, and conversion electron, ce, peaks, the areas of each are:

$$N_{ce} = 3.0$$

$$N_{pe} = 2.95$$

Ratio of conversion and photoelectron source strengths:

$$\frac{I_{ce}}{I_{pe}} = \frac{38.6}{1}$$

Using the efficiency of the Au converter as determined in this energy range from the 173 and 247 kev lines of In^{111} along with the energy variation given in Reference 16, the efficiency at 187 kev is:

$$e_{187} = 1.1 \times 10^3$$

$$a_{187} = \frac{N_{ce}}{N_Y} = \left(\frac{N_{ce}}{N_{pe}} \right) \frac{1}{e_{187}} = 9.05 \pm 1.0 \times 10^{-2}$$

Theoretical values of the conversion coefficients for $A = 36$ and $E_Y = 187$ kev for various multipole orders¹⁰ are given in the following table:

M1	E1	M2	E2	M3	E3	Experiment	Multi-pole Order
2.25×10^{-2}	1.4×10^{-2}	2.45×10^{-1}	9.2×10^{-2}	8.8×10^{-1}	5.2×10^{-1}	$9.05 \pm 1.0 \times 10^{-2}$	E2

The assignment in this case to E2 is rather unambiguous since the probable error of the experimental measurement does not cause overlapping with theoretical values of other multipole orders.

APPENDIX II:

Apparatus for Scintillation Crystal Pulse Height Analysis

The most important advance made recently in the experimental techniques used in the study of artificial radioactivity is the application of scintillation crystal pulse height analysis to γ -ray energy measurements. The main disadvantage in using β -spectrometers for γ -ray energy measurements is the necessity of having strong sources. Normally γ -ray energies in the region 30 to 600 kev can be determined with a β -spectrometer by observing either conversion or photoelectrons. However, below 30 kev absorption in the counter window is a serious problem; above 600 kev the γ -ray is usually so weakly converted that conversion electrons are difficult to observe and one has to resort to measuring photoelectrons which requires extremely strong sources. Crystal spectrometers can be used with weaker sources since the γ -rays can be observed more or less directly without depending upon a secondary process such as photo-conversion.

The most satisfactory scintillator at present for this type of work is Thallium activated Sodium Iodide crystals. The main advantage of these crystals is in their ability to produce relatively large light pulses from γ -rays. The pulses have been found to be proportional, up to 2.8 Mev, to the energy of the γ -ray, an essential feature for pulse height analysis. Further, the efficiency of most gas counters for γ -rays in this energy region is less than one percent while the efficiency of NaI-Th used is roughly 100 percent up to 200 kev and decreases up to 10 percent beyond 1 Mev. The 669 kev line of Cs^{137} has been resolved to between 9 and 10 percent and the equipment has been used to measure lines ranging from the 15 kev Am^{241} X-radiation to 1.33 Mev γ -rays from Co^{60} . The apparatus is designed with two discriminators in coincidence. One crystal can be held with the discriminator set to count a γ -ray of known energy, and the second crystal is scanned over the energy region - a plot of the coincidence counting rate against energy will give the γ -rays in cascade with the original. The equipment can be used with a β -spectrometer to decide which γ -rays are in coincidence with the continuous β -spectrum.

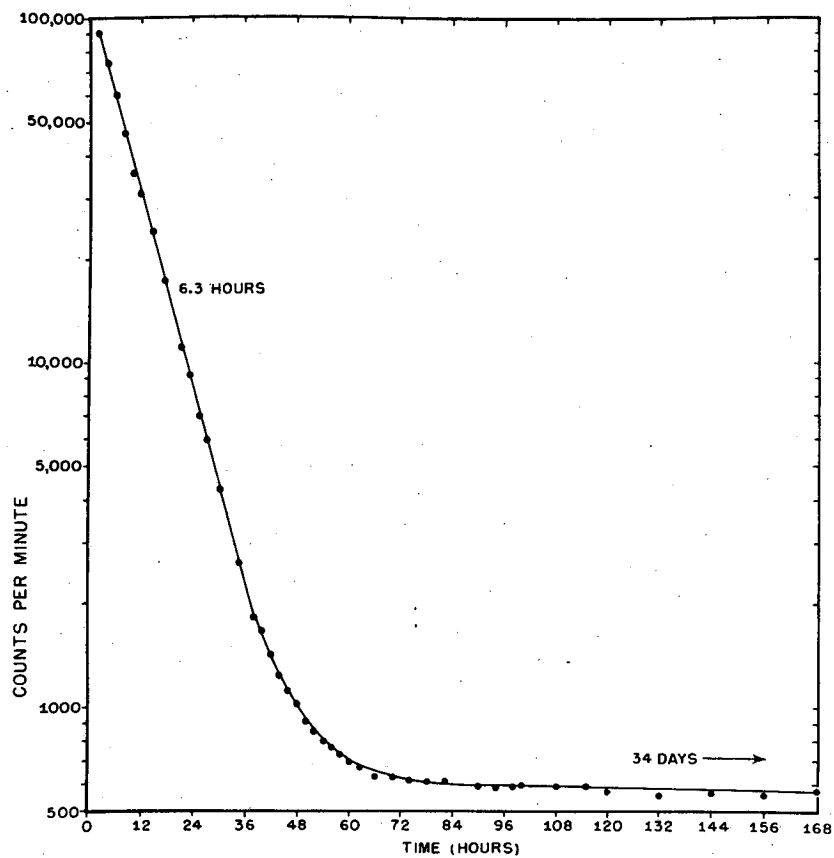
In the following, details will be given as to the mounting of the crystal to the photomultiplier tube along with schematics of all of the electronics needed for the apparatus. The preamplifier, amplifier and differential discriminator were designed by William Goldsworthy of the Radiation Laboratory.

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FIGURE CAPTIONS

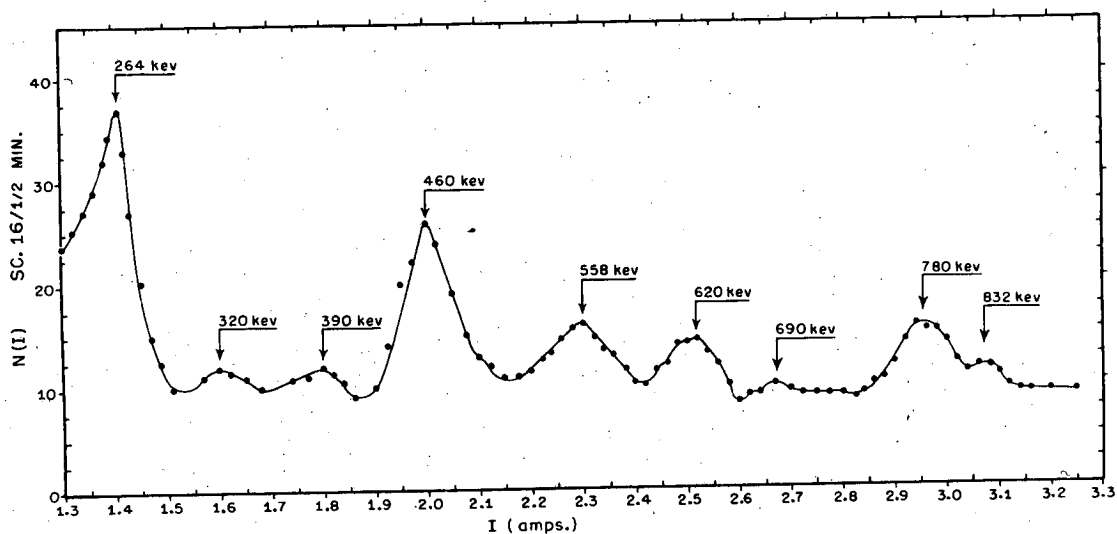
- Fig. 1 Half life of the Rb activity produced with 14 Mev α 's on CuBr.
- Fig. 2 γ -ray spectra - conversion electrons.
- Fig. 3 γ -ray spectra - photoelectrons.
- Fig. 4 γ -ray spectra - NaI pulse height analysis.
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- Fig. 17 Block diagram.
- Fig. 18 Photomultiplier amplifier.
- Fig. 19 Preamplifier - photomultiplier assembly.
- Fig. 20 Amplifier - differential discriminator.
- Fig. 21 380 volt - 325 ma regulated power supply.
- Fig. 22 HV power supply.



HALF-LIFE OF Rb ACTIVITY PRODUCED BY
14 Mev α 's ON CuBr

MU-5245

Fig. 1



CONVERSION ELECTRONS Rb^{82}

MU-5244

Fig. 2

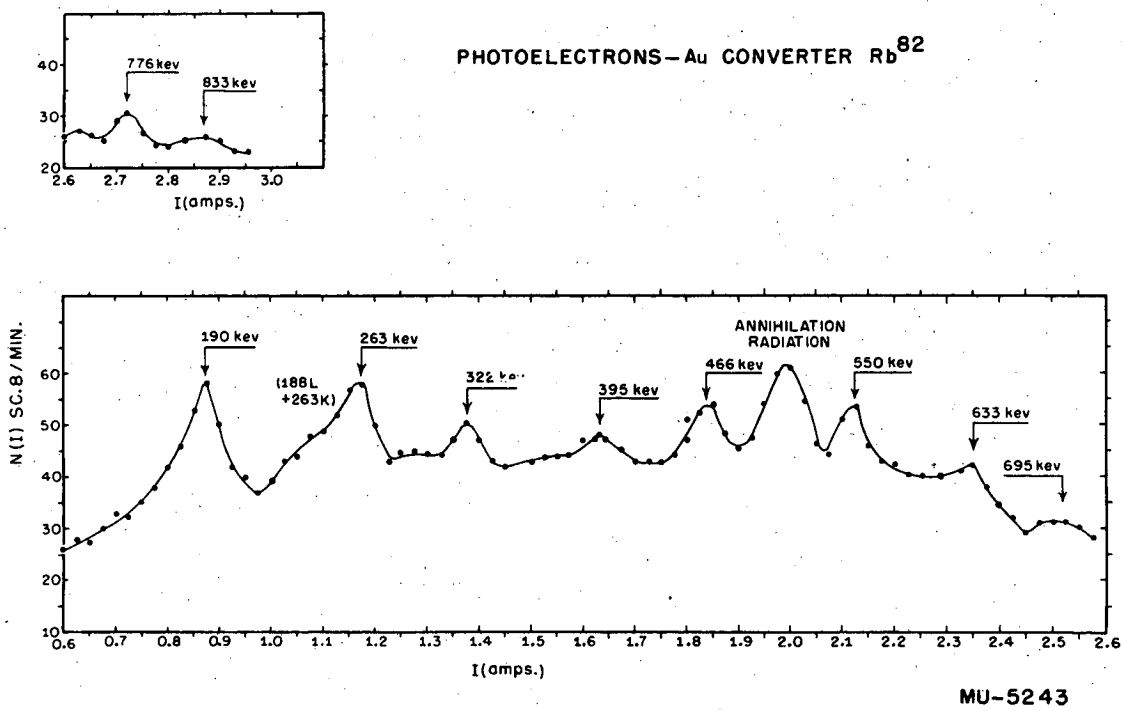


Fig. 3

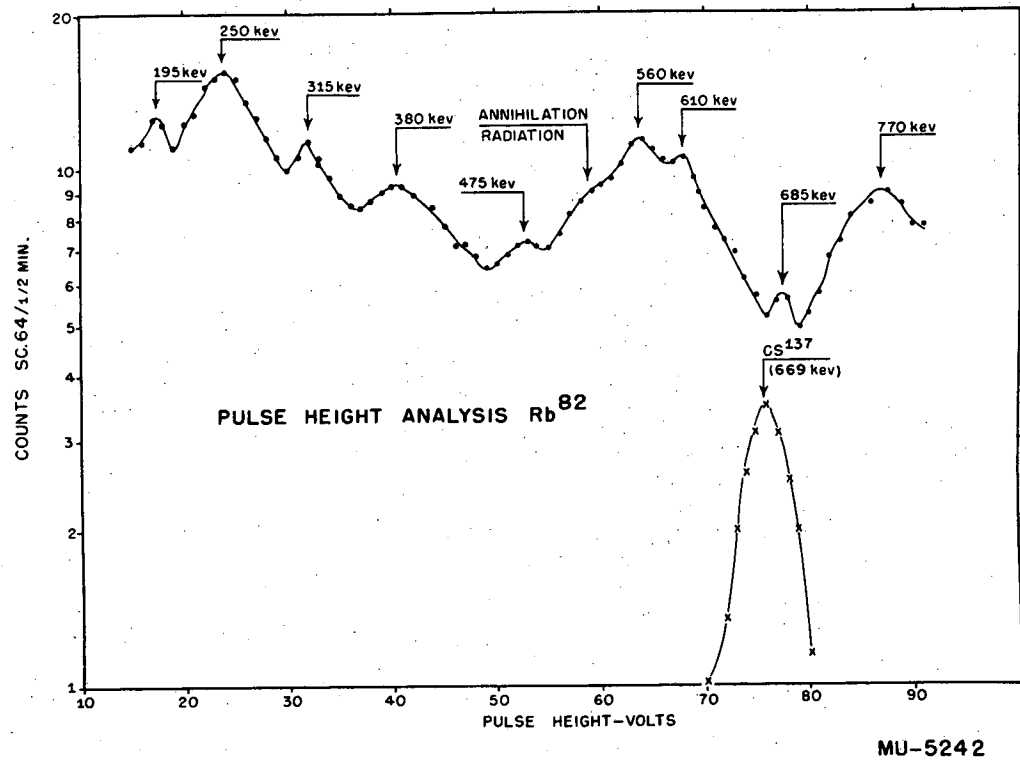
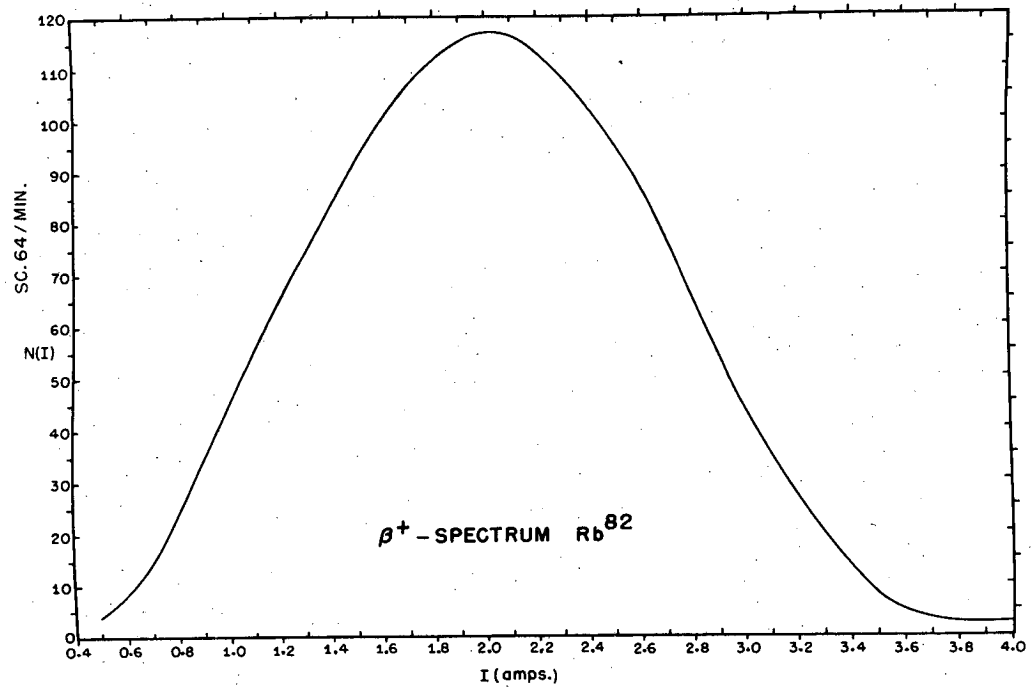


Fig. 4



MU-5241

Fig. 5

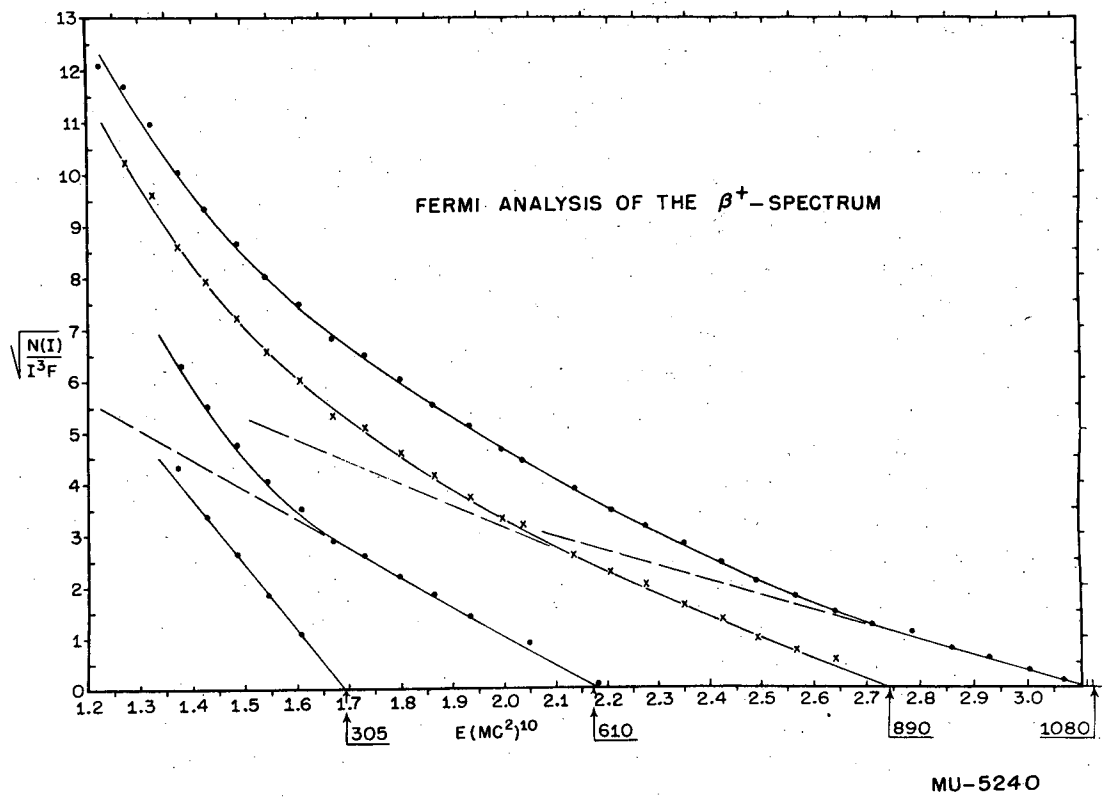
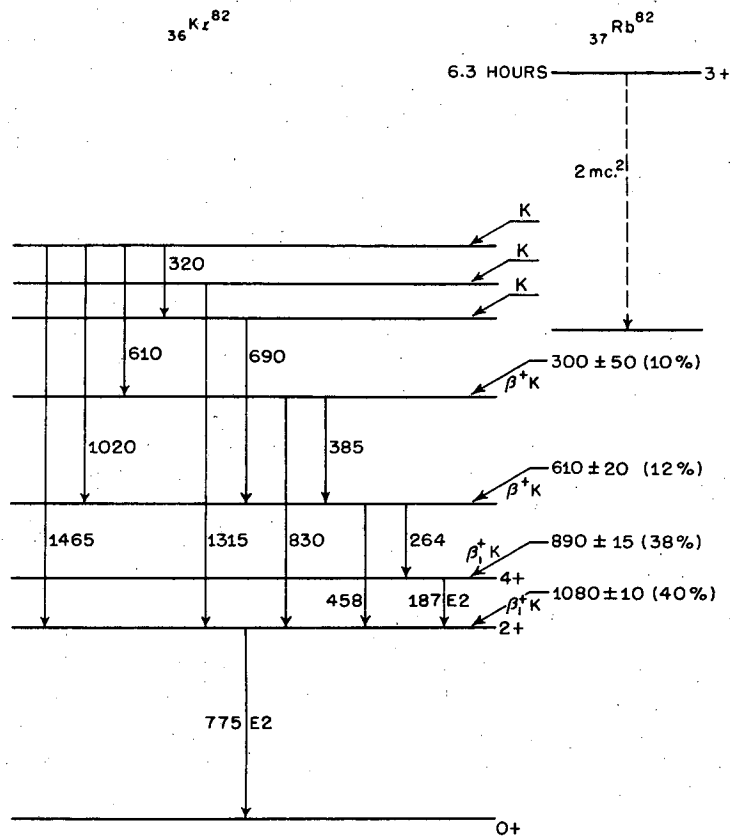


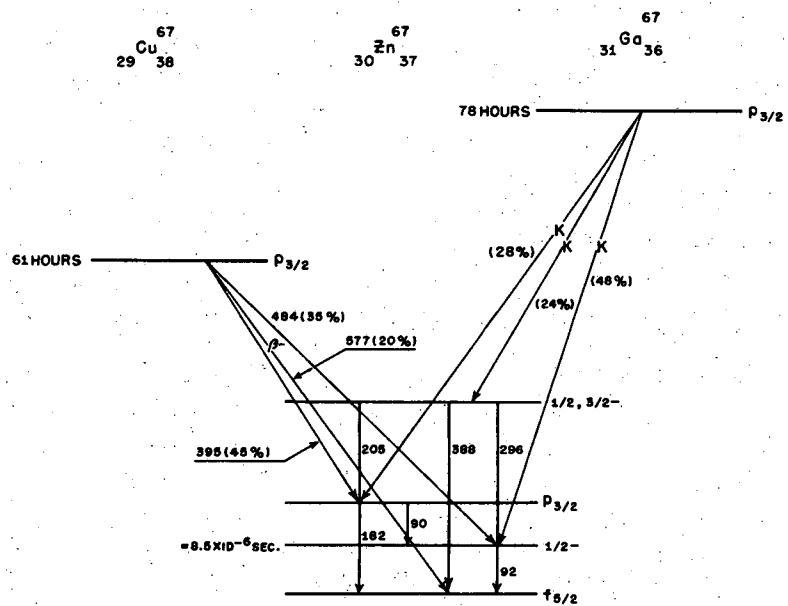
Fig. 6



SUGGESTED DECAY SCHEME FOR Rb^{82}
(PERCENTAGES REFER TO POSITION BRANCHING RATIOS)

MU-5239

Fig. 7



MU-4774

Fig. 8

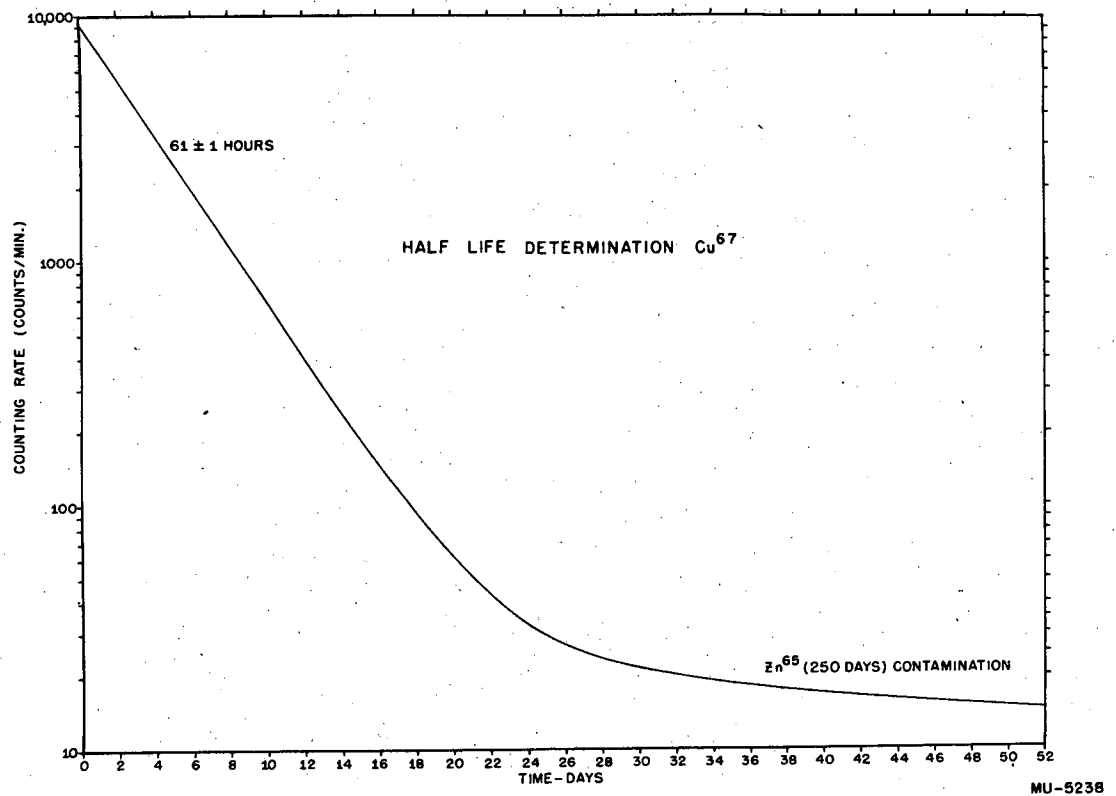


Fig. 9

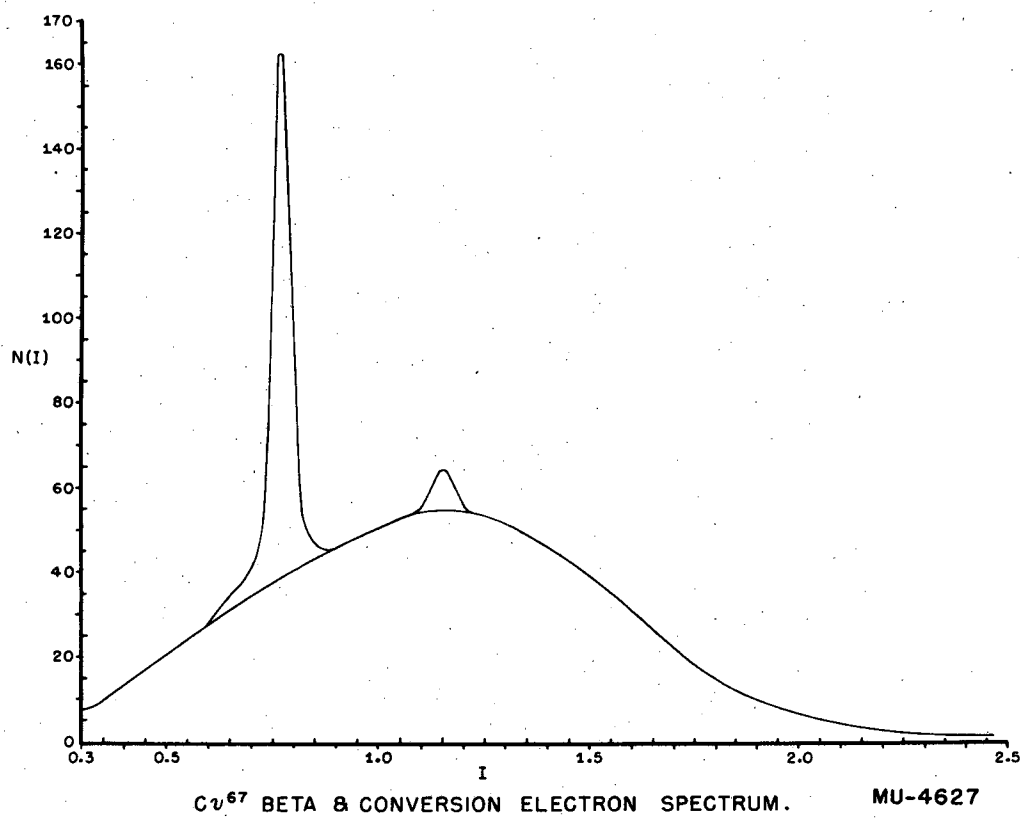
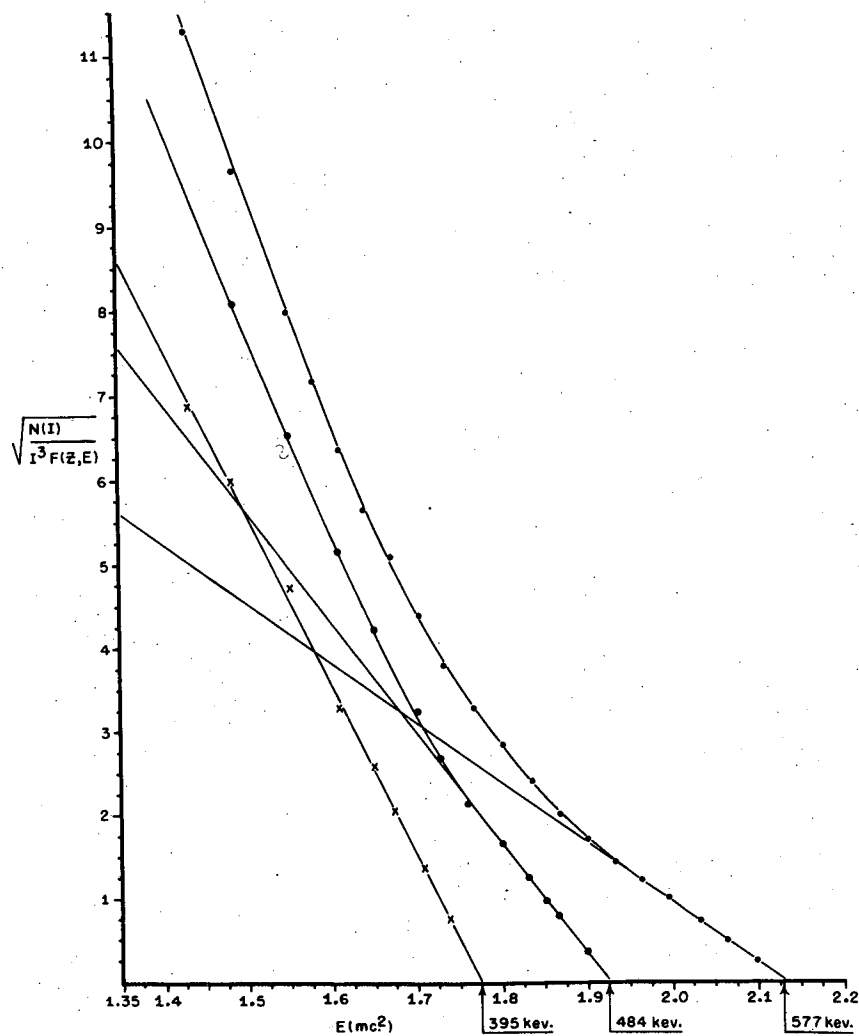


Fig. 10



C^{67} : FERMI ANALYSIS OF BETA SPECTRUM. MU-4628

Fig. 11

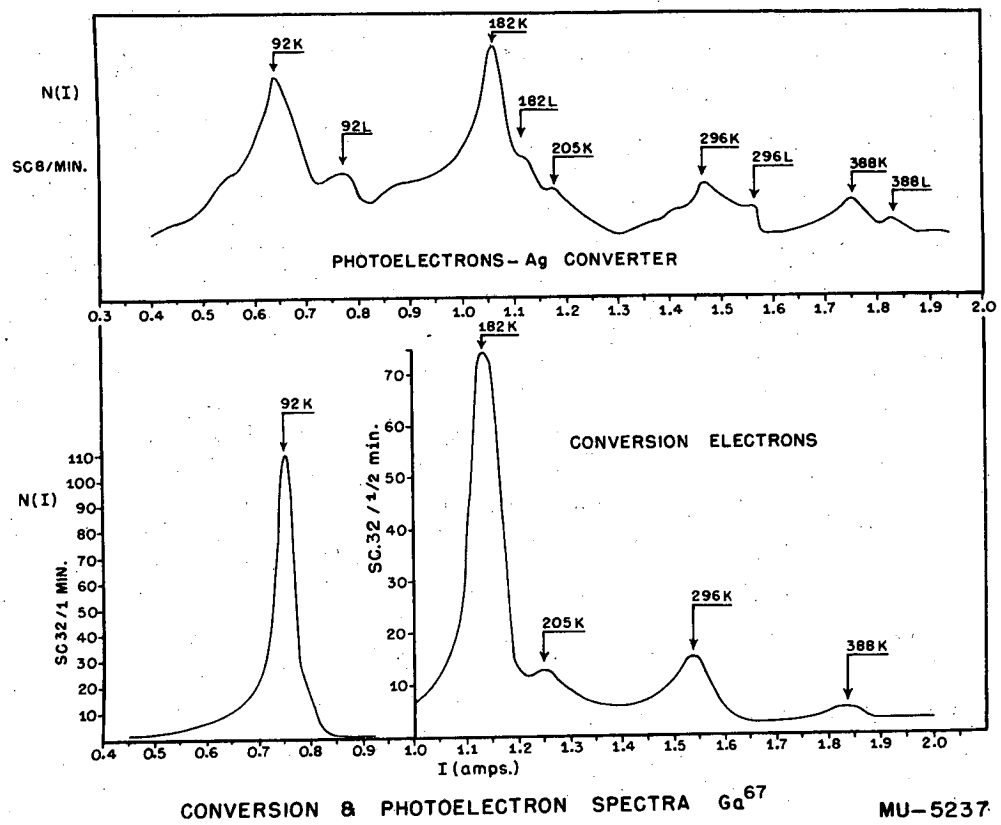
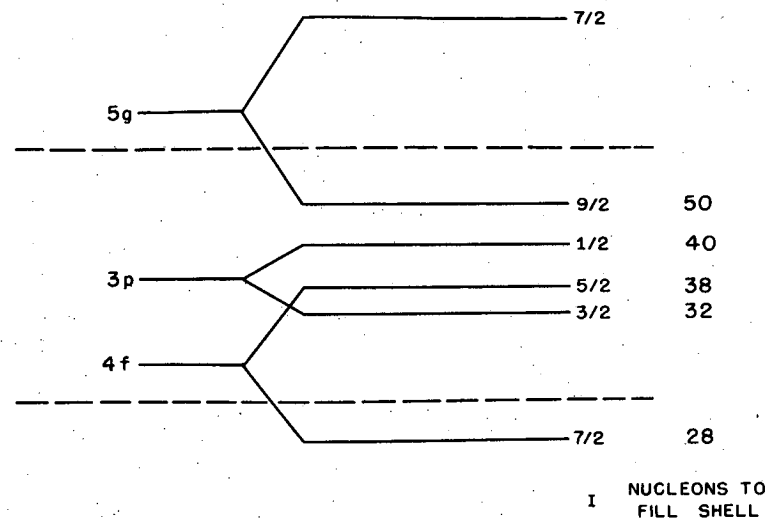
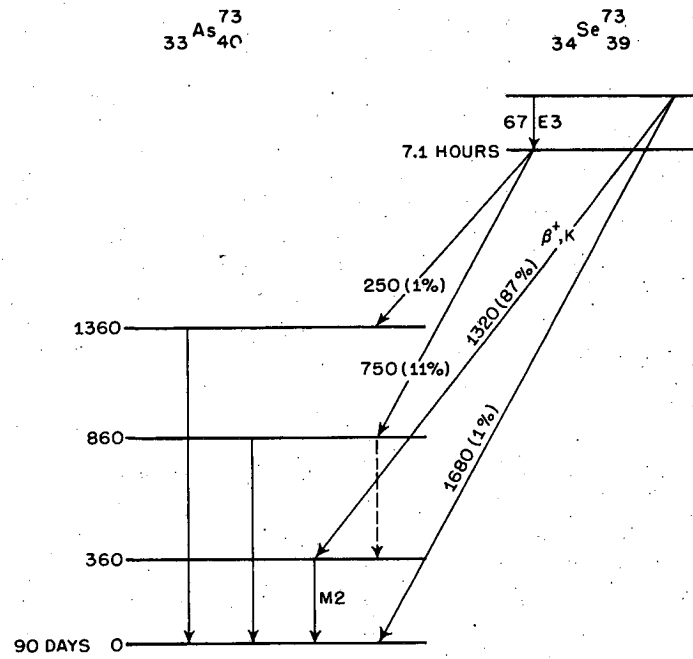


Fig. 12



MU-5236

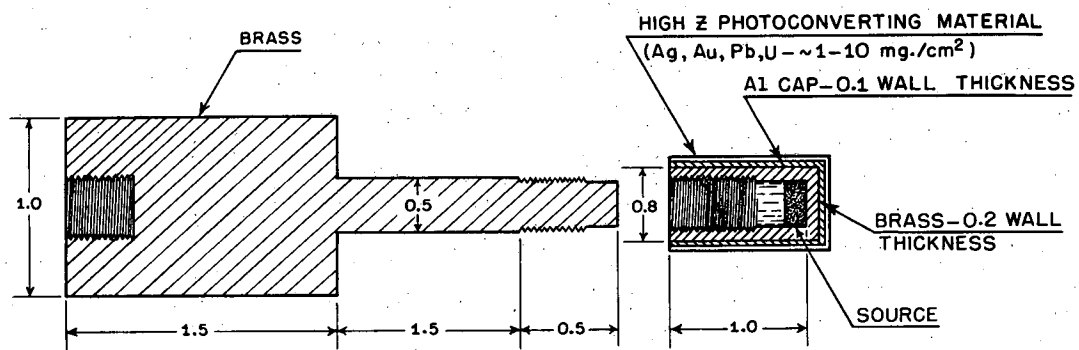
Fig. 13



$^{73}\text{Se} - ^{73}\text{As}$ DECAY SCHEME.

MU-5235

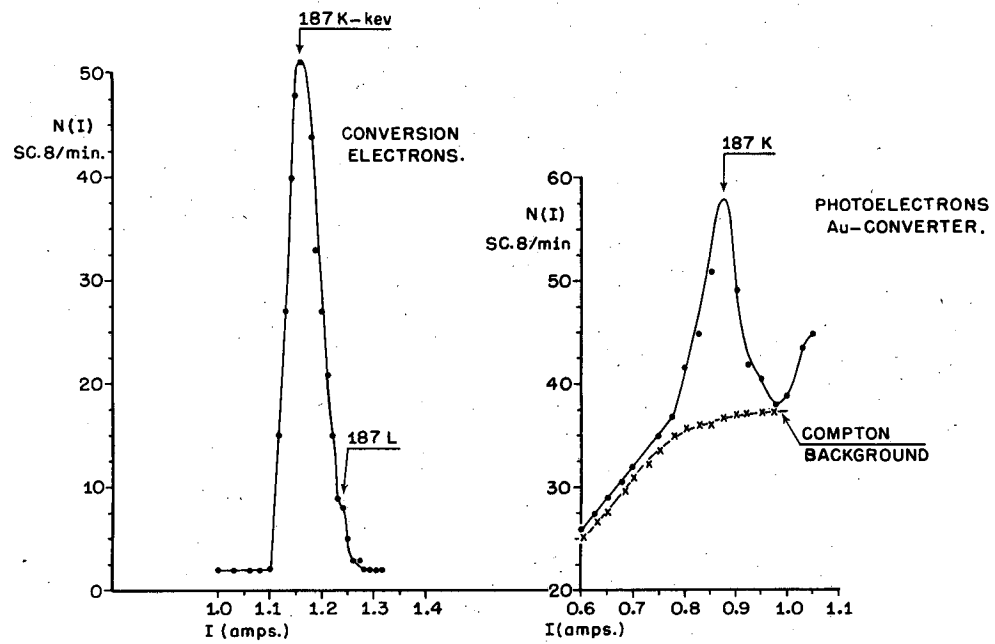
Fig. 14



PHOTOELECTRON CONVERTER
(DIMENSIONS IN CENTIMETERS)

MU-5234

Fig. 15



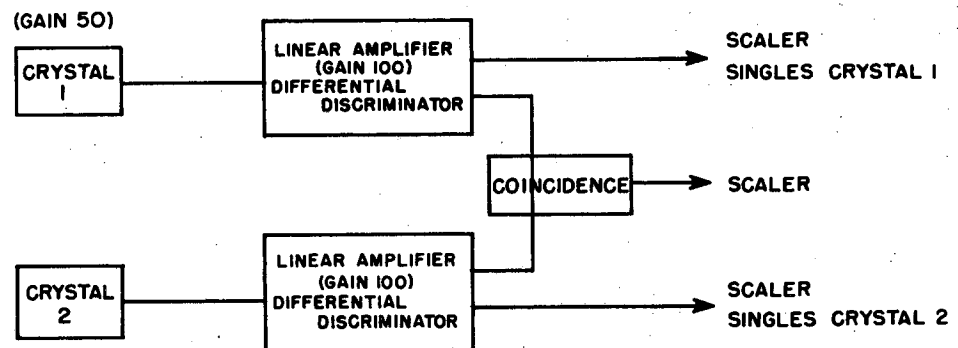
CONVERSION AND PHOTOELECTRON ON PEAKS,
187 kev TRANSITION IN Rb^{82}

MU-5233

Fig. 16

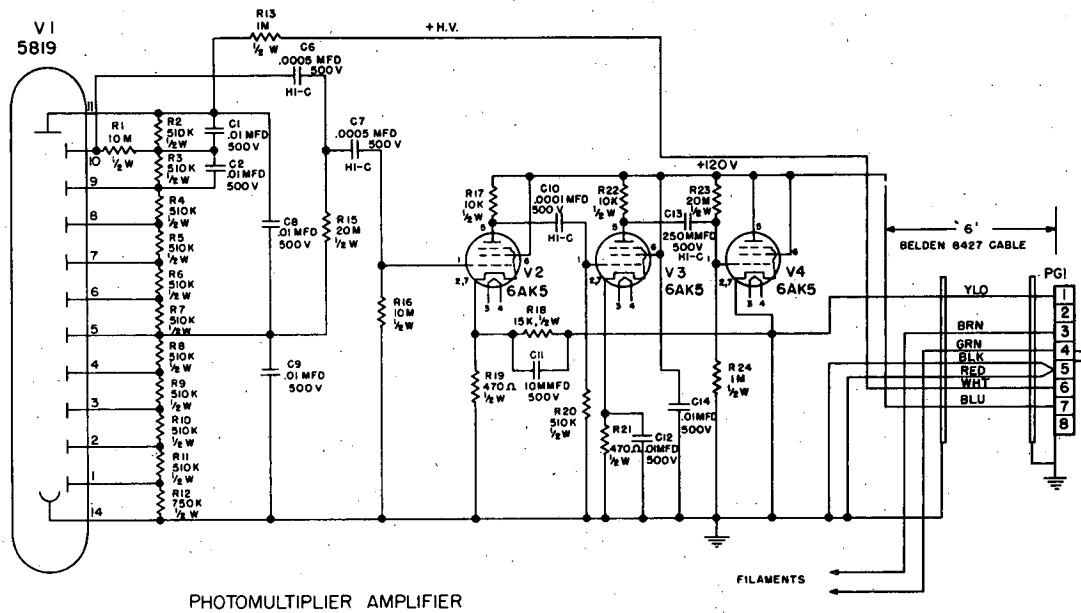
BLOCK DIAGRAM

RCA-5819 PHOTOTUBE
AND PRE-AMPLIFIER ASSEMBLY



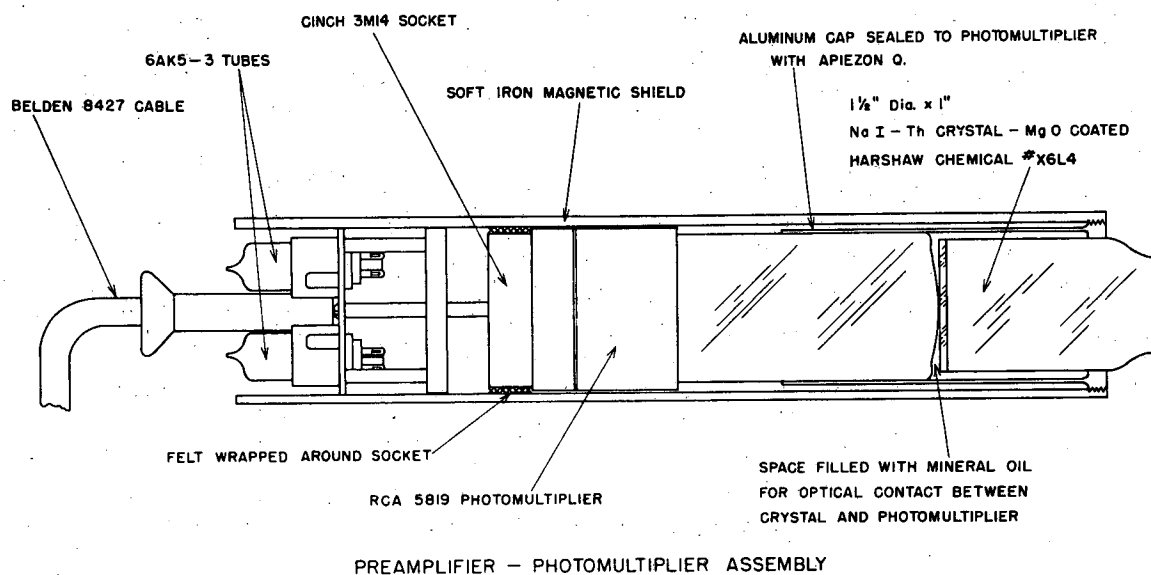
MU-5316

Fig. 17



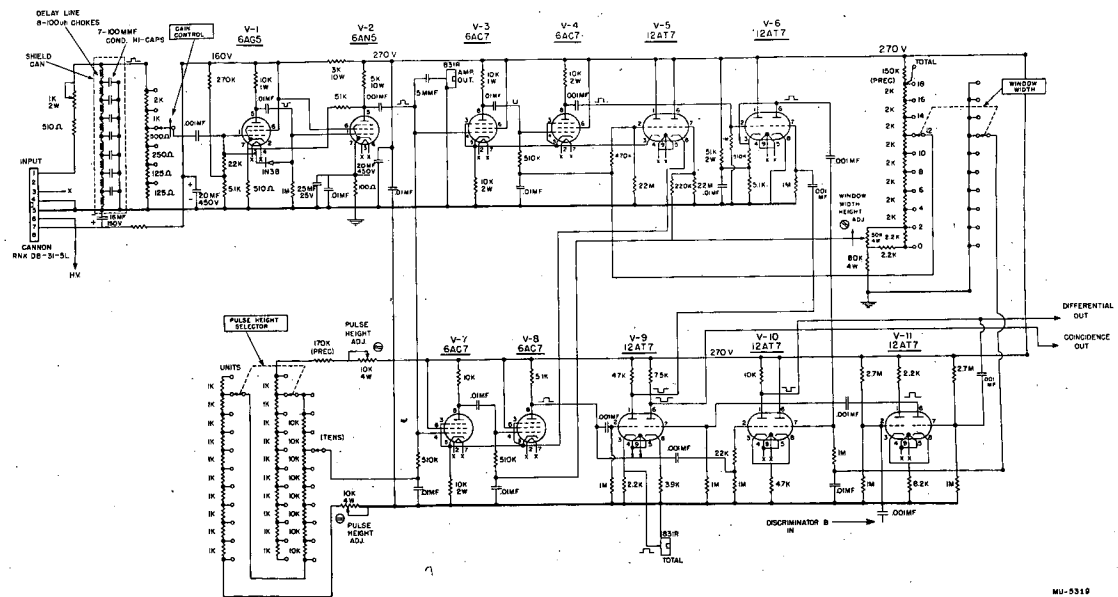
MU-5317

Fig. 18



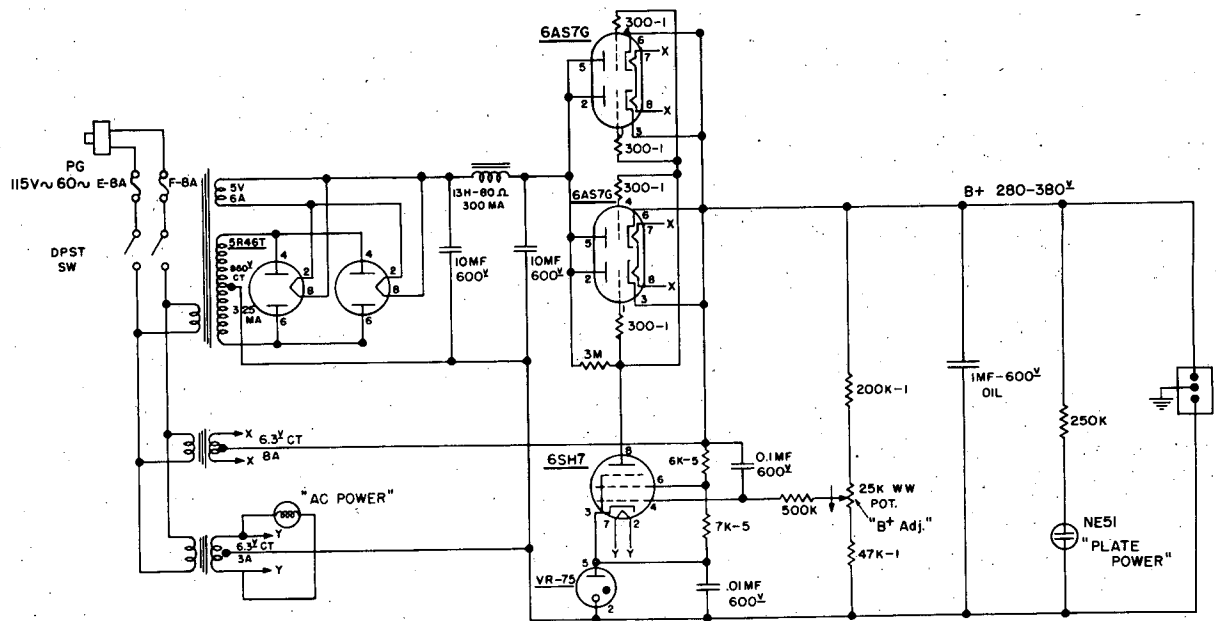
MU-5318

Fig. 19



AMPLIFIER - DIFFERENTIAL DISCRIMINATOR

Fig. 20



380 V - 325 Ma REGULATED POWER SUPPLY

MU-5320

Fig. 21

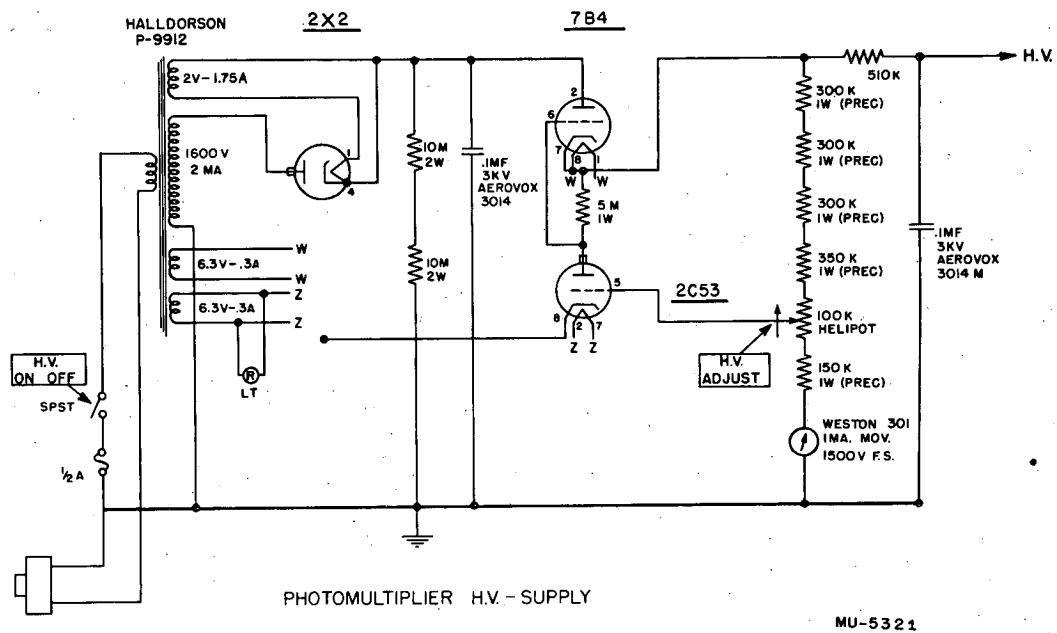


Fig. 22