IFUSP/P-05

SPIN ASSIGNMENTS OF NEUTRON RESONANCES IN ODD-ODD SILVER COMPOUND NUCLEI.

by

A.M.Gonçalves*, N.Lisbona* - Centro Brasileiro de Pesquisas Físicas

S. de Barros** - Instituto de Física da Universidade de São Paulo

To be published in Revista Brasileira de Física

* - Present address: Instituto de Física da Universidade de São Paulo.

** - Research Fellow of the Conselho Nacional de Pesquisas.

Setembro/1973

ABSTRACT

SPIN ASSIGNMENTS OF NEUTRON RESONANCES IN ODD-ODD SILVER COMPOUND NUCLEI

The gamma-rays following the reaction $^{107,109}Ag$ $(n,\gamma)^{108,110}Ag$ have been studied with a time of flight neutron spectrometer.

The method for determining spins of neutron resonances based on the gamma-ray cascade multiplicity dependence on the spin of the initial compound state, previously applied only to even odd target nuclei with relatively high spin, is sucessfully used in the case of silver odd even isotopes with spin 1/2. Single and coincidence γ rays counts were compiled separately, for a neutron energy range from 7 to 440 eV. Spin 0 is ascribed to the 139.7 eV level of ^{110}Ag compound nuclei.

R E S U M O

Os raios γ emitidos após a reação $^{107,109}Ag(n\gamma)$ $^{108,110}Ag$ foram estudados em um espectrômetro de tempo de vôo de neutrons sendo a região de energia escolhida a que vai de 7 a 440 eV. A totalidade das contagens simples e em coincidência dos raios γ foram registradas separadamente e a partir de limiares de energia pré-fixados.

O método de atribuição de spin a ressonâncias de neutrons baseado na dependência da multiplicidade da cascata γ com o spin do estado composto inicial, previamente aplicado a núcleos alvos par-ímpar com spin relativamente alto, foi empregado com sucesso no caso dos isótopos ímpar-par de Ag com spin 1/2.

Spin 0 foi atribuido ao nível 139.7 eV do núcleo composto ^{110}Ag.

SPIN ASSIGNMENTS OF NEUTRON RESONANCES IN ODD-ODD SILVER COMPOUND NUCLEI

INTRODUCTION

It is well known that spin assignments of neutron resonances based on total cross sections and scattering measurements are hard to carry out, especially with weak resonances or high spin nuclei. Transmission techniques using polarized neutron beams, as well as polarized targets, provide a poweful tool for these determinations but require very elaborated apparatus[1][2].

Spin assignments making use of gamma-ray spectrum characteristics are generally reached in a simple and rather streight forward way. They have been perfomed initially by means of intensity measurements of low-energy lines[3][4] or E1 high-energy transitions of gamma-ray spectra[5].

The two-step cascade method[6][7] is useful for spin determinations because it measures the relative intensity of the cascades, proceeding by just two transitions from the compound state to some low-lying level, which maintain a spin and parity dependence on the initial state. Other kinds of cascade measurements[8] or further systematic investigations concerning correlations between resonance parameters[9][10] are also used sucessfully for this purpose.

In addition to the above mentioned methods, Coceva et al [11][12][13][14] also have attempted to determine the spin of neutron ressonances assuming that the average gamma-ray cascade multiplicity maintains a remarkable dependence on the spin of the initial compound state. This dependence is the basis of the gamma-ray cascade multiplicity method, the application of which can be qualitatively understood for even-even compound nuclei, if the initial part of the cascade is governed by a simple statistical relationship and the low-energy states have a band structure. In odd-odd compound nuclei there is no energy gap, so a prompt statistical equilibrium must be reached after neutron capture and a weak dependence on the spin paramater is expected(15).

The present experimental investigation was undertaken with the aim to provide additional information that might allow a wider and more critical utilization of this method.

^{108}Ag and ^{110}Ag nuclei were chosen because they are odd-odd nuclei having low spin (both with $I = 1/2$). These characteristics do not favour the application of the method. On the other hand, spins were also attributed to resonances of ^{108,110}Ag in previous experiments, using several experimental methods: self-induction, transmission and scattering. Such methods provide reliable values in the case of nuclei with low ground state spin. So, the application of the γ ray cascade multiplicity method to the resonances of ^{108,110}Ag and the comparison between its results and those obtained by the remaining methods allow the effective verification of the applicability of the method for nuclei with similar characteristics as $^{108,110}Ag$.

OUTLINE OF THE METHOD

The method in discussion is extensively described in papers(11)(12). We will confine ourselves here to a brief summary.

The gamma-ray cascade multiplicity method consists of the study of the cascade originating from the de-excitation of the compound nucleus formed by neutron capture. The assumption that the difference between the spin of the initial state and the spin of the final state after each transition must be 1 or 0 is based on the fact that dipole radiation prevails in γ ray capture spectra, except in transitions between low-lying levels.

Such conclusions justify the hypothesis that the spin difference ΔJ between the initial and final states of the cascade affects the average multiplicity, if isomeric states are not present. Indeed, in several nuclides (16) variations of as much as 25% on multiplicity have been found.

A quantity directly related to average multiplicity can be obtained compiling simultaneously, for s-wave resonances, the single and coincidence counting rates from two gamma-ray detectors placed symmetrically to the target. Since good energy resolutions is not required, very efficient gamma-ray detectors can be used.

Single and coincidence counting rates (A_γ^S and A_γ^C)

related to a resonance λ are equal to:

$$A_\lambda^S = k_J^S \cdot I_o(E_n) \cdot Y_\lambda(E_n,E_o,\tau_o,\Gamma)$$

$$A_\lambda^C = k_J^C \cdot I_o(E_n) \cdot Y_\lambda(E_n,E_o,\tau_o,\Gamma)$$

where:

$I_o(E_n)$ - incident neutron flux with energy E_n, integrated over the target surface;

$Y_\lambda(E_n,E_o,\tau_o,\Gamma)$ - number of radiative capture per incident neutron observed at the neutron energy E_n;

E_o,τ_o and Γ - parameters of the resonance λ;

k_J^S and k_J^C - single and coincidence average numbers of counts per radiative capture.

The coefficiente k_J^C depends on the cascade characteristics, that is, on the average multiplicity r_J. Consequently, it is affected directly by the spin J.

The ratio r_J of $A_\lambda^S$to A_λ^C corresponds to the ratio of the coefficients k_J^S and k_J^C, since both counting rates are proportional to the same factor $I_o(E_n) \cdot Y_\lambda(E_n;E_o,\tau_o,\Gamma)$:

$$r_J = \frac{A_\lambda^S}{A_\lambda^C} = \frac{k_J^S \cdot I_o(E_n) \cdot Y_\lambda(E_n,E_o,\tau_o,\Gamma)}{k_J^C \cdot I_o(E_n) \cdot Y_\lambda(E_n,E_o,\tau_o,\Gamma)} = \frac{k_J^S}{k_J^C}$$

The ratio r_J, depends strongly on the spin resonance through the average multiplicity. This results in the separation of its values into two different groups, related to the two possible spin values.

The determination of the r_J - value distribution, then, allows spin assignments for the s-wave resonances.

The absolute r_J values, because of its dependence on the characteristics of the detection system used, are normalized relative to the average value $\bar{r}$, that is:

$$\bar{r} = \frac{\langle r_0\rangle + \langle r_1\rangle}{2}$$

$$R_J = \frac{r_J}{\bar{r}}$$

where $\langle r_0\rangle$ and $\langle r_1\rangle$ are the average values of the ratios r_J, each one associated to a spin resonance family.

It is then possible to define the spin effect index as being equal to the difference between the normalized average values:

$$d = \langle R_0\rangle - \langle R_1\rangle$$

EXPERIMENTAL CONDITIONS

Our measurements were obtained using the C.B.P.F. eletron linear accelerator with:

electron energy - 28 MeV

r m s current - 25 μA

pulse width - 500 ns

repetition frequency - 360 Hz

The experimental set-up is shown in Fig. 1 . Neutrons are produced by Bremsstrahlung radiation in a water cooled Pb target, 6.5 cm high and 2.5 cm in diameter, as shown in Fig. II. These neutrons, after being moderated by a 2 cm thick polyethylene slab, strike a silver sample placed at about 12 m from the neutron moderator. Pb absorbers were conveniently placed on the axis of the neutron beam in order to reduce the gamma flash due to Bremmstrahlung in the target and the fast neutron flux viewed by the detector.

The detection system is shown in Fig. III.

Two NaI(Tℓ) crystals were used, with 12,5 cm x 12,5 cm, connected to 56 AVP photomultipliers. A 1mm thick lead foil and a 1,5 cm absorber of borated paraffin were used to shield the crystals from scattered neutrons in the detectors and in surrounding building materials.

In order to get a better separation between the two groups of R_J values, energy thresholds in the gamma-ray measurements are introduced in both detection systems (E_s and E_c). The choice of their most convenient values depends on the nuclei studied. There is a compromise between the emphasis given to the effect of spin dependence by the choice of convenient thresholds values and the internal dispersion of the two R_J groups due to the reduction of the number of transitions which contribute to the cascade.

The selected value of E_s was obtained with the aid of Fig. IV and the data of ref.[11]. (The threshold values indicate in Fig. IV always allowed a complete separation between the two groups of resonance).

The E_S and E_C values were 2.5 MeV and 300 KeV respectively. The choice of the E_S = 2.5 MeV energy threshold is justified by the fact that, for this value, the ratio $\frac{<R_0>}{<R_1>}$ has a well-marked spin effect. Although intensity considerations would favour a coincidence energy threshold as low as possible, its value must be such that it prevents several low energy effects which tend to increase the random coincidence counting rate.

Background measurements under comparable conditions were obtained and subtracted from the spectra.

The radiative background caused by a small superposition of the wings of close resonances was also subtracted and areas were calculated using only a narrow region near the peak of the resonances.

Fig. V and VI show the typical time-of-flight neutron resolution obtained.

The neutron energy range was 7-440 eV. However, in the coincidence spectrum it was only possible to analyse the peak resonances up to 210 eV, due to insufficient statistics in the high energy region of this spectrum.

RESULTS AND DISCUSSION

The results of the quantitative analysis of spectra and spin assignments are listed in table I. The first two columms indicate the resonance energies and the respective isotopes. The normalized ratio R_J are shown in the third columm, while the fourth one shows the deviation from the third columm value $<R_1>$ or $<R_0>$. Our results are shown in the last columm, spin 0 being assigned to the 139.7 ± 0.2 eV level.

In order to facilitate resonance identification table II shows energy values obtained in this experient and those compiled from ref. 20.

In table III, the results of present work are compared to those of previous measurements. Resonances marked by * are p-wave levels and hence were not analysed in present work. The 40.1 ± 0.1, 41.5 ± 0.1 and 173.1 ± 0.2 eV resonances could not be analysed. The two first ones were not sufficiently resolved in the coincidence count spectrum, while the third one overlaps with the 169.8 ± 0.2 eV. The 83.5 ± 0.2 eV resonance which is extremely weak, was not observed in our spectra. As can be seen from this table there is an encouraging agreement between our results and the current experimental information.

It is also worth noticing that a large number of different gamma-rays were collected from each resonance even using our experimental conditions. Thus, Porter and Thomas fluctuations of $\Gamma_{\lambda i}$[17] are negligible. There was no marked isotope effect in $^{108,110}Ag$ radiation widths[18] and the characteristic parameters of each one are the same[19].

The R_J values for different resonances are grouped around two values, Fig. VII, with a dispersion probably due to statistical fluctuations in the partial radiative widths. The relative separations of the two resonance groups is 23%.

CONCLUSION

For silver odd-odd compound nuclei, the clear separation between the two R_J- value groups and the agreement of our results with those of other authors show the sucessful application of the method. Spin 0 was assigned to the 139.7 ± 0.2 eV resonance. Such assignment could be made in this paper since the γ ray cascade multiplicity method only needs capture measurements and also since this resonance has a large Γ_γ value (Γ_γ = 133 ± 46 meV)[20]. Besides that, its extremely small Γ_n value ($2g\Gamma_n$ = 2.2 ± 0.3 meV)[20] makes the application of methods based on transmission measurements extremely difficult.

The excellent results obtained in the present experiment stimulate future applications of the method.

Also, it would be desirable that more experimental information could be made availably in order to obtain a definitive conclusion as to the validity of the extension of the method. If it shows applicability to all nuclei, it will probably be the most effective tool (up to now) for spin assignments of low energy neutron resonances [15]. This method has also been applied to other odd-odd compound nuclei such as ^{76}As and ^{134}Cs, and these results will be published in a later paper.

REFERENCES

1. EICHLER,J. & DJADALI,F.- Measurement of the average circular γ-polarizarization and determination of spins for compound states formed in thermal neutron capture. Nucl.Phys.,A147:150-160, 1970.

2. RAYNAL,J.- Geometrical properties of nuclear reactions. Saclay, Centre d'Ětudes Nucleaires, 1972. 118p. (CEA-N-1529).

3. DRAPER,J.E.; FENSTERMACHER,C.A. & SCHULTZ,H.L.- Variations in spectra of resonance neutron capture gamma-rays in indium. Phys.Rev.,111:906-12, 1958.

4. BHAT,M.R.; CHRIEN,R.E.; GARBER,D.I. & WASSON,O.A.- Gamma-rays from thermal and resonance neutron capture in Sb^{121} and Sb^{123}. Phys.Rev.,2C:1115-25, 1970.

5. LANDON,H.H., & RAE,E.R.- Gamma radiation from resonance neutron capture in mercury. Phys.Rev.,107:1333-36, 1957.

6. ARGONNE NATIONAL LABORATORY, Ill. - Physics Division Summary report for April-May, 1960; by L.M.Bollinger and E.R. Rae. Argonne, 1960. 48p. (Contract W-31-109-eng-38) (ANL-6146).

7. BOLLINGER,L.M.; COTE,R.E. & JACKSON,H.E.- Determination of spins of neutron resonances from two-step gamma--ray cascade. In: Congrès International de Physique Nucleaire. Paris, 1964. v.2,p.673-4.

8. LONE,M.A.; CHRIEN,R.E.; WASSON,O.A.; BEER,M.; BHAT,M.R. & MUETHER,H.R. - Resonant and nonresonant capture of slow neutrons in $Tm^{169}(n,\gamma)$ Tm^{170}. Phys.Rev., 174:1512-24, 1968.

9. CORGE,C.; HUYNH,V.D.; JULIEN,J.; MORGENSTERN,J. & NETTER,F. In: SPAEPEU,J.,ed.- Neutron time of flight methods. Brussels, Euratom, 1961. p.167.

10. RAE,E.R. & BLOCK,R.C.- Neutron scattering and capture cross-section measurements. In: EXPERIMENTAL NEUTRON RESONANCE SPECTROSCOPY; edited by J.A. Harvey. New York, Academic Press, 1970. cap. 3, p.155-233.

11. COCEVA,C; CORVI,F.; GIACOBBE,P. & CARRARO,G.- A method of spin assignment of neutron resonances based on capture gamma-ray detection. Nucl.Phys.,A117:586-614, 1968.

12. GIACOBBE,P.; STEFANON,M & DELLACASA,G.- Numerical simulation of the γ decay of a nucleus from a excited state. Roma, Comitato Nazionale per l'Energia Nucleare, 1968. 22p. (RT/FI-(68)20).

13. COCEVA,C.; CORVI,F.; GIACOBBE,P. & STEFANON,M.- J-dependence of level density in ^{180}Hr and ^{178}Hr from statistical properties of series of resonances with assigned spin. In: INTERNATIONAL CONFERENCE ON STATISTICAL PROPERTIES OF NUCLEI,Albany, 1971. New York, Plenum Publ.Corp.,1972. p.447-54.

14. CORVI,F.; STEFANON,M; COCEVA,C. & GIACOBBE,P.- Spin assignments of ^{235}U neutron resonances and estimate of (Γ_f) for $J^\pi = 3^-$ and 4^- levels. In: CONFERENCE EUROPÉENE DE PHYSIQUE NUCLEAIRE,Aix-en-Provence, 1972. (Abstract in Nucl.Sci.Abstr.,27:26343, 1973.

15. BOLLINGER,L.M.- Gamma-rays from neutron capture in resonances. In:EXPERIMENTAL NEUTRON RESONANCE SPECTROSCOPY, edited by J.H.Harvey. New York, Academic Press, 1970. cap.4, p.235-345.

16. DRAPER,J.E. & SPRINGER,T.E.- Multiplicity of resonance neutron capture gamma-rays. Nucl.Phys.,16:27-37, 1960.

17. PORTER,C.E. & THOMAS,R.G.- Fluctuations of nuclear reaction widths. Phys.Rev.,104:483-91, 1956.

18. BOLOTIN,H.H. & NAMENSON,A.I.- Low-lying excited states of Ag^{108} and Ag^{110} populated in thermal-neutron--capture reactions. Phys.Rev.,157:1131-36, 1967.

19. BARROS,S.de; HUYNH,V.D.; JULIEN,J.; MORGENSTERN,J. & SAMOUR,C.- Dētermination du spin et des paramētres des rēsonances pour ^{107,109}Ag+n, ^{169}Tm+n, Pt+nDE4 eV ā 830 eV. NuclPhys.,A131:305-342, 1969.

20. GOLDBERG,M.D. et alii - Neutron cross sections. Volume IIB Z=41To60. Upton, Brookhaven National Laboratory, 1966. (BNL-325(2nd.ed.)(Suppl.2)(Vol.2B).

21. GARG,J.B.; RAINWATER,R. & HAVENS JR.,W.W.- Neutron Resonance spectroscopy. V. Nb,Ag,I and Cs. Phys.Rev.,137B:547-75, 1965.

22. RAE,A.E.; COLLINS,E.R.; KINSEY,B.B.; LYNN,J.E. & WIBLIN,E.R.- An analysis of slow neutron resonances in silver. Nucl.Phys.,5:89-121, 1958.

23. SINGH,P.P.- Slow-neutron resonance scattering in silver and thulium. Bull.Am.Phys.Soc.,8:334,1963. (Abstract K3).

24. MOXON,M.C. & RAE,E.R.- In: SPAEPEU,J.,ed.- Neutron time-of-flight methods. Brussels, Euratom, 1961. p.439.

25. FLUHARTY,R.G.; SIMPSON,F.B. & SIMPSON,O.D.- Neutron resonance measurements of Ag, Ta and U^{228}. Phys. Rev.,103:1778-86,1956.

26. CHRIEN,R.E.- Neutron resonance parameters of Ag^{109}. Phys.Rev.,141:1129-32, 1966.

27. DESJARDINS,J.S.; ROSEN,J.L.; HAVENS JR., W.W. & RAINWATER,J.- Slow neutron resonance spectroscopy. II - Ag,Au,Ta. Phys.Rev.,120:2214-26, 1960.

28. ASGHAR,M; MOXON,M.C. & CHAFFEY,C.M.- The low energy neutron resonance parameters of $^{107,109}Ag$, ^{169}Tn, ^{197}An, ^{159}Tb and ^{165}Ho. In: CONFERENCE ON THE STUDY OF NUCLEAR STRCTURE WITH NEUTRONS, Antwerp, 1965. Paper nº 65.

ENERGY (eV)	Isotope	R_J	$R_J - \langle R_J \rangle$	J
16.30 ± 0.05	107	1.09 ± 0.02	- 0.02	0
30.4 ± 0.1	109	0.90 ± 0.02	+ 0.01	1
44.8 ± 0.1	107	1.12 ± 0.05	+ 0.01	0
51.3 ± 0.1	107	0.88 ± 0.02	- 0.01	1
55.6 ± 0.2	109	1.13 ± 0.03	+ 0.02	0
70.6 ± 0.2	109	0.85 ± 0.02	- 0.04	1
87.4 ± 0.2	109	0.87 ± 0.03	- 0.02	1
133.9 ± 0.2	109	0.89 ± 0.02	0.00	1
139.7 ± 0.2	109	1.10 ± 0.07	- 0.01	0
144.2 ± 0.2	107	1.13 ± 0.06	+ 0.02	0
202.5 ± 0.2	107	0.91 ± 0.04	+ 0.02	1
209.6 ± 0.2	109	0.92 ± 0.04	+ 0.03	1

TABLE I

$\langle R_J \rangle$ is the average value associated to the J spin resonance family.

ENERGY (eV) This work	ENERGY (eV) Ref.(20)
16,3 ± 0,1	16,30 ± 0,05
30,3 ± 0,2	30,4 ± 0,1
40,5 ± 0,3	40,1 ± 0,1
41,6 ± 0,3	41,5 ± 0,1
44,9 ± 0,3	44,8 ± 0,1
51,6 ± 0,4	51,3 ± 0,1
55,9 ± 0,5	55,6 ± 0,2
71,4 ± 0,7	70,6 ± 0,2
88,0 ± 0,9	87,4 ± 0,2
134 ± 2	133,9 ± 0,2
139 ± 2	139,7 ± 0,2
144 ± 2	144,2 ± 0,2
173 ± 3	173,1 ± 0,2
201 ± 3	202,5 ± 0,2
208 ± 3	209,6 ± 0,2
249 ± 4	251,3 ± 0,3
261 ± 5	264,7 ± 0,3
287 ± 5	290,9 ± 0,3
311 ± 6	310,9 ± 0,2
323 ± 6	327,8 ± 0,3
356 ± 7	361,8 ± 0,2
381 ± 8	387,0 ± 0,4
397 ± 9	398,0 ± 0,4
420 ± 9	428,4 ± 0,4

TABLE II

E_o (eV)	Garg (21)	Rae (22)	Singh (23)	Moxom (24)	Fluharty (25)	Chrien (26)	Desjardins (27)	Asghars (28)	This Work
16.3 ± 0.5		0	0	0				0	0
30.4 ± 0.1		1	1	1		(1)		1	1
40.1 ± 0.1		1		1		(1)		1	
41.5 ± 0.1				1				1	
44.8 ± 0.1				0				0	0
51.3 ± 0.1		1	1	1		(1)		1	1
55.6 ± 0.2		0	0	0	0	(0)		0	0
70.6 ± 0.[illegible]		1	1	1	1	(1)		1	1
83.5 ± 0.2									
87.4 ± 0.2		0		0		(1)		1	1
106.3 ± 0.2							*		
110.9 ± 0.2							*		
133.9 ± 0.2	1	1	1	1		(1)	1	1	1
139.7 ± 0.2									0
144.2 ± 0.2				(0), (1)			(0)	0	0
169.8 ± 0.2							*		
173.1 ± 0.2			1	1		(1)	1		
183.6 ± 0.2	*						*		
202.5 ± 0.2				1			1	1	1
309.6 ± 0.2				1		(1)	1	1	1

TABLE III

FIGURE AND TABLE LEGEND

Fig. I - Experimental Set-up.

Fig. II - Pb Target.

A - Electron beam

B - Window

C - Safety window

D - Pressurer

E - Wings

F - Water in

G - Thermometer

H - Water out

Fig. III - Detection System Block Diagram.

Fig. IV - Variation of the ratio $\frac{\langle R_0 \rangle}{\langle R_1 \rangle}$ as function of gamma-ray energy threshold for single counts (E_s).

Fig. V - Single gamma-ray spectrum.

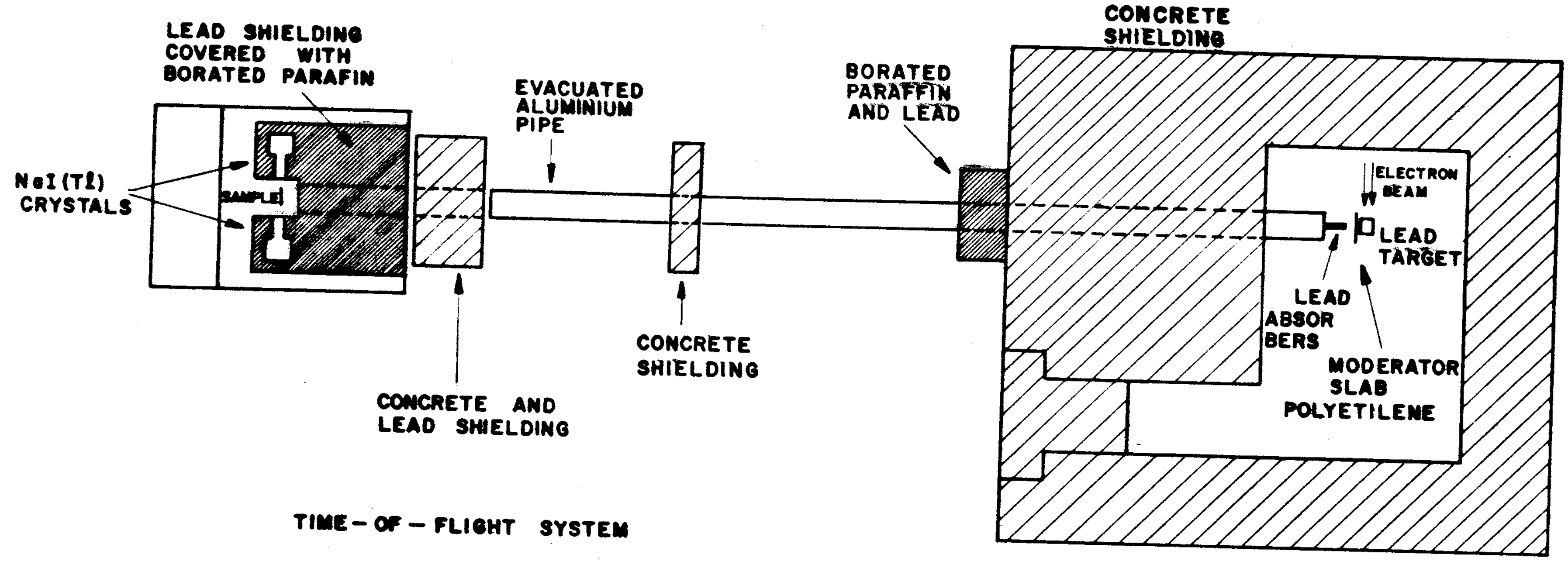
Fig. VI - Coincidenfe gamma-ray spectrum.

Fig. VII - Frequency distribution of R_J values for 0 and 1 spin resonances.

Table I - Spin assignments by the cascade multiplicity method.

Table II - Resonance Identifications.

Table III - Comparison among the spin atributions of different authors.



TIME – OF – FLIGHT SYSTEM

Fig. I

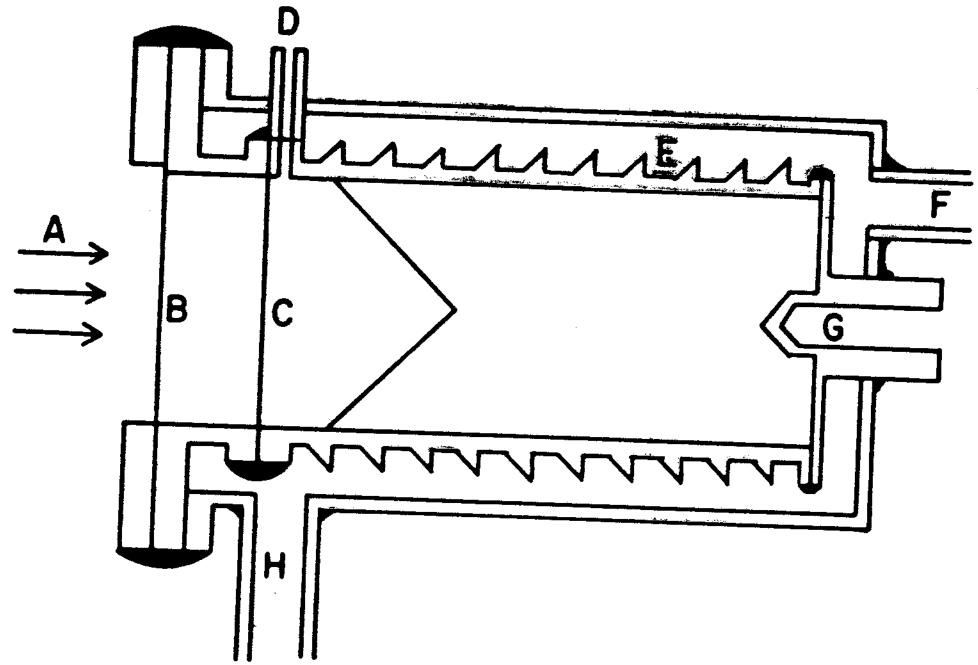


Fig. II

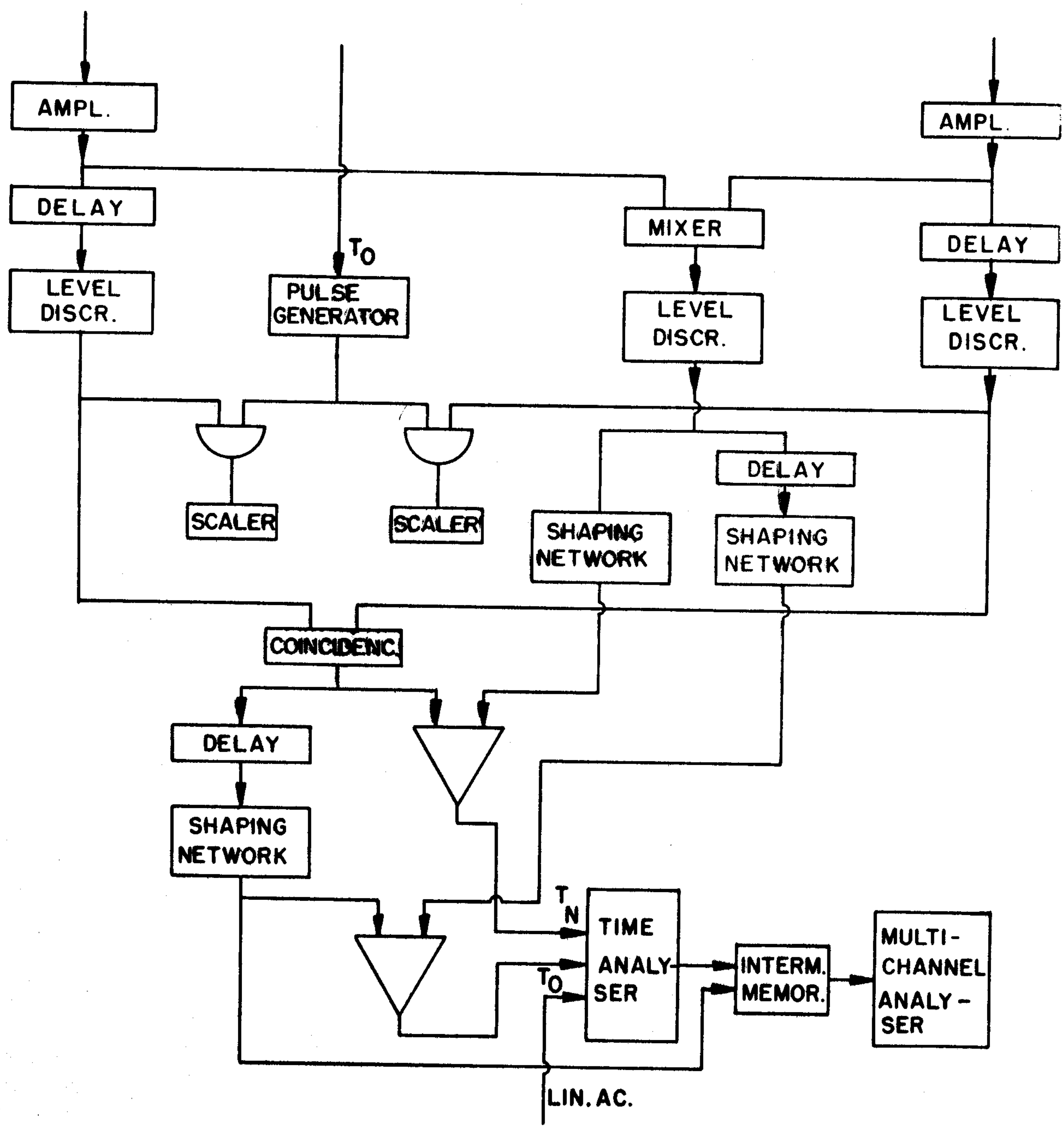

AMPL.
DELAY
LEVEL DISCR.
T_O
PULSE GENERATOR
MIXER
LEVEL DISCR.
AMPL.
DELAY
LEVEL DISCR.
SCALER
SCALER
SHAPING NETWORK
DELAY
SHAPING NETWORK
COINCIDENC.
DELAY
SHAPING NETWORK
T_N
T_O
TIME ANALYSER
INTERM. MEMOR.
MULTI-CHANNEL ANALYSER
LIN. AC.

Fig. III

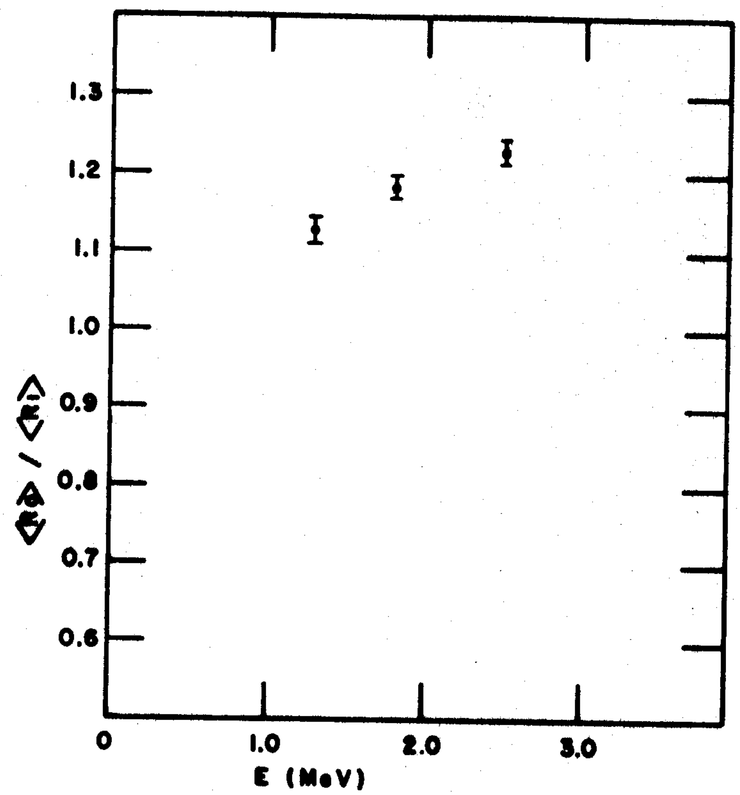
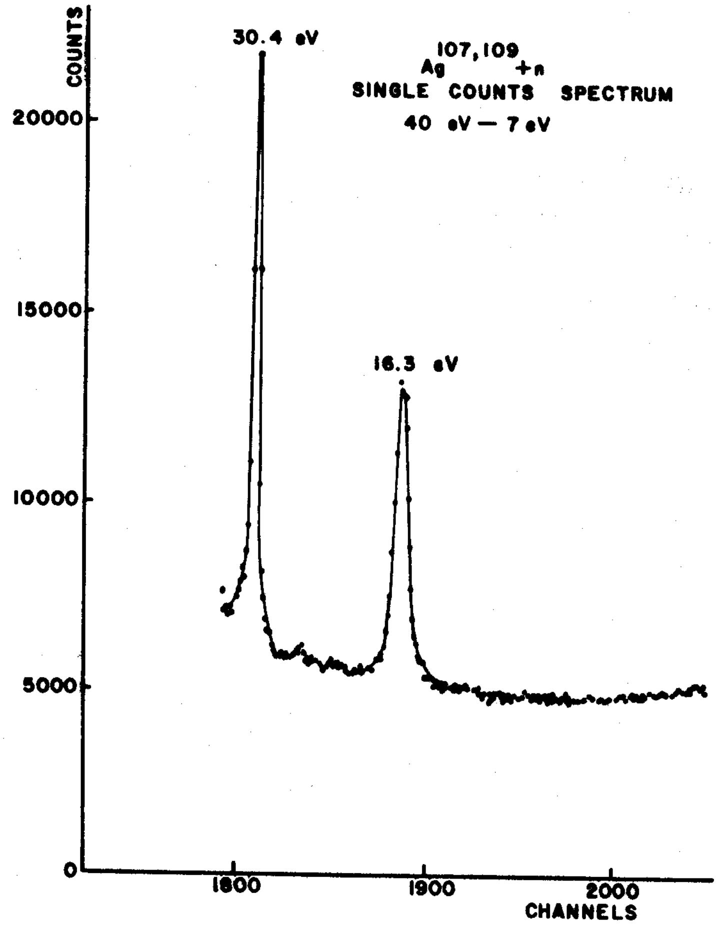
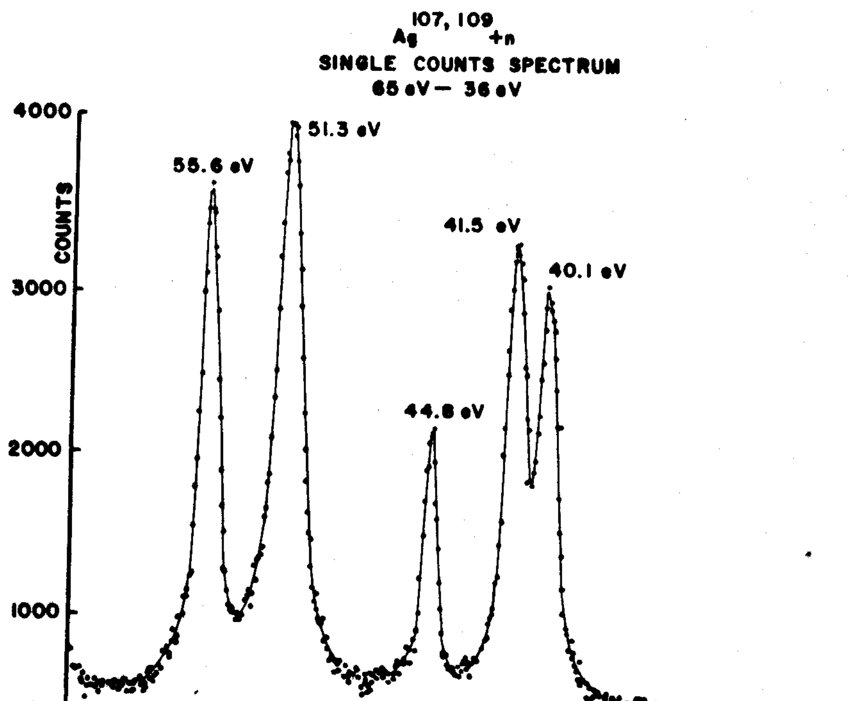


Fig. IV



COUNTS
30.4 eV
$Ag^{107,109}+n$
SINGLE COUNTS SPECTRUM
40 eV — 7 eV
16.3 eV
20000
15000
10000
5000
0
1800
1900
2000
CHANNELS

Fig. V a



$Ag^{107,109}+n$
SINGLE COUNTS SPECTRUM
65 eV — 36 eV
4000
3000
2000
1000
0
COUNTS
55.6 eV
51.3 eV
44.8 eV
41.5 eV
40.1 eV
1500
1600
1700
1800 CHANNELS

Fig. V b

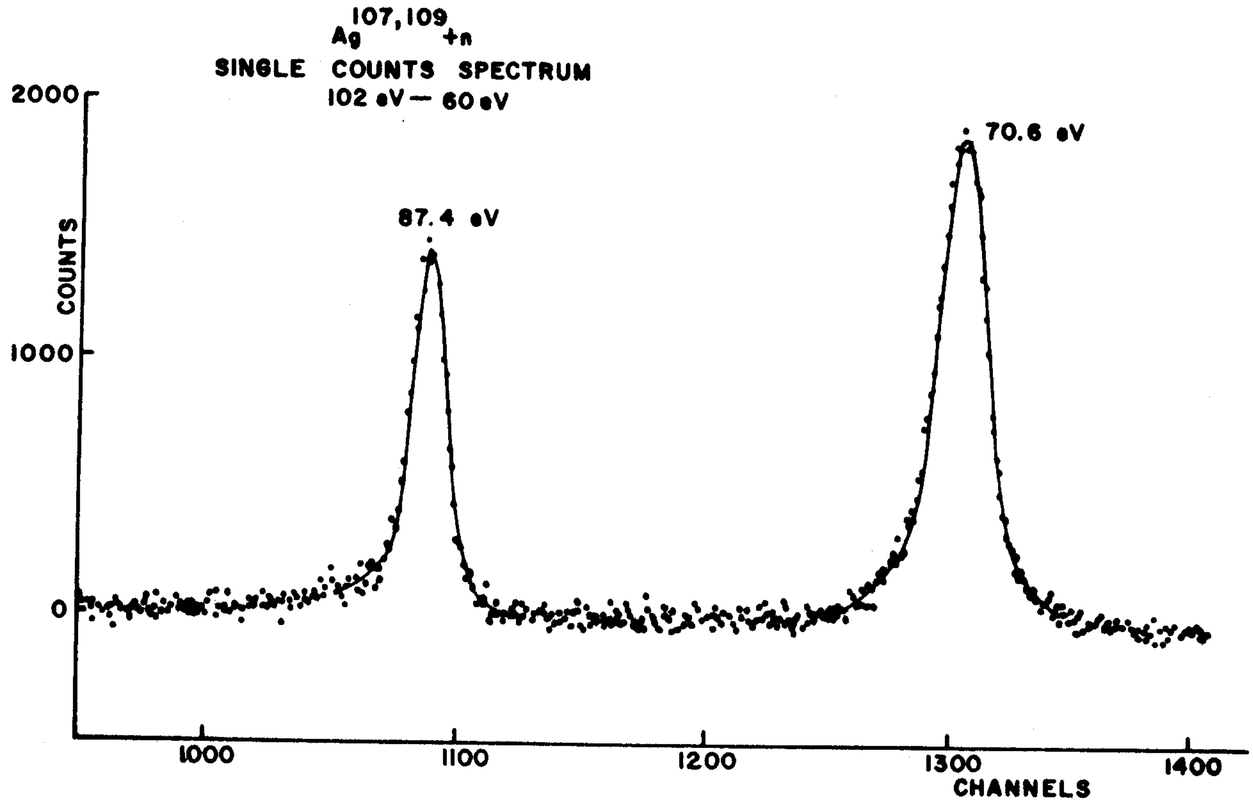

$Ag^{107,109}+n$
SINGLE COUNTS SPECTRUM
102 eV — 60 eV
2000
1000
0
COUNTS
87.4 eV
70.6 eV
1000
1100
1200
1300
1400
CHANNELS

Fig. Vc

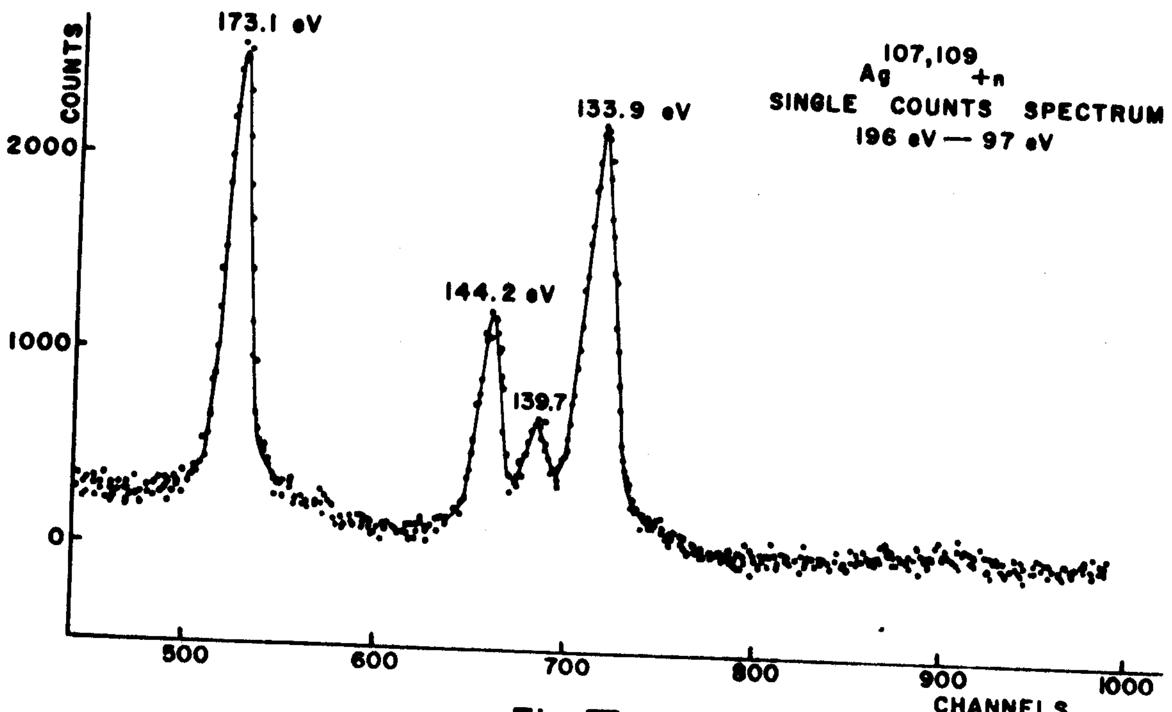

COUNTS
2000
1000
0
173.1 eV
144.2 eV
139.7
133.9 eV
$Ag^{107,109}+n$
SINGLE COUNTS SPECTRUM
196 eV — 97 eV
500
600
700
800
900
1000
CHANNELS

Fig. Vd

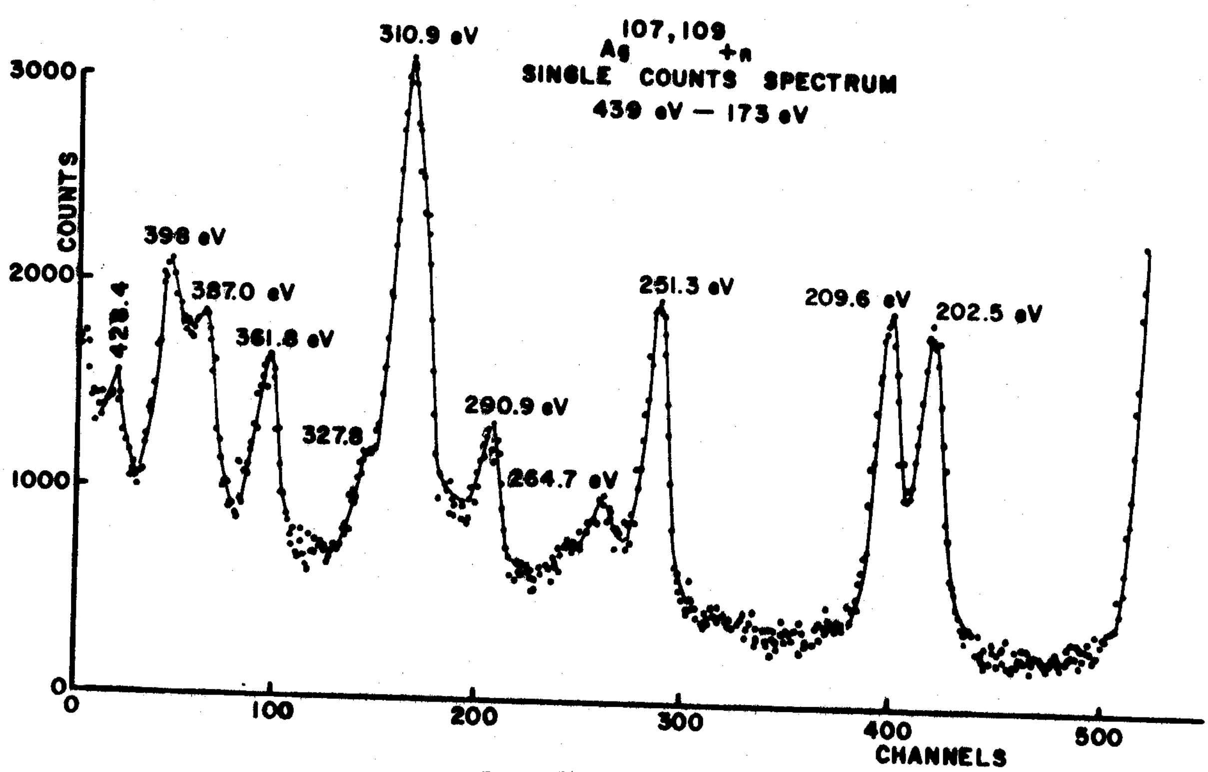

310.9 eV
Ag 107,109 +n
SINGLE COUNTS SPECTRUM
439 eV — 173 eV
3000
2000
1000
0
COUNTS
398 eV
387.0 eV
361.8 eV
428.4
327.8
290.9 eV
264.7 eV
251.3 eV
209.6 eV
202.5 eV
0
100
200
300
400
500
CHANNELS

Fig. V e

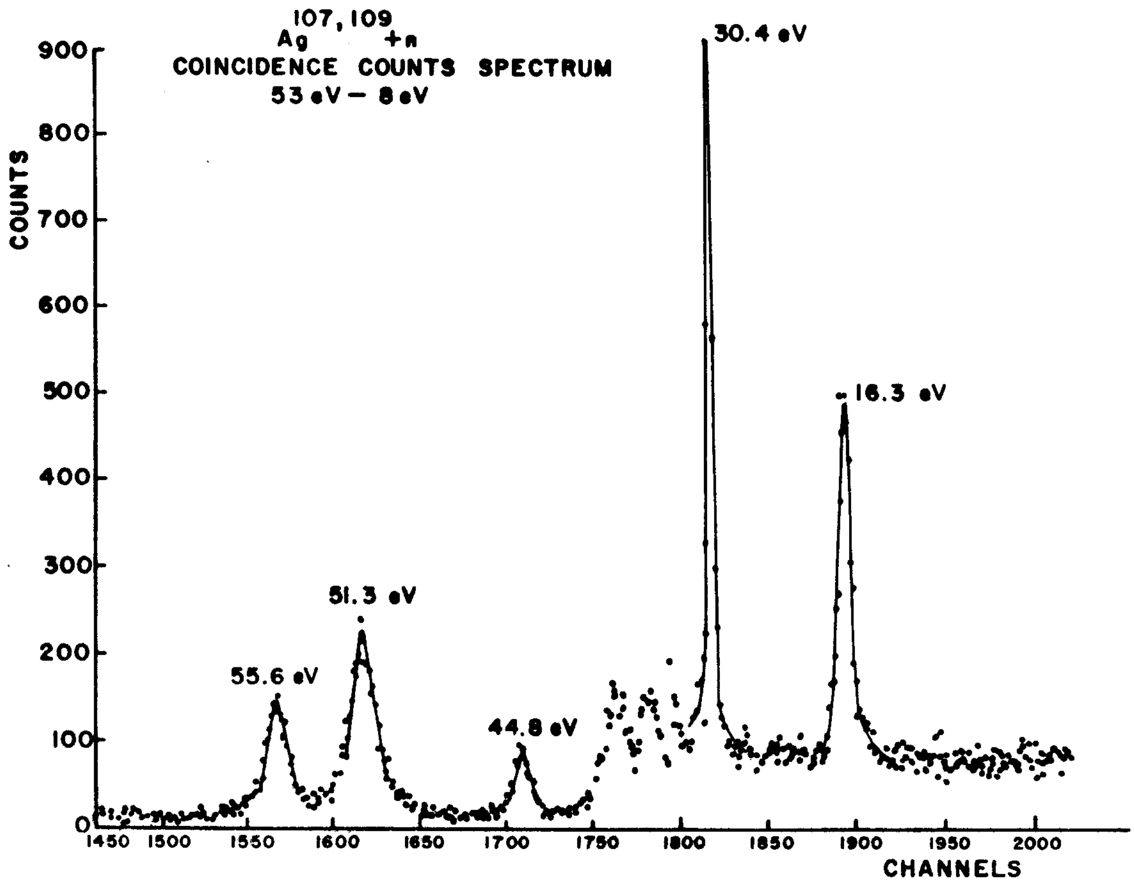


Fig. VI a

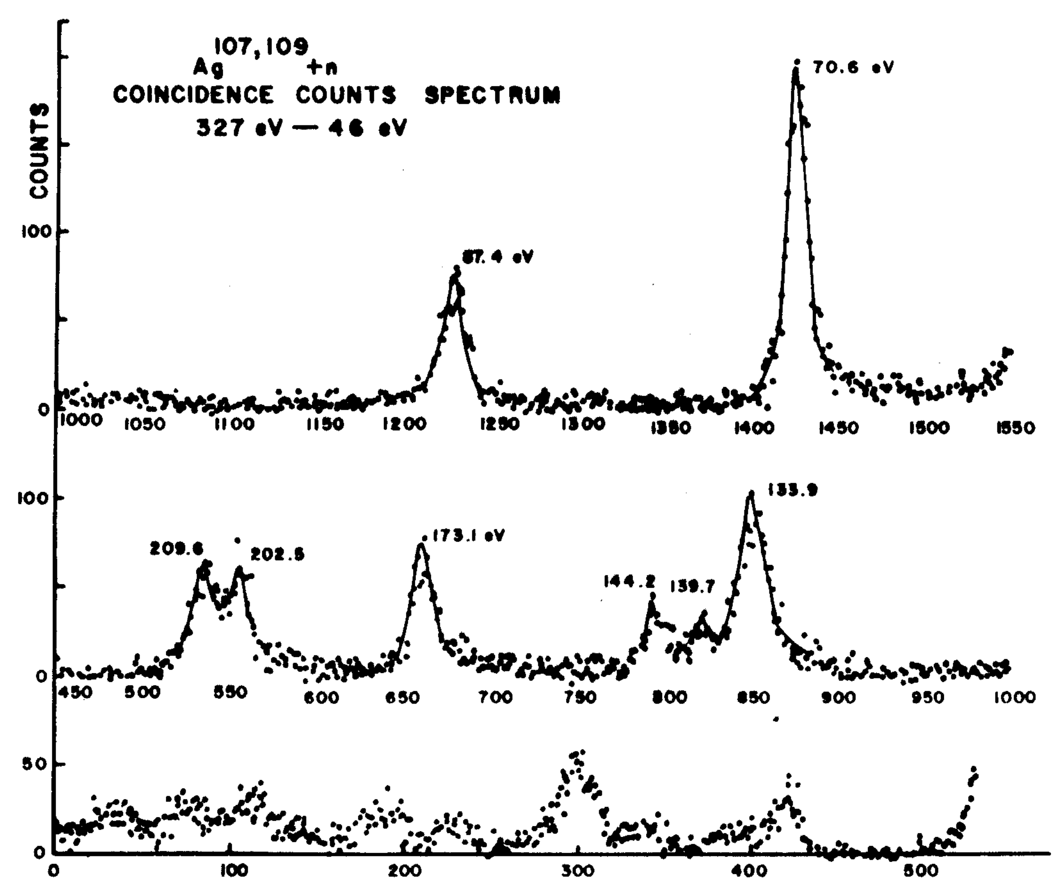


Fig. VI b

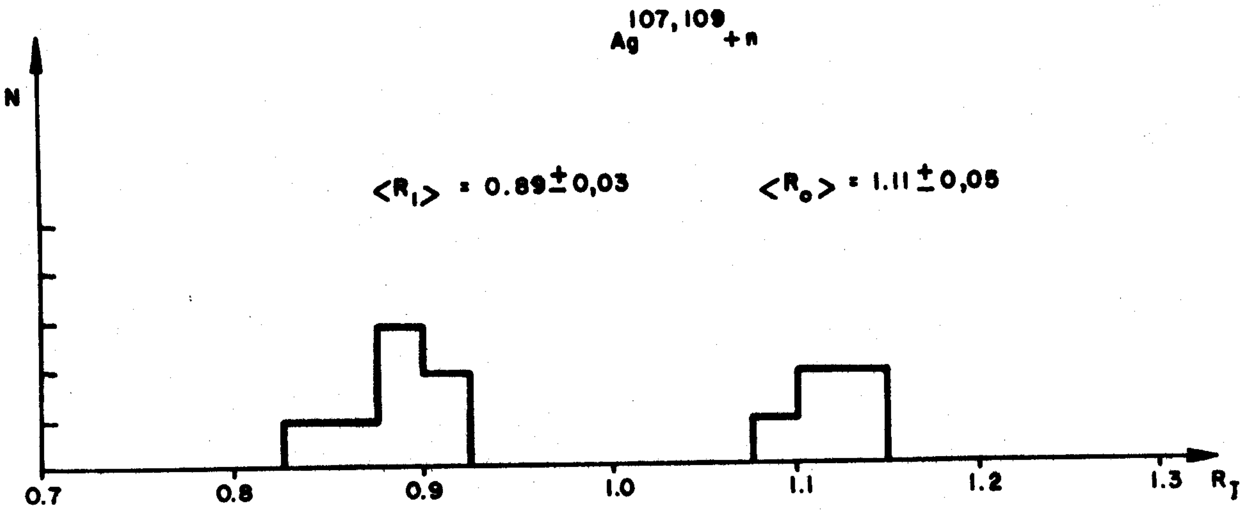


Fig. VII