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GOVERNMENT OF INDIA
ATOMIC ENERGY COMMISSION

VAN DE GRAAFF LABORATORY PROGRESS REPORT

Compiled by

T. P. David
Nuclear Physics Division

BHABHA ATOMIC RESEARCH CENTRE
BOMBAY, INDIA
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CONTENTS

INTRODUCTION

This report covers the period of operation of the 5.5 MeV Van de Graaff Accelerator at Trombay from 1st January 1970 to 31st December 1970. The accelerator has completed 9 years of operation and has been working on a round-the-clock 7 day week basis from the end of 1964.

The five-port beam switching magnet designed and fabricated in the laboratory has been under continuous operation since April 1969 and has been giving very satisfactory performance.

The data analyzing facilities of the laboratory have been supplemented by a two-parameter 4096 channel (Nuclear Data Inc.) analyzing system with the line printer and paper punch units and a two-parameter 1024 x 400 channel analyzing system (Electronics Division, B.A.R.C), both received during the year.

A number of research experiments have been carried out during the period and these are summarized in this report.

A 400 KeV (PN 400) Van de Graaff accelerator has been installed in the beam room of this laboratory. Though the presently available shielding precludes the use of this machine for experiments which need high neutron flux, it is now used for the study of channeling and blocking of protons through single crystals.

ACCELERATOR OPERATION

I. Analysis of Machine operation

Machine Run

Total time available from

1st January 1970 to 31st December 1970		8760 Hours
Holiday observed during the year		24 Hrs.
Time utilized for major maintenance		312 "
Time utilized for routine maintenance		216 "
Time lost due to chiller failure		154 "
Time lost due to power failure		78 "
Time lost due to water failure		16 "
Time lost due to non-availability of liquid nitrogen		43 "
Time lost due to breakdowns	*	2641 "
Total time machine run		5276 "

Research utilization

Time used for research experiments	3569	Hrs.
Time lost due to failure of Airconditioning plant	696	"
Time used for machine conditioning, beam alignment etc.	1011	"
Total	5276	"

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* 854 Hours have been spent in transferring insulating gas and pumping out air from the accelerator tank.

II. Modifications and additions to the accelerator

1. A new 4-element beam steerer unit has been designed and fabricated in the laboratory. This has been installed in the beam tube before the 5-port switching magnet to improve the transmission and help in aligning the beam through all the five ports.

2. The gas manifold has been modified to reduce the number of couplings, thus minimising the possibility of gas leak into the accelerating tube when the tank is pressurized.

   A new and compact gas manifold using leak proof valves and threaded '0' ring - sealed couplings has been designed and is under fabrication in the Nuclear Physics Workshop.

3. A microswitch operated water supply failure alarm has been fabricated and installed in the pump cooling water feeder line.

4. A new current control unit has been fabricated and this, together with the R.F. type High Voltage supply (50 KV) obtained from the Technical Physics Division constitutes a complete standby system for the belt charge power supply.

5. One two-parameter 4096 channel (Nuclear Data) analyzing system with line printer and paper punch unit and another two parameter 1024 x 400 channel

(BARC) analysing system have been added to the data analyzing facilities of the laboratory.

III. Major breakdowns

1. There was a breakdown of the air conditioning system in March due to defects in the plant and the cooling tower blower. Though the accelerator was running, the experimental programme had to be put off for about three weeks before the system was put under operation.

2. A leak of the insulating gas into the accelerating tube was noticed when the tank was being pressurized in the middle of July 1970. The leak was traced to a point of the sealing of glass section in the accelerating tube head. This was sealed with araldite and the defect rectified.

3. The machine operation was again hindered during the October-November period due to pressure leaks into the accelerating tube. A number of days of machine time was lost in the leak chasing process as the leak was intermittent. The leaks were ultimately traced to couplings in the gas manifold assembly. Modifications were then carried out in the existing gas manifold to minimise the recurrence of such breakdowns.

IV. Accelerator components

1. Ion Sources: Ion sources to be used with the accelerator are fabricated in the laboratory since 1965. These are giving satisfactory service, giving an average source life of over 1000 hours.

2. Thermo-mechanical leaks: The thermo-mechanical leaks used for feeding the various gases into the source bottle are fabricated in the laboratory. A modification in the fabrication process has been introduced recently to minimise the development of cold leak. These modified leaks are now under fabrication.

3. Tube Head: The cracked glass section of one damaged tube head has been removed. After proper cleaning and polishing, the chamber and the flange has been reassembled with a ceramic ring in place of the glass section and has been sealed using vinyl thermo-setting compound. A chamber is being designed to carry out voltage and pressure tests on this assembly.

4. Miscellaneous components: Various accelerator replacement components are now fabricated in the laboratory. These include corona points, charge spray combs and spray assembly,high voltage bushings, belt spacers and column resistor assembly.

V. Five Port Beam Switching Magnet

The five port beam switching magnet designed and fabricated in the laboratory[1)] has been under continuous use with the accelerator since April 1969.The slit controlled feed back system is working very satisfactorily resulting in extremely good beam stability.

1) Five Port Beam Switching magnet for use with the 5.5 MeV Van de Graaff Accelerator - T.P. David, N. Sarma, P.R. Sunder Rao and M.Bhatia,BARC-372(1968)

VI. PN 400 Van de Graaff Accelerator

The 400 KeV Van de Graaff Machine originally installed in the Zerlina Reactor hall has been dismantled and reassembled in the beam room of this laboratory. Attempt was made to provide shielding with the available paraffin blocks, concrete blocks and lead bricks. However, it was found that this was inadequate to high flux neutron work. The accelerator is now being used for experiments such as the study of channeling and blocking of protons through single crystals, for the testing and calibration of fabricated neutron detectors and irradiation of crystals for the study of thermo-luminescence characteristics through atomic displacements.

VII. Development Projects

A Pre-injection e/m analyser System for use with Van de Graaff Ion sources - S.N. Misra and M.R. Dwarkanath - A test bench e/m analyser system has been built and tested. It separates doubly charged helium ions from other ions coming out of the ion source and selectively injects the same into accelerating tube. This system when used with 5.5 MeV Van de Graaff accelerator, will then produce helium ions of energies upto 11 MeV, thus enhancing the energy range of the accelerator considerably.

The pre-separation is achieved by a crossed field analyser in which the beam axis is unaltered and it coincides with the axis of the accelerating tube. A fixed magnetic field of 900 gauss is produced across a pole gap of 3.5 cms. by a bank of 24 ceramic permanent magnet wafers and a continuously variable electric field is produced by applying 0-1600 volts across a pair of parallel plate electrodes kept 2.5 cms apart. A 3 mm acceptance aperture placed below the analyser, allows only the undeflected beam to enter the accelerating tube. Prefocussing of the divergent beam is best achieved by an Einzel lens which produces focussing without accelerating the ions and this immensely increases the resolving power of the analyser. The schematic of the system is shown in Fig.1.

Ion current of the analysed beam can be monitered by connecting faraday cup to an ion current meter. Fig.2 shows a plot of ion current against deflector voltage by feeding ^{4}He, ^{3}He and ^{40}A gases into the ion source. Various peaks had been assigned on this graph and the deflector voltages were measured at which the peaks appear. A graph of $\sqrt{Z/M}$ plotted against deflector voltage is shown in Fig.3. The closeness of experimental points to the straight line confirms the assignment for the various peaks. It can be seen that the He^{++} yield from the test bench assembly is 1 to 2 microamperes.

Reported at the Nucl.Phys. and Solid State Phys.Symp. (India) 1970.

RESEARCH EXPERIMENTS

1. <u>A Doorway State Observed as a Resonance in the $^{35}Cl(p,p_0)^{35}Cl$ Reaction</u> - S. K. Gupta, S. S. Kerekatte, S. Swami*, M. R. Dwarakanath**, K. K. Sekharan*** and A. S. Divatia - We have investigated the elastic proton scattering from the ^{35}Cl nucleus from $E_{p\ lab}$= 2.380 MeV to 2.620 MeV. This reaction was studied to look for the isolated bound doorway states having a large coupling to the entrance channel. Doorway states were postulated to describe microscopically, the mechanism of nuclear reactions. So far the isobaric analog states have been the only reported doorway states. The difficulties encountered in pinning down a doorway state of another type, experimentally and theoretically, are numerous. Once we concentrate our attention on the bound isolated doorway states with a large decay width to the entrance channel, the experimental identification becomes definite. Payne[1] has theoretically investigated the elastic scattering of neutrons from the single closed shell even-even nuclei. His calculations are approximate and are applicable to a very limited number of cases. The calculations for other cases are not actually available. The major difficulty in solving the doorway state problem theoretically is to deal with the complications of the

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* Member of I.I.T., Powai, Bombay-76

** Now at the California Institute of Technology, California, USA.

*** Now at the University of Kentucky, USA nuclear structure as well as the nuclear reaction calculations. Here we are describing briefly our results and an approximate comparison with the theoretical calculations.

The 5.5 MeV Van de Graaff accelerator was the source of protons. The targets were prepared using NaCl having ^{35}Cl enriched to 99.32% on carbon backings. The scattered particles were detected using four solid state detectors at lab. angles of 98°,113.8°,138.5° and 155°. The data was taken in 2 KeV steps. Bosnjakovic et al[2] have already investigated the $^{35}Cl(p,\alpha_0)^{32}S$ reaction in the same energy range. We show in Fig.4 their results along with our data. A resonance at E_p lab = 2.463 MeV with a width of 16 KeV appears only in the proton channel. As this resonance anomaly appears at all the four angles, it is consistent with an $l_p = 0, J^{\pi} = 2^+$ assignment. This assignment is not unique.

The calculations of Payne[1] reveal that the isolated bound doorway states should appear at an incident energy of 2 to 3 MeV with a typical width of 50-100 KeV in neutron elastic scattering. Taking into account the Coulomb effects, the width of the doorway state changes from 100 KeV to 15 KeV for $l_p = 0$ protons at E_p = 2.0 MeV. Glaudemans et al[3] have carried out bound state calculations within s-d shell using an empirically determined residual interaction.

In the configuration space made up of $S_{1/2}$ and $d_{3/2}$ subshells, the doorway states ca have only $(S_{1/2})^3$ $(d_{3/2})^5$ or $(S_{1/2})^4$ $(d_{3/2})^4$ configurations. Glaudemans et al find a level at an excitation of 10.5 MeV with $J^\pi = 2^+, T = 0$ in ^{36}Ar with a 67% $(S_{1/2})^3(d_{3/2})^5$ and a 11% $(S_{1/2})^4(d_{3/2})^4$ configuration. The resonance observed by us corresponds to a state in ^{36}Ar at 10.901$\pm$.005 MeV with a c.m.width of 15 KeV. Thus our observations are consistent with the expected behaviour of the doorway states as calculated by Payne as well as the shell model calculations for bound states which will not differ substantially for the unbound states. Further work is in progress on this problem.

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2) B. Bosnjakovic, J. Bouwmeester, J.A. Van Best and H.S. Prays, Nucl.Phys. A114(1968)7

3) P.W. Glaudemans, G. Wiechers and P.J. Brussard, Nucl.Phys. 56,(1964) 529;56(1964)548.

2. Evidence for doorway States in $^{29}Si(\alpha,n)^{32}S$ Reaction - M. Balakrishnan, M.K. Mehta and A.S. Divatia - Since Block and Feshbach[1] and Kerman et al[2] suggested that simple modes of excitation of compound nucleus might lead to structures with widths intermediate in value between those of the states in compound nucleus formation, and those of single particle resonances, many attempts have been made[3,4] to identify these states in

nuclear reactions. According to Feshbach et al[4] doorway states will be most readily observable if the number of open channels which are detected experimentally is small, so that total cross-section in a neutron induced reaction is least sensitive to the presence of doorway states. Hence the most suitable case for detection of a doorway state is in the cross-section measurements for light nuclei at low energies, wherein the spreading width $\Gamma_d\downarrow$ can be relatively small. From this point of view the reaction $^{29}Si(\alpha,n)^{32}S$ seems appropriate.

Fig.5 shows the experimental data, the details for which are given elsewhere[5]. There is good agreement between the two separate sets of data.

An examination of data shows following details. (a) Resonances are about 10 KeV wide, and $\frac{\langle\Gamma\rangle}{\langle D\rangle} > 0.3$ for the region of excitation around 10 MeV in ^{33}S. This is in agreement with the widths and $\langle\Gamma\rangle/\langle D\rangle$ ratio known for ^{33}S in this region[6,7]. (b) There is an indication for the presence of gross structures, superposing the finer variations in cross-sections with energy. (c) The gross structures are not distributed at random, but there is a regularity in the distribution of widths and energy spacings of these structures. (d) The cross sections show more intense peaks within each of these broad structures than in between them.

The excitation function averaged over 100 KeV is shown in Fig.6, where structures of width around 270 KeV with spacing of 500 KeV are present. From observation (a), it can be seen that we are not in the region of excitation where Ericson fluctuations[8] are valid. This is also supported by the fact (n,α) and (n,p) correlation exists[9] in ^{32}S and that compound nucleus cross-sections are not damped. Hence accidental lumping of resonance states as discussed by Singh et al[10], wherein spurious "intermediate" like structures are built up, can be ruled out. For the region of excitation where $\langle \Gamma \rangle / \langle D \rangle$ is not too large and correlation exists between various entrance or exit channels, the structures have been qualitatively explained as due to statistical fluctuations in the average level densities of the compound nuclei involved[11]. From the observations (b) and (c) above, it is improbable that such an explanation can account for these structures.

A more realistic possibility is to explain these structures as due to simple modes of excitation of the compound nucleus. The reduced alpha width, for the single particle Wigner limit $\theta^2 = 3\hbar^2/2MR^2$ is 430 KeV which is twice as great as the observed width 270 KeV. Doorway states described as three quasi-particle states can account for a width of about 200 to

250 KeV for nuclei in this mass region[4]. Skakin[12], and Lande and Block[13] estimated that the number of three quasi-particle states that can occur per MeV energy spread is around three, in this region of excitation for medium heavy nuclei. This is consistent with the separation of 500 KeV observed for light nuclei as in the present experiment. Since each three quasi-particle states should be characterised by a unique angular momentum, it will be quite interesting to see the differential cross-sections for these structures, to check whether a unique angular momentum can be attributed to each of them. The expected spreading of the doorway states over many compound nuclear states (observation, d) may make it more difficult to observe this.

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4) H. Feshbach, A.K. Kerman and R.H. Lemmer; Ann.Phys. (N.Y.) 41, (1967)230

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3. A Study of the ^{64}Ni(p,n)^{64}Cu Reaction - S. S. Kerekatte, S.K. Gupta and A.S. Divatia - The (p,n) reaction on a ^{64}Ni target, was investigated to identify the isobaric analog resonances in the nucleus ^{65}Cu,corresponding to the parent nucleus ^{65}Ni. Recently, this reaction has also been studied by the Duke Group[1] from $E_p = 2.5 - 3.3$ MeV. In the energy range $E_p = 2.5 - 5.5$ MeV scanned by us, strong resonances have been observed which are superimposed upon the Ericson type statistical fluctuations.

A metallic ^{64}Ni target (enriched to 97%) was prepared by evaporating ^{64}Ni metal from a heated tungsten ribbon on to a tantalum backing foil. A 4π - geometry neutron counter was used to measure the yield of the reaction. The absolute cross-section has not been extracted. The relative cross-section is accurate to within $\pm$ 5%. The measured excitation function is shown in Fig.7 (a) and (b).

The threshold of the reaction has been observed at E_p = 2.500 $\pm$ .005 MeV. The average cross-section gradually increases with the incident proton energy due to the increase in the penetrability factor. The cross-section shows fluctuations. The average width of the compound nuclear levels is calculated to be $\sim 7 \pm 1.5$ KeV, using the peak counting method[2] and has been approximately corrected for the experimental resolution.

The g.s. analog of ^{65}Ni cannot be observed because it is due to $\ell_p = 3$. The Duke group observed the analog of the first excited state at E_p = 3.217 MeV. Accordingly, the other analog resonances are expected at $E_{p\ lab}$ = 3.471, 3.861, 4.188, 4.502, 4.591, 4.779,4.968, 5.100 and 5.338 MeV. Out of these, on the basis of the spectroscopic factor for the parent states observed through the ^{64}Ni(d,p)^{65}Ni reaction[3] and the penetration factor criterion, the resonances at 3.861,4.591, 4.779 and 5.338 MeV are strong. Experimentally, we observe strong resonances at $E_{p\ lab}$ = 3.895, 4.620 and 4.790 MeV, corresponding to the expected resonances. Strong resonances are observed at $E_{p\ lab}$ = 3.235,4.310 and 5.470 MeV which do not correspond to the known levels in ^{65}Ni. The resonance at E_p = 3.895 MeV is having the asymmetry predicted by Robson et al[4] in the (p,n) reactions.

A more detailed analysis of the data is in progress.

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4. Isobaric Analogue States in ^{67}Ga - M.G.Betigeri, C.M. Lamba, D.K. Sood, N. Sarma and N.S. Thampi - In this work the observation and study of the isobaric analogue states of ^{67}Zn in the compound nucleus ^{67}Ga which is formed by the proton bombardment on ^{66}Zn is reported.

Excitation functions at three angles θ_{cm} = 90°, 125° and 165° were measured in the incident protons energy range of 2.9 to 3.9 MeV. A thin target of ^{66}Zn (enriched to 90%) evaporated on thin carbon backing (10 μg/cm) was bombarded with protons from 5.5 MeV Van de Graaff accelerator. The error on the measurement is 2% including the statistical error.

At high excitation energies in medium weight nuclei the level width is much larger than spacing. On this background of compound nucleus states of isospin T the analogue state with isospin T stands out as an anomaly in the cross section. Interference also occurs between potential and resonant scattering. These anomalies have been observed in ^{67}Ga which are analogues of 93, 184, 390, 978 and 1142 KeV levels in ^{67}Zn. The states analogues to the ground and 602 KeV states could not be observed because of high values involved. The resonances have been fitted with the program BRIGIT as modified for the CDC-3600 computer[1]. Values for the resonances energy total width and partial widths are obtained. The results are shown in Table 1.

Table 1

Energies of levels in ^{67}Zn	Previous assignments J	Γ	Γ_p	Present assignments l	J
184	$3/2^-$	3.62	0.04	1	$3/2^-, 1/2^-$
978	$5/2^+$	10.54	0.34	1	$1/2^-, 3/2^-$
		No unique fit		2	$5/2^+$
1142	$1/2^-$	14.10	0.75	1	$1/2^-, 3/2^-$

The l and j values for the various resonances agree with the results obtained from (d,p) reaction data except for the 978 KeV level. The present experiment suggests a value of $l = 1$ for this resonance. No unique fitting can be obtained for this level for $l = 2$ assignment.

1) M.G. Betigeri, C.M. Lamba, N. Sarma, D.K. Sood and N.S. Thampi, Nucl. Phys. A133(1969)465.

5. <u>Study of Analogue States of ^{73}Ge through Inelastic Proton Scattering</u> - M.G. Betigeri, C.M. Lamba, N. Sarma, D.K. Sood and N.S. Thampi - In this work levels are observed in the compound nucleus, ^{73}As which are analogues of the states of ^{73}Ge through the proton bombardment of ^{72}Ge. The levels of ^{73}As decay by proton emission to the first excited state of ^{72}Ge, a (0^{+}) state at 0.691 MeV; this in turn decays to (0^{+}) ground state by electron conversion. The electrons were detected by a six gap "orange" beta ray spectrometer with a transmission 10%. It is described elsewhere in this report.

A natural Ge target of thickness approximately 30 microgram cm^{-2} was bombarded by protons in the energy range 3.30 MeV to 4.80 MeV. The excitation function is shown in Fig.8. Seventeen analogue states corresponding to various parent levels of ^{73}Ge in the energy range of 13 KeV to 1310 KeV have been identified and are listed in Table 2. The energy positions agree well with the results[1,2] obtained from ^{72}Ge(d,p), ^{73}Ge(p,p) and ^{72}Ge(p,p) reactions.

Further analysis to determine the total and partial widths, the spectroscopic factors and the nature of states is in progress.

1) G.Heymann, P.Van der Merwe, I.J. Van Heerden and I.C. Dormehl - Z. Physik <u>218</u> (1969)137

2) M.G. Betigeri, C.M. Lamba, N. Sarma, D.K. Sood and N.S. Thampi - Nucl.Phys. <u>A133</u> (1969)465.

Table 2

Resoname Number	Energy (KeV)*	Energies as observed in $^{72}Ge(d,p)$	$^{73}Ge(p,p')$	$^{72}Ge(p,p)$
I	13	13	-	13
II	65	67	67	-
III	370	368	-	368
IV	400	396	-	-
V	515	512	498	-
VI	570	563	551	-
VII	673	666	656	-
VIII	725	727	-	-
IX	805	-	825	-
X	860	864	867	-
XI	900	904	-	-
XII	930	926	918	-
XIII	1055	1051	1039	1063
XIV	1130	1141	1132	-
XV	1180	1176	-	-
XVI	1250	1274	-	-
XVII	1310	1322	1318	-

* Assuming Coulomb energy displacement = 9053 KeV

6. Transient Fields on ^{103}Rh in Fe at Low Recoil

<u>Energies</u> - S.K. Bhattacharjee*, H.G. Devare*, H.C. Jain*, M.C. Joshi* and C.V.K. Baba - Transient magnetic fields at nuclei recoiling into ferro-magnetic materials in IMPACT experiments have been discussed by Grodzins[1]. In most of these experiments the recoil energy is about 10 MeV. Varga et al[2] made measurements on the 298 KeV ($3/2^-$, τ = 9.1 ps) and 360 KeV ($5/2^-$, τ = 85 ps) states in ^{103}Rh with a $Fe_{51.5}\,Rh_{48.5}$ alloy using Coulomb excitation by 2.5 MeV protons. They found the presence of large transient fields even for recoil energies below 100 KeV.

^{103}Rh is a suitable case for studying transient field effects because it has two states easily excited in Coulomb excitation having half-lives differing by a factor of ten. Further, the Core Excitation Model makes a prediction for the ratio of the g-factors of the two states.

In this contribution, we present results on 5 at % Rh-Fe alloy using Coulomb excitation with 5.0 MeV alpha particles. We have made Integral Reversed Field (IRF) measurements with a polarising field of 1 KG using a 20 cc Ge(Li) detector. The rotation angle $\omega\tau$ in the angular distribution was measured for the 298 KeV and 360 KeV gamma rays. The values of $\omega\tau$ obtained are shown in Table 3, together with the results of other workers. We note that the sign of $\omega\tau$ is positive for both the states. If we assume that the g-factors of both these states are positive, this indicates that no large transient

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* Tata Institute of Fundamental Research, Bombay-5.

fields are present as reported in ref.2).

Assuming that transient fields are absent and that only the static field H = - 540 KG[3] acts, we obtain g(298 KeV) = 1.15 ± 0.31 and g(360 KeV) = 0.48 ± 0.09. The ratio g(298 KeV)/g(360 KeV) = 2.4 ± 0.8 is in agreement with the value 1.7 ± 0.4 obtained by Miller et al[4] who used the method of recoil in gas. This ratio is also consistent with the value 1.8 expected on the basis of the Core Excitation Model. Thus this experiment suggests that no appreciable transient fields are present in this case.

This work was reported at the International Conference on "Hyperfine Integrations detected by Nuclear Radiations" held at Rehovot, Israel (1970).

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<u>Table 3</u>

Summary of angular precession ($\omega\tau$) and g for levels in ^{103}Rh

Energy(KeV)	τ (ps)	$\omega\tau$ Present work[a]	Varga et al[b]	Roney et al[c]	g (Present work)
298	9.1 ± 0.7[d]	$+ 0.029\pm0.007$	$- 0.017\pm0.004$	$- 0.0004\pm0.0050$	(1.15 ± 0.31)[e]
					(1.41 ± 0.42)[f]
360	85.2 ± 6.1[d]	$+ 0.108\pm0.014$	$+ 0.030\pm0.012$	$+ 0.099\pm0.007$	(0.48 ± 0.09)[e]
					(0.49 ± 0.09)[f]

a) 5 at % RhFe alloy; 5 MeV alpha particles
b) ref.2) $Fe_{51.5}Rh_{48.5}$ alloy; 2.5 MeV protons
c) ref.5) IMPACT; 30 MeV O^{16} ions
d) ref.6)
e) assuming zero transient field effect; $H_{static} = - 540$ KG[3)]
f) assuming $\int_0^{T_s} H(t)\,dt = 1.24$ MG PS.

7. <u>Coulomb Excitation of Selenium Isotopes ($^{74,76,77,78,80,82}Se$</u> - A. P. Agnihotry*, K.P.Gopinathan*, M.C. Joshi* and K.G. Prasad* - A thick target of selenium natural material was exposed to alpha particles from the 5.5 MeV. Van de Graaff accelerator at Trombay. The γ-rays emitted from the target were detected by a high resolution Ge(Li) detector (20 cc) (Fig.9). The gamma-rays corresponding to Coulomb excitation of different isotopes $^{74-82}Se$ were identified. From measurements of thick target yields corrected for their natural isotopic abundances, the relative $B(E_2)\uparrow$ values were determined. Using a well-known $B(E_2)\uparrow$ value of 2^+ level of ^{78}Se, absolute values of $B(E_2)\uparrow$ in units of $(10^{-50}.e^2.cm^4)$ for all the other gamma-rays were determined. ^{77}Se : (23 ± 2), (18.6 ± 2.0), (1.0 ± 0.2) for 440, 240 and 250 KeV levels respectively. ^{74}Se: (48.0 ± 15) for 635 KeV(2^+) level, ^{76}Se: (45 ± 4) for 560 KeV(2^+) level, ^{78}Se: $(38.4\pm.8)$ for 612 KeV(2^+) level, ^{80}Se: (27.6 ± 2.5) for 665 KeV(2^+) level and ^{82}Se: (20 ± 4) for 654 KeV(2^+) level. The $B(E_2)\uparrow$ value for ^{74}Se is new. The $B(E_2)\uparrow$ value for 250 KeV level in ^{77}Se is more accurate compared to the earlier value obtained from unresolved gamma-rays 240 and 250 KeV using NaI(Tl) scintillation detector. Our improved value is in good agreement with the value obtained from the half life measurements of this level. From the

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observed $B(E_2)$ values the r.m.s. quadrupole distortion $\beta_{r.m.s.}$ are deduced for the Selenium isotopes.

8. **Study of low lying levels in ^{51}Cr and ^{59}Ni**

- B.Lal* and Baldev Sahai* - The low lying levels in ^{51}Cr and ^{59}Ni have been excited by means of $(p,n\gamma)$ reaction on ^{51}V and ^{59}Co targets. The angular distribution of ground state electromagnetic transitions from 0.749, 1.165, 1.353, 1.479 and 1.557 MeV states in ^{51}Cr and 0.339, 0.465 and 0.879 MeV states in ^{59}Ni have been measured at the incident proton energies slightly above the threshold for the excitation of the respective states, so that the major contribution to the reaction cross-section comes from the s-wave neutrons in the outgoing reaction channels.

The angular distribution of various gamma rays obtained were "least-squares" fitted to the even order Legendre polynomial expansion and the coefficients of expansion were obtained.

The theoretical calculations were made using Sheldon and Van Patter's formalism of Hauser Feshbach Statistical model assuming various possible spins of the levels under investigation with values of multipole mixing ratio parameter of the transition varying from $-\infty$ to $+\infty$. The experimental results obtained were

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then compared with the theoretical results whence the spins of 0.749, 1.165 and 1.479 MeV levels in ^{51}Cr and 0.879 MeV level in ^{59}Ni have been confirmed to be $3/2^-$, $9/2^-$, $11/2^-$ and $3/2^-$ respectively.

9. <u>The level structure of ^{75}Se</u> - Baldev Sahai* and B. Lal* - A large number of gamma-ray spectra have been recorded from $^{75}As+p$ reaction for incident proton energies from 1.50 MeV (which is below the threshold of $(p,n\gamma)$ reaction) upto 3.75 MeV by bombarding an arsenic pellet (an "infinitely thick" target for the incident energies used in the experiment). A 30 c.c. Ge(Li) detector and a 400 channel TMC analyser were used for recording the data. Spectra were also obtained using a thin arsenic target deposited on a thin carbon film and utilizing a 4096 channel Nuclear Data analyser. Thus the excitation functions of various gamma-rays arising from $^{75}As(p,n\gamma)^{75}Se$ reaction together with their precise energies were obtained. The gamma rays observed were attributed to various levels in ^{75}Se based on their thresholds and excitation functions. The cascade transitions in ^{75}Se were further investigated by studying gamma-gamma coincidences using the 30 c.c Ge(Li) detector for the gated spectrum and NaI(Tl) detectors for the gated spectrum and NaI(Tl) detectors of ½" and 1" thicknesses for the gating gamma-rays. The gamma-rays taken

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in gate were 112, 141, (287 + 293 + 299) KeV at incident proton energy 3.0 MeV and 112, (287 + 293 + 299) and (492 + 515) at 3.5 MeV incident proton energies. The chance spectra were also obtained simultaneously. Based on this data a detailed level scheme upto an excitation energy of 1500 KeV has been worked out for ^{75}Se along with branching ratios for some of the levels.

10. <u>Study of the Isobaric Analogue State in ^{33}Cl by the $^{32}(p,\gamma)^{33}Cl$ Reaction</u> - M. A. Eswaran, M. Ismail and N.L. Ragoowansi - Proton decay of the T = 3/2, T_Z=-1/2 states are energetically possible only to the T = 0 states in the neighbouring (A = 4n, Z = 2n) nucleus although such a breakup is isospin forbidden. However, since the only isospin-allowed decay is by gamma emission, even a slight violation of isospin conservation will permit proton emission to compete successfully. Hence the T = 3/2, T_Z= 1/2 states can be formed by proton capture and the exit channel in which these states are most likely to be clearly exhibited is in the gamma channel since this is the only decay mode, that is not T-forbidden. In the present work the (p,γ) reaction has been used to study the lowest T = 3/2 state in ^{33}Cl.

A mechanically chopped proton beam ($\sim$ 1.5 μA) passed through thin ($\sim$ 200 $\mu g/cm^2$) natural Sb_2S_3 target evaporated onto a thick gold backing which was watercooled

The detector consisted of a 30 cm^3 Ge(Li) γ-ray detector with a single channel analyser set to select the pulses in the 511 KeV annihilation radiation peak, generated by the annihilation of positrons, arising from the decay $^{33}Cl \rightarrow {}^{33}S$ with 2.52 sec. half-life. The 511 KeV peak pulses from the single channel analyser were fed into a pulse-height analyser operated in a multiscaler mode with 0.1 sec per channel. The operating cycle (bombard the target for 4 sec, and then count for 20 sec.) was repeated until a fixed charge was accumulated. The resultant time spectrum showed the expected 2.52 sec. activity plus a constant background. For obtaining the excitation function over the resonance, only the counts in the time spectrum corresponding to first two half-lives were taken after subtracting the constant background.

The delayed proton work[1)] had found the lowest $T = 3/2$ level in ^{33}Cl at 5.556 ± 0.020 MeV, E_p(c.m.) = 3.266 ± 0.020 MeV. In agreement with this, a search through this region (Figure 10 a) located the resonance at E_p = 3.371 ± 006 MeV E_p(c.m.) = 3.269 MeV . This corresponds to an excitation energy in ^{33}Cl of 5.559±006 MeV. The slope of the yield curve at resonance could be entirely attributed to the energy spread in the proton beam. From this it is deduced that the total width of the level is less than 2.5 KeV. The proton width Γ_p and the total width Γ for this resonance as determined from proton elastic scattering experiments have been reported[2] to be 125 eV. The integrated yield over the (p,γ) resonance in the present work was found by comparison with the resonance in the same reaction at E_p = 2.547 MeV as well as from the comparison of the gamma ray yield at the E_p = 0.588 resonance. From these measurements preliminary value of the resonance strength and hence Γ_γ for the E_p = 3.371 MeV resonance has been obtained.

At this resonance the γ-spectrum was measured with the 30 c.c Ge(Li) detector and is shown in Fig.11. For comparison the gamma spectrum taken at "off-resonance" is also shown. These measurements show that the only significant transition from the resonance is to the 0.806 MeV($1/2^+$) first excited state in ^{33}Cl. This transition from the 5.559 MeV(J = 1/2, T = 3/2) state in ^{33}Cl (which is the analogue of the ground state of ^{33}P) to the 0.806 MeV (J = 1/2, T = 1/2) state in ^{33}Cl is a pure M1 of moderate strength and can be conjectured to the "analogue to the anti-analogue" transition. Preliminary results of this work has been reported in reference (3).

1) A.M. Poskanzen, R.McPherson, R.A. Esterlund and P.L. Reader; Phys. Rev.152(1966),995

2) G.M. Temmer in 'Nuclear Isospin' (Proc.Conf.on Nucleon Isospin, Asitomar; (1969) 87

3) M.A. Eswaran, M. Ismail and N. L. Ragoowansi; Bull. Am. Phys. Soc. 15(1970)1689.

11. Charge form Factor And Quadrupole Moment of ^{6}Li - A. K. Jain and N. Sarma - The charge density of ^{6}Li is calculated using antisymmetrised and modified cluster model wave functions. Satisfactory agreement with the measured charge form factor and quadrupole moment has been obtained. Exchange terms have been found to be important in both calculations.

Published in Phys. Lett. 33B (1970)271.

12. $^{7}Li(p,pt)^{4}He$ Reaction at Medium Energies - A.K. Jain and N. Sarma - Formalism has been developed in which the reaction $^{7}Li(p,pt)$ ^{4}He[1,2] can be analysed in the distorted wave impulse approximation (DWIA). The analysis makes use of a cluster model wave function for ^{7}Li nucleus which is having a correct asymptotic behavicur for the intercluster part and is completely antisymmetrised. It has, however, been observed that the triple exchange term contributes very significantly in the plane wave case. It is expected that the contribution from the exchange terms will be reduced by the inclusion of distortions in the waves.

1) D.L. Handrie, M. Chabre and H.G. Pugh, U.C.R.L. Report No. 16.580(1966)146

2) D. Bachelier, M.K. Brusel, P. Radvanyi, M. Roy, M. Sowinski, B. Bernas and I. Brissaud, High Energy Physics and Nuclear Structure, Ed.S. Devons, Plenum Press (1970)p.318.

13. Systematics of Ground State Spins of Light Odd-Odd Nuclei - S.K. Gupta - A coherent survey of the rules predicting ground spins of the odd-odd nuclei upto $A \sim 60$ has been carried out. The odd-odd nuclei in which the valence nucleons under the j-j coupling shell model are filling different subshells are divided into five categories. Two of these obey strong rules while two out of the remaining three obey weak rules.

For the odd-odd nuclei when the valence nucleons are filling the same subshell two new empirical rules have been found. All the nuclei except ^{34}Cl and the $f_{7/2}$ subshell nuclei obey the first rule. The second rule is applicable to the nuclei excluded by the first rule. Both the rules coincide for $T_Z = 1$ cases. In order to understand these rules the separation between the $T = 0$ lowest and $T = 1$ states $T_Z = 0$ odd-odd nuclei has been plotted. This plot indicates an oscillatory behaviour in the nature of the two body residual interaction. For the $f_{7/2}$ shell nuclei an empirical formula has been found to describe the separation between the lowest $T = T_Z$ and $T = T_Z + 1$ states. This formula resembles the second rule for the ground state spins of the same subshell nuclei.

14. Computer Code for calculating the reaction cross-sections of gamma-rays in (p,nγ) reactions - B.Lal* - For

* Tata Institute of Fundamental Research, Bombay-5.

theoretical analysis of gamma-ray excitation function and the gamma-ray angular distribution in a reaction of the type $A(p,n\gamma)B$ where statistical model is applicable in the compound nucleus a program NATTU has been developed. This program is an improved and more versatile version of the earlier HF Model program[1]. The calculations are based on the theoretical treatment by Wolfenstien, Hauser and Feshbach as later extended by Satchler and Sheldon[2].

This program can accept ℓ dependent or j dependent transmission coefficients for both the incoming and outgoing particles. It can take any number of ℓ values in the incoming and outgoing channels. The maximum value for the two channels need not be same.

The program takes into account for calculation not only the levels in the residual nucleus which are excited but also the levels in the target nucleus which are excited with reasonable intensity.

The program can calculate the excitation function of a gamma-ray in $(p,n\gamma)$ reaction from its threshold to any desired bombarding energy in whatever steps. This calculation is carried for various values of spin of a particular level under investigation.

For the analysis of angular distribution of gamma-rays the program can find out the even order Legendre polynomial expansion coefficients a_2, a_4, a_6 etc., for various values of multipole mixing ratio of a transition for comparison with the experimental values. The program can also calculate the angular distribution of gamma-rays for a definite spin sequence and known multipole mixing ratio of the transition.

1) K.V.K. Iyengar, B. Lal and S.K. Gupta, Nucl.Phys. A103 (1967) 592

2) E. Sheldon, Van Palter, Rev.Mod.Phys.38,(1966)143.

15. Formalism for the Study of Two Hole States in Nuclei with the (π^-,NN) Reaction - B.K. Jain - A formalism has been developed to study the two hole states in atomic nuclei with the (π^-,NN) reaction. For the interaction of pions with nucleus two nucleon model has been used. The interaction of outgoing nucleons with the residual nucleus has been incorporated through the optical model potential. The spectroscopic amplitude for the two nucleons in the nucleus has been given in the LS coupled basis states of shell model.

Published as a BARC Report No. BARC - 512 (1970)

16. Analysis of the (π^-,NN) Reaction on ^{6}Li, ^{7}Li and ^{12}C Nuclei - B.K. Jain and B. Banerjee* - With a view to studying the two-hole states in nuclei, the (π^-,nn) reaction on ^{6}Li, ^{7}Li and ^{12}C has been analysed using the

* Tata Institute of Fundamental Research, Bombay-5.

two-nucleon absorption model and including the interaction of the outgoing neutrons with the residual nucleus. The calculated recoil momentum and angular-correlation distributions are in satisfactory agreement with the available experimental data.

Published in IL Nuovo Cimento LXIX A (1970)419.

17. Analysis of (p,2p) and (e,e'p) Reaction on ^{12}C Nucleus - R. Shanta* and B.K. Jain - The experimental data on the (p,2p) reaction at 460 MeV and 1 GeV incident proton energies and (e,e'p) at 605 MeV incident electron energy have been analysed for ^{12}C nucleus in the distorted wave impulse approximation (DWIA). It is found that the single particle wave function for the bound protons which fit the elastic electron scattering and the (p,2p) reaction at 460 MeV fails to fit the shapes of the angular distributions for $^{12}C(p,2p)$ at 1 GeV and $^{12}C(e,e'p)$ at 605 MeV.

Presented at the Nucl.Phys. and Solid State Phys.Symp., India (1970).

18. Study of the Two Hole States in ^{12}C Nucleus with the (π^-,nn) Reaction - B. K. Jain - The (π^-,nn) reaction on ^{12}C nucleus has been analysed to study the two hole states in nuclei using Ecksteins two nucleon model for the

* Now at I.I.T. Powai, Bombay.

pion-nucleus interaction. The distortion of the outgoing neutrons has been incorporated by the use of the optical model potential. The results for the absorption of pions from its 1S atomic state are roughly in accord with the experiments.

Presented at the Nucl.Phys.and Solid State Phys.Symp., India (1970).

INSTRUMENTATION

1. <u>On-line Internal Conversion Electron Studies</u> - C.V.K. Baba, S.K. Ambardekar* and S.M. Bharathi* - A six gap 'orange' beta-ray spectrometer, with a transmission of 10% at a 1% momentum resolution, has been set up at one of the beam ports. It has already been used to study the isobaric analogue states in ^{73}As by $^{72}Ge(p,p')Ge^{72*}$. The inelastic scattering to the 0.691 MeV 0_2^+ level in ^{72}Ge was studied by measuring the internal conversion electrons ($0_2^+ \rightarrow 0_1^+$) in the spectrometer. Preliminary data on the internal conversion lines has also been callected in $^{65}Cu(p,n)^{65}Zn$ and $^{75}As(p,n)^{75}Se$ reactions. The instrument is automatised. It is also possible to place a gamma detector at 2 - 10 cms from the source and use it in coincidence operation. Preliminary data on the halflife 287 KeV level in ^{75}Se also has been obtained.

2. <u>Determination of the Efficiency of the 4π - Neutron Counter</u> - S.K. Gupta and S.S. Kerekatte - The efficiency of the 4π -geometry neutron counter has been measured within an accuracy of $\pm 7\%$. This measurement supercedes an earlier measurement by Sekharan[1] which was accurate to $\pm$ 12%

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Two accurately weighed LiF targets were used to produce the neutrons, using the $^7Li(p,n)^7Be$ reaction. The data was corrected for the dead time of the scalars, and the background. The estimates of errors were ±1% for the beam current integrator, ±4% for the reproducibility of the data and the target thickness; and ±5% for the $^7Li(p,n)^7Be$ cross section[2]. All these errors combine to give an r.m.s. value of ±7%. The efficiency has been measured in the neutron energy range of 0.03 to 1.6 MeV and is shown in Fig.12. The anomalous behaviour around the neutron energy of 0.2 MeV has been already explained by Sekharan[1].

1) K.K. Sekharan, M.Sc. Thesis, University of Bombay,1965.

2) J.H. Gibbons and R.L. Macklin,Phys. Rev. 114(1959)571.

3. <u>Target Evaporation Facility</u> - B. Lal*,M.V.Vaze and Baldev Sahai* - Preparation of targets, from highly enriched isotopes which are available in small quantities due to their prohibitive cost, is not possible in the conventional manner as the same needs large quantities of substance, the major part of which goes waste. Special apparatus has been designed and got fabricated which enables the preparation of targets from milligram quantities of substance using the principle of electron bombardment.

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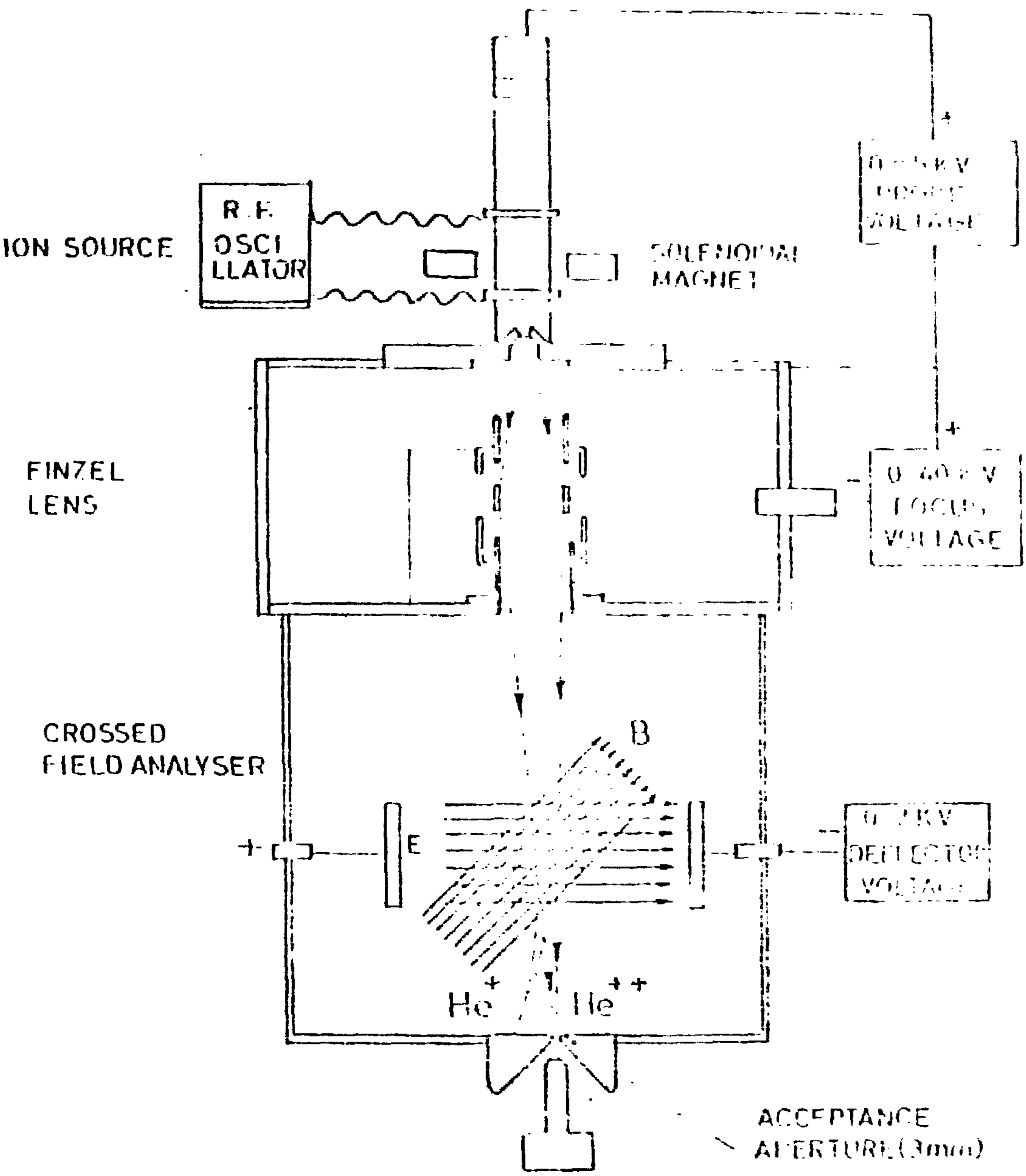
4. Efficiency Measurements of the 30 c.c.Ge(Li) Gamma-ray Detector - M. Ismail and M.A. Eswaran - Absolute efficiency measurements were made for the 30 c.c. coaxial Ge(Li) gamma ray detector for the energy range 0.2 to 6.13 MeV. For lower energies the radioactive sources ^{133}Ba, ^{137}Cs, ^{22}Na, ^{54}Mn and ^{60}Co were used and for higher energies the nucleon reactions $^{27}Al(p,\gamma)^{28}Si$ (E_p = 0.992 MeV) and $^{19}F(p,\alpha\gamma)^{16}O$ (E_p = 1.375 MeV) were used which yield 1.78 MeV and 6.13 MeV gamma rays respectively. These measurements were made at source to detector distance of 4.5 cm and the source strengths were calibrated using the known efficiency of the 7.6 x 7.6 cm NaI(Tl) crystal. Fig.13 shows the results, for the full energy peak efficiency. The ratios ,double escape peak K_0 full energy peak and single escape peak to full energy peak are also shown in the figure which were obtained for gamma rays produced in the above mentioned reactions as well as in $^{32}S(p,\gamma)^{33}Cl$ and $^{34}S(p,\gamma)^{35}Cl$ reactions.



ION SOURCE
R.F. OSCI LLATOR
SOLENOIDAL MAGNET
FINZEL LENS
FOCUS VOLTAGE
CROSSED FIELD ANALYSER
B
E
He+
He++
ACCEPTANCE APERTURE (3mm)

FIG. 1

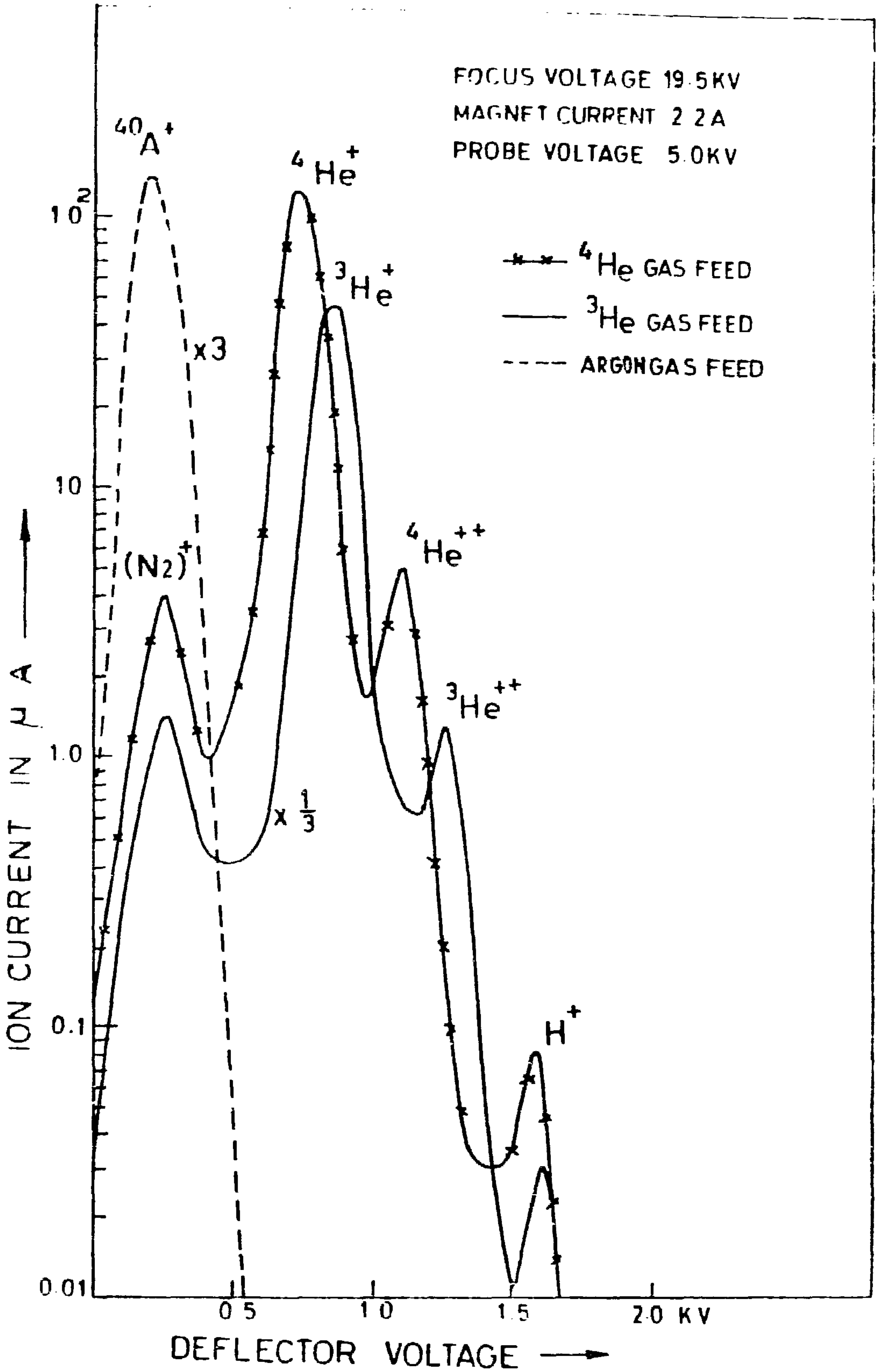

FOCUS VOLTAGE 19.5KV
MAGNET CURRENT 2.2A
PROBE VOLTAGE 5.0KV
^{4}He GAS FEED
^{3}He GAS FEED
ARGONGAS FEED
$^{40}A^+$
$^4He^+$
$^3He^+$
$^4He^{++}$
$^3He^{++}$
$(N_2)^+$
H^+
x3
x $\frac{1}{3}$
10^2
10
1.0
0.1
0.01
0.5
1.0
1.5
2.0 KV
ION CURRENT IN μA
DEFLECTOR VOLTAGE

FIG. 2

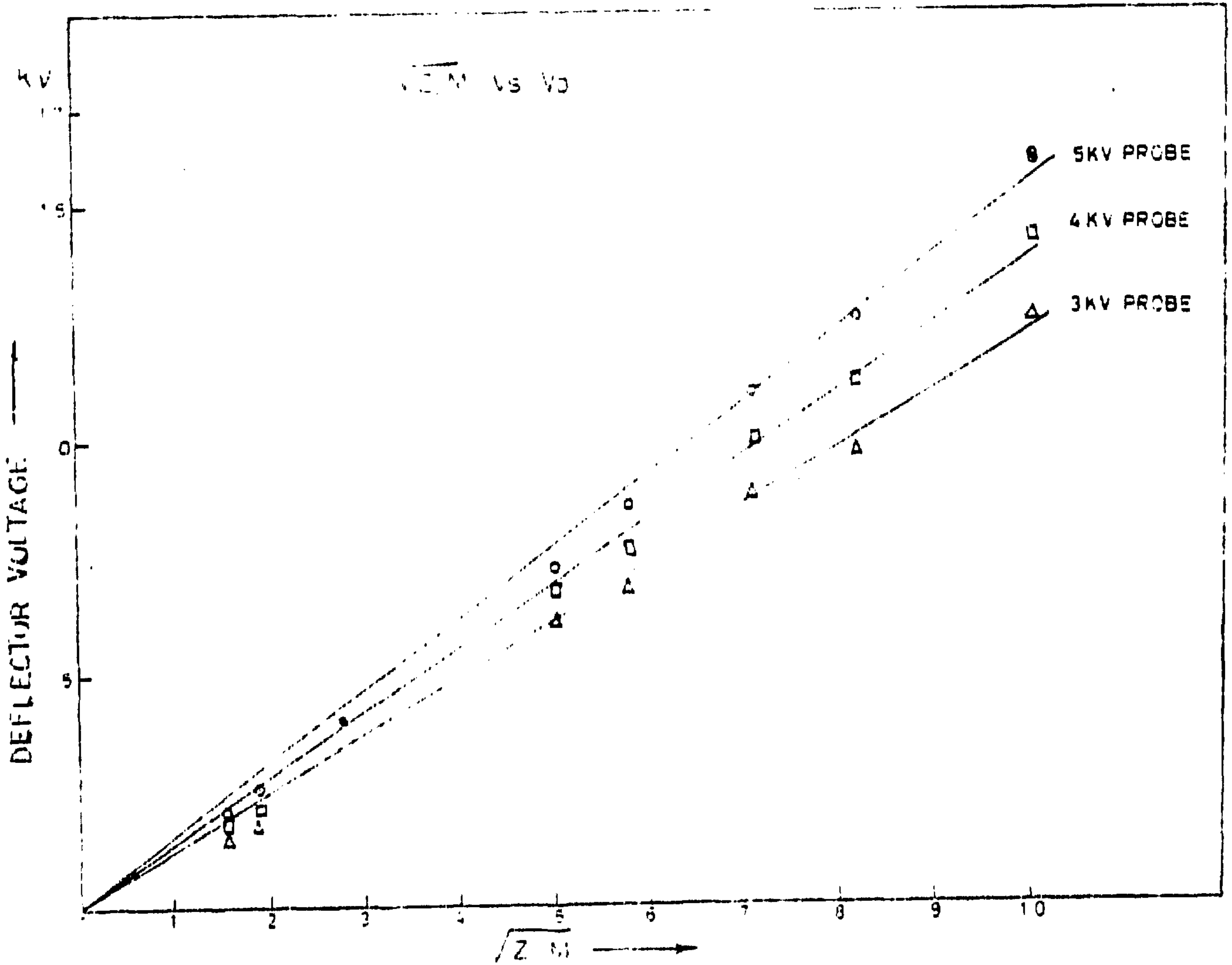
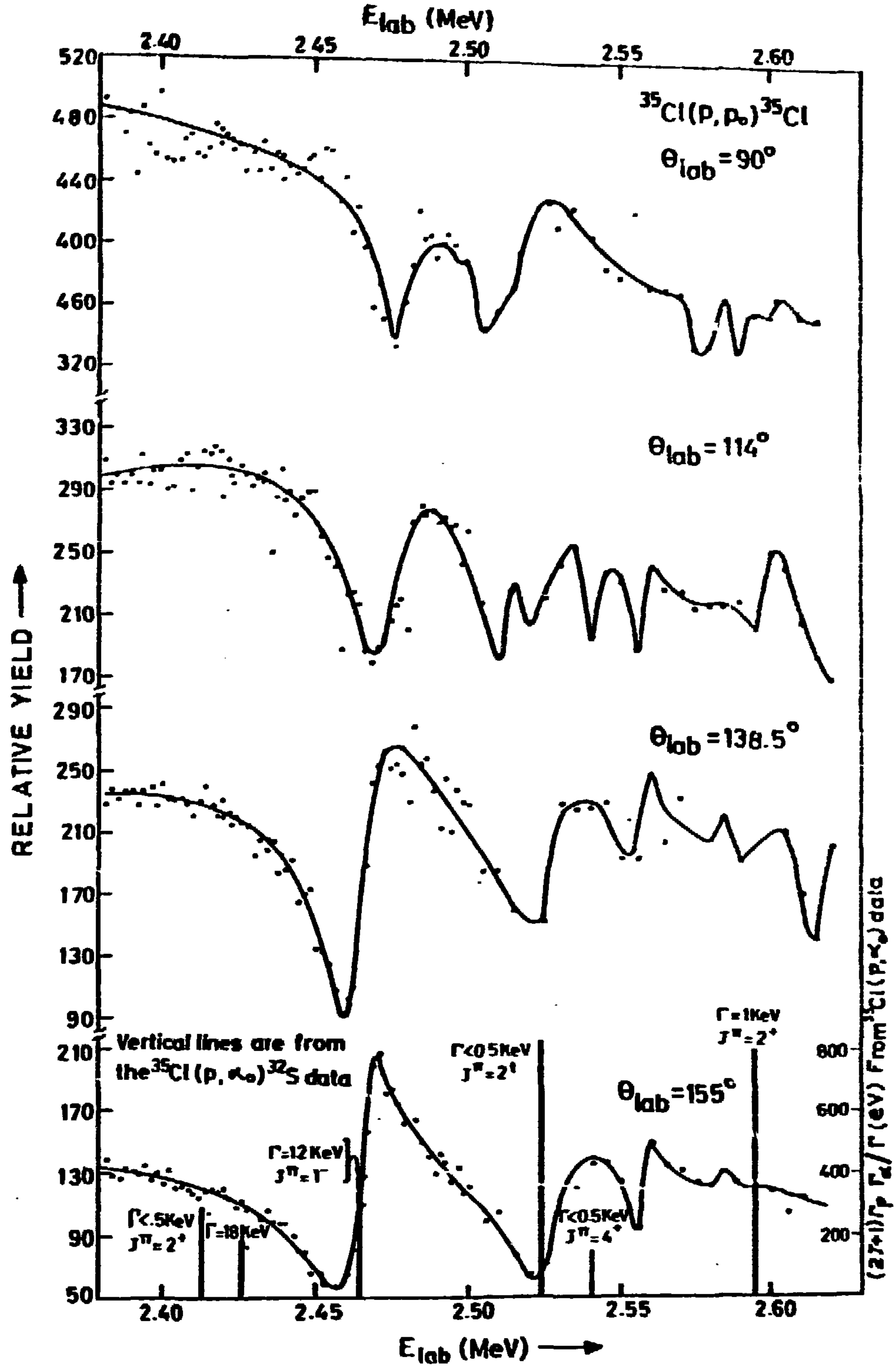
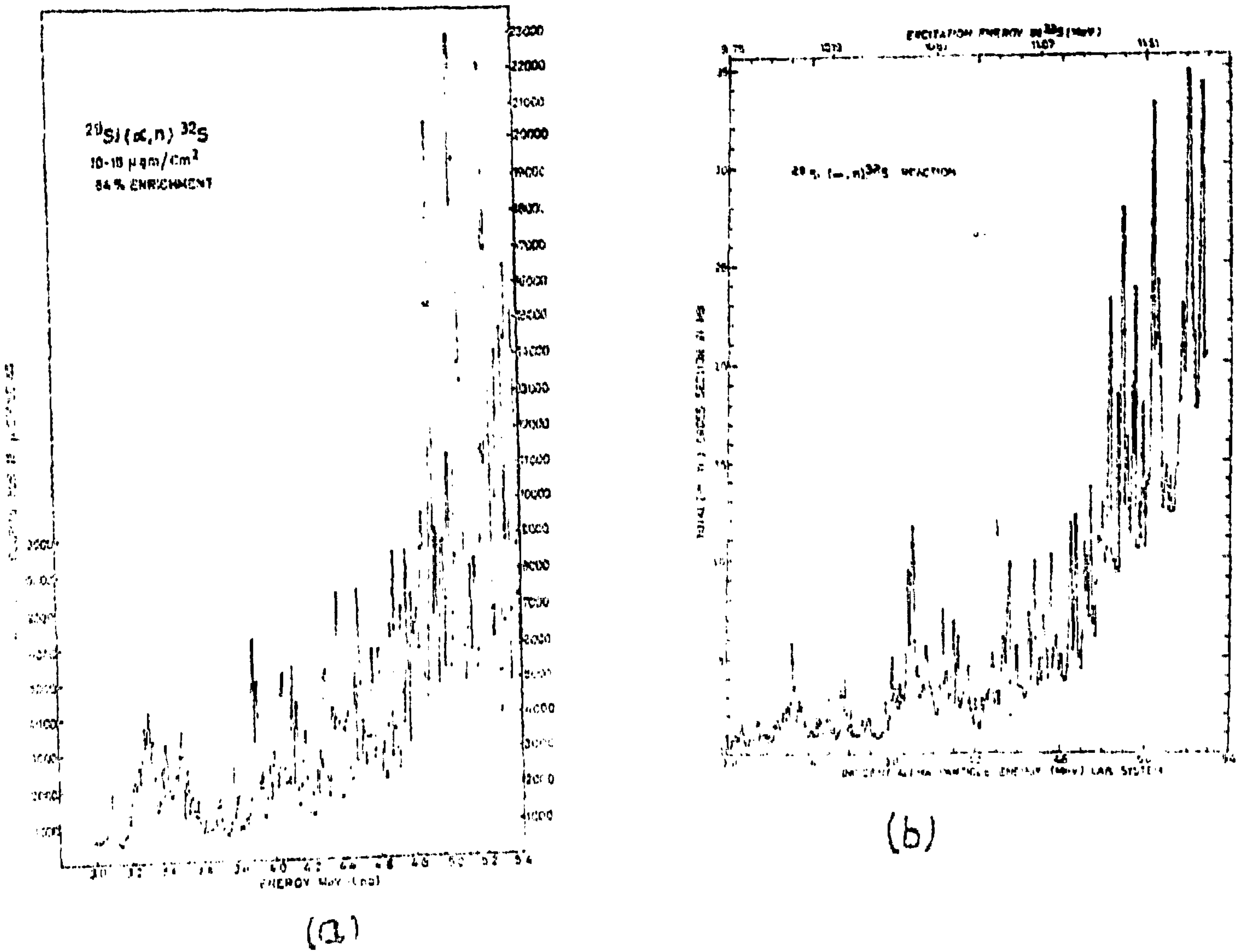

KV
Vs VD
5KV PROBE
4KV PROBE
3KV PROBE
DEFLECTOR VOLTAGE
5
1
2
3
4
5
6
7
8
9
10

FIG.3



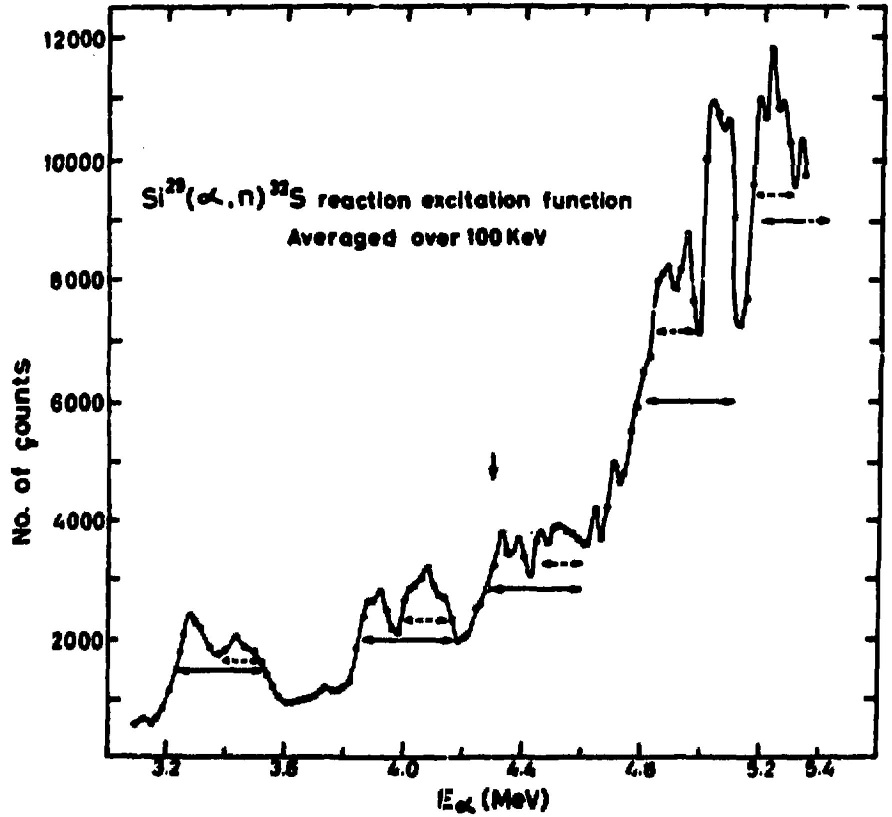
E lab (MeV)
35Cl(p,p0)35Cl
θlab=90°
θlab=114°
θlab=138.5°
θlab=155°
RELATIVE YIELD
Vertical lines are from the 35Cl(p,α0)32S data
Γ<.5KeV Jπ=2+
Γ=18KeV
Γ=12KeV Jπ=1−
Γ<0.5KeV Jπ=2+
Γ<0.5KeV Jπ=4+
Γ=1KeV Jπ=2+
(2J+1)Γp Γα/Γ (eV) From 35Cl(p,α0) data
E lab (MeV)

FIG. 4



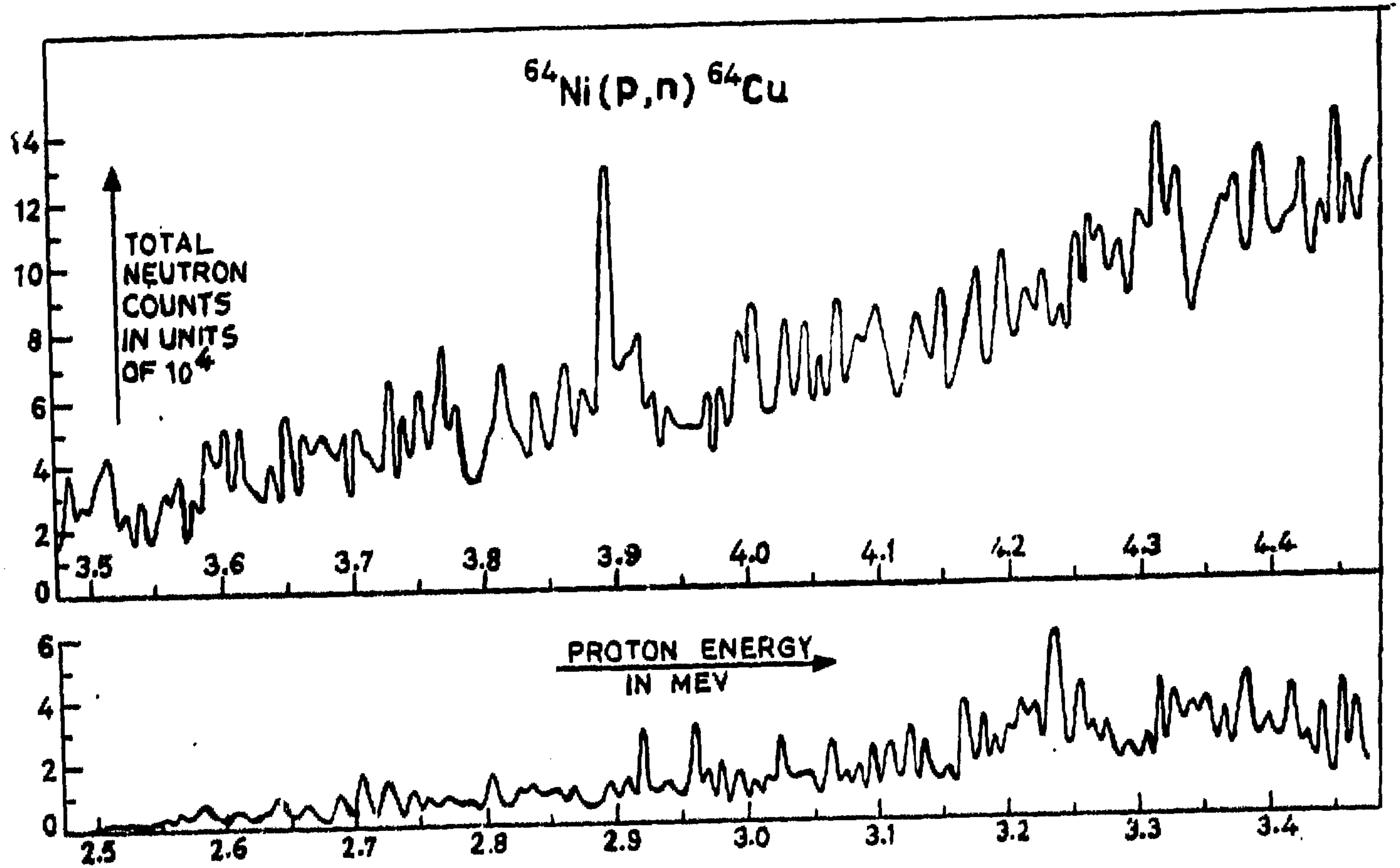
$^{29}Si(\alpha,n)\ ^{32}S$
10-18 μgm/cm^2
84% ENRICHMENT
ENERGY MeV (lab)
(a)
EXCITATION ENERGY IN ^{32}S (MeV)
$^{29}Si(\alpha,n)^{32}S$ REACTION
(b)

FIG. 5



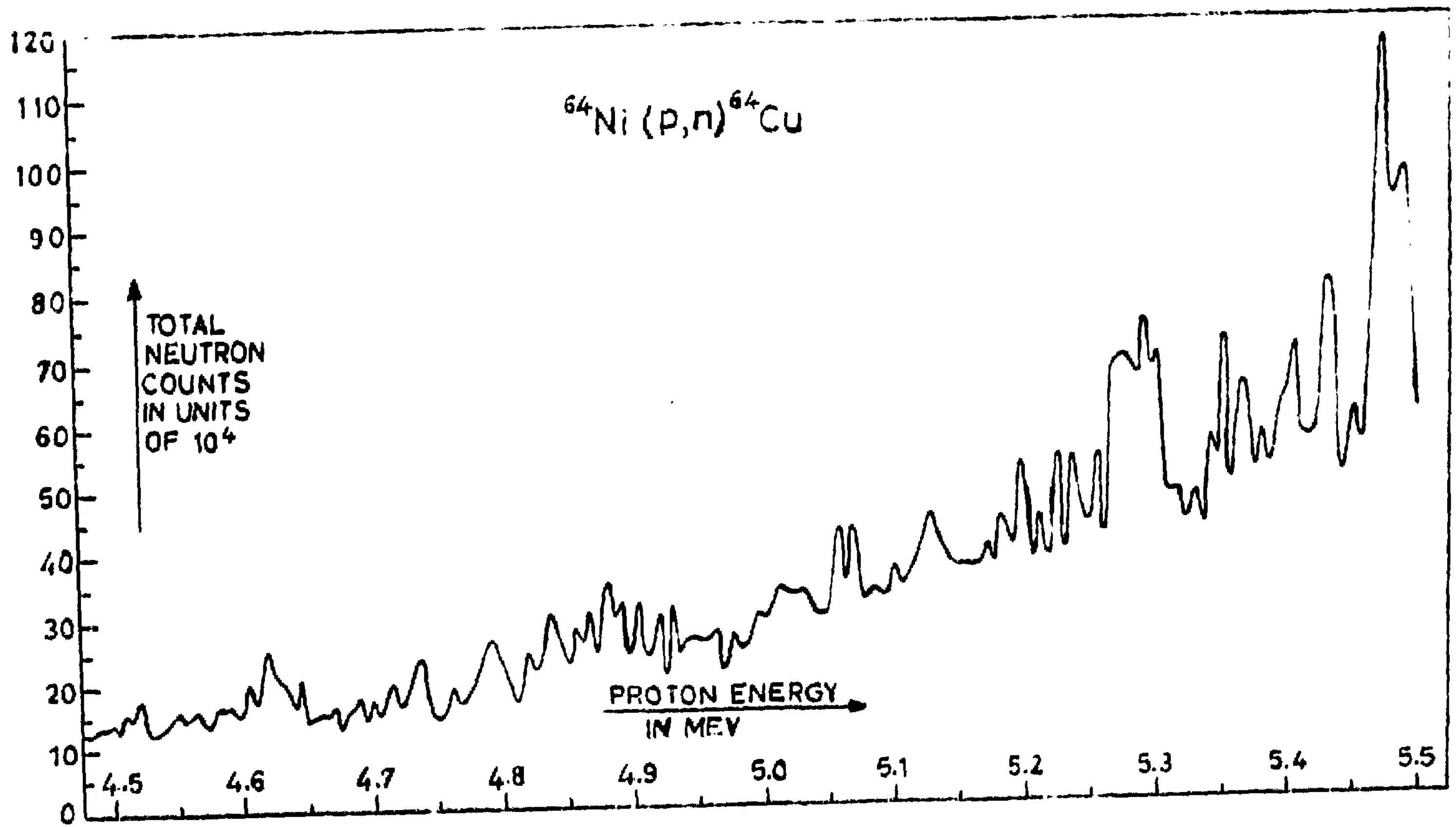
$Si^{29}(\alpha, n)^{32}S$ reaction excitation function
Averaged over 100 KeV
12000
10000
8000
6000
4000
2000
No. of counts
3.2
3.6
4.0
4.4
4.8
5.2
5.4
E_α (MeV)

FIG. 6



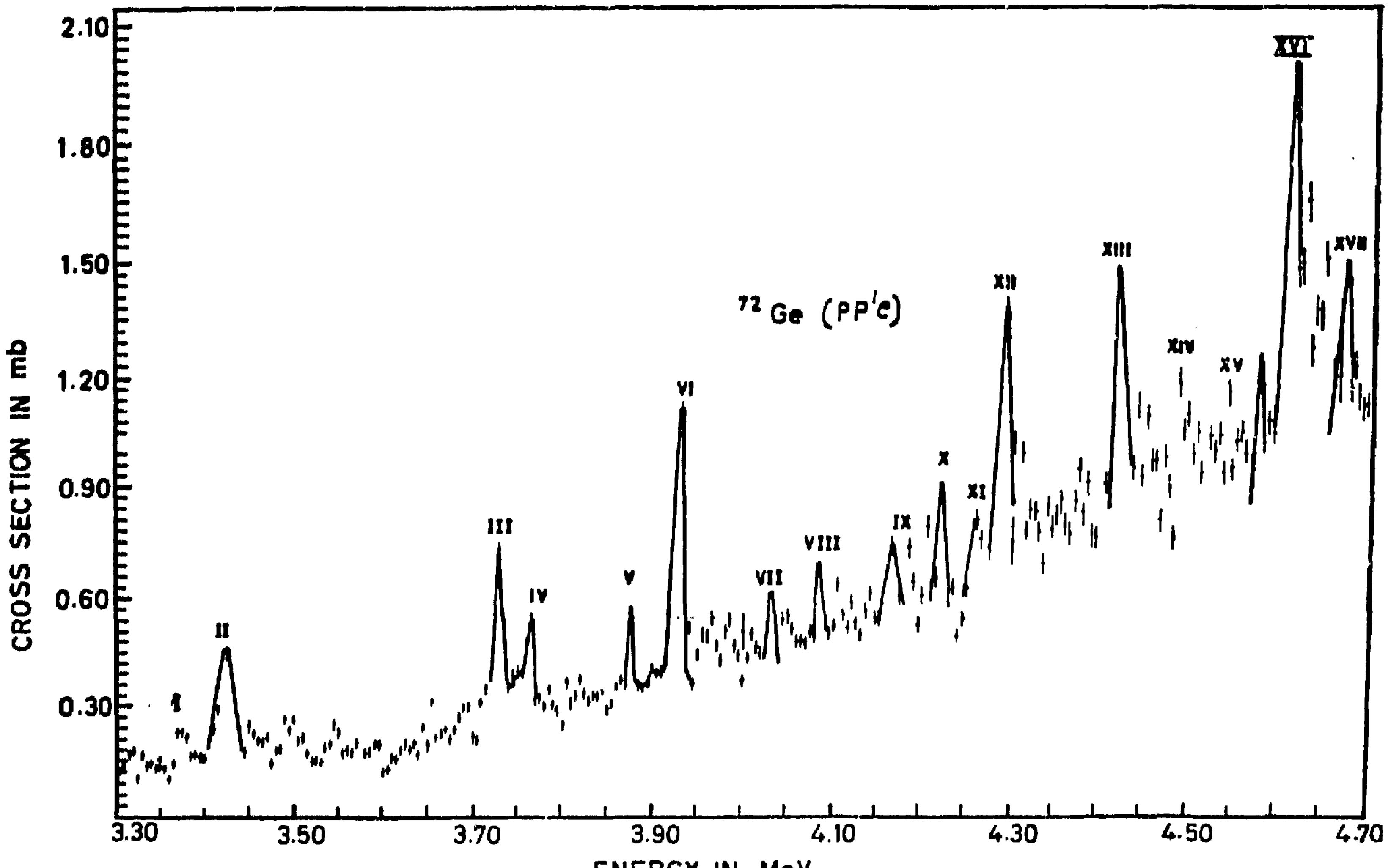
64Ni(p,n)64Cu
TOTAL NEUTRON COUNTS IN UNITS OF 10
0
2
4
6
8
10
12
14
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
PROTON ENERGY IN MEV
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4

FIG. 7 (a)



$^{64}Ni\ (p,n)^{64}Cu$
TOTAL NEUTRON COUNTS IN UNITS OF 10^4
PROTON ENERGY IN MEV
0
10
20
30
40
50
60
70
80
90
100
110
120
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5

FIG 7 (b)



^{72}Ge (PP'c)
CROSS SECTION IN mb
2.10
1.80
1.50
1.20
0.90
0.60
0.30
ENERGY IN MeV
3.30
3.50
3.70
3.90
4.10
4.30
4.50
4.70
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII

FIG. 8

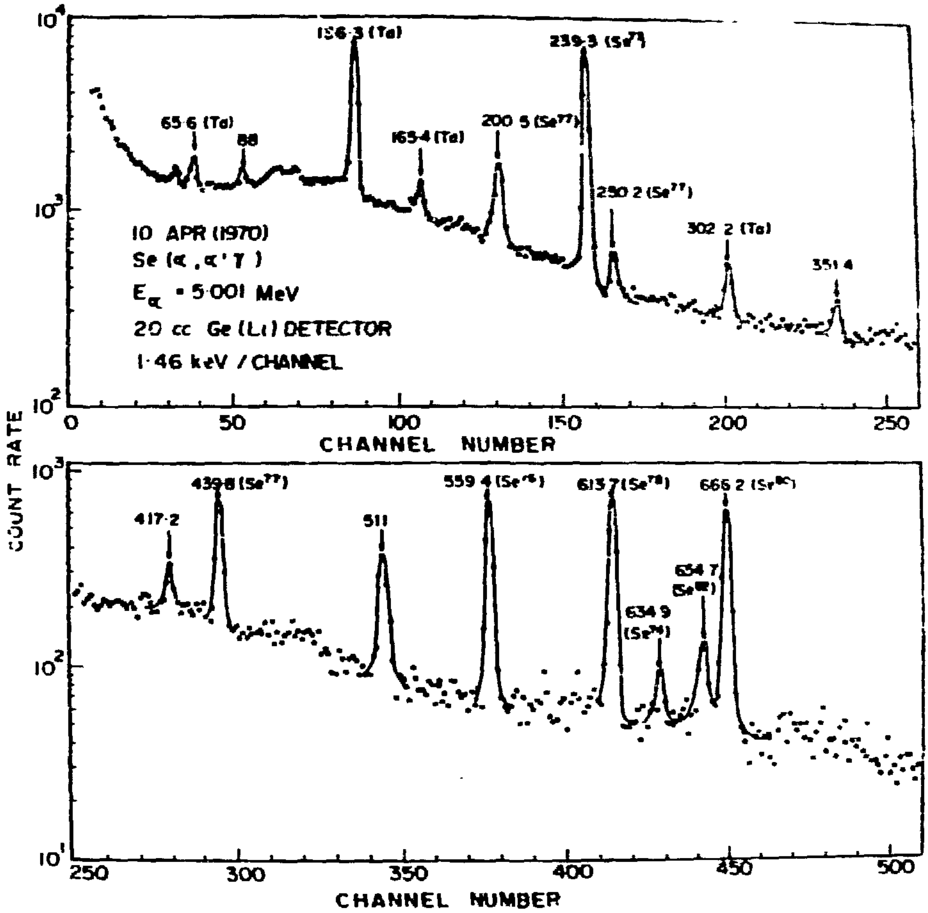


Fig. 9

γ spectrum of natural Selenium target bombarded with alpha particles, using 20 c. c. Ge Li detector

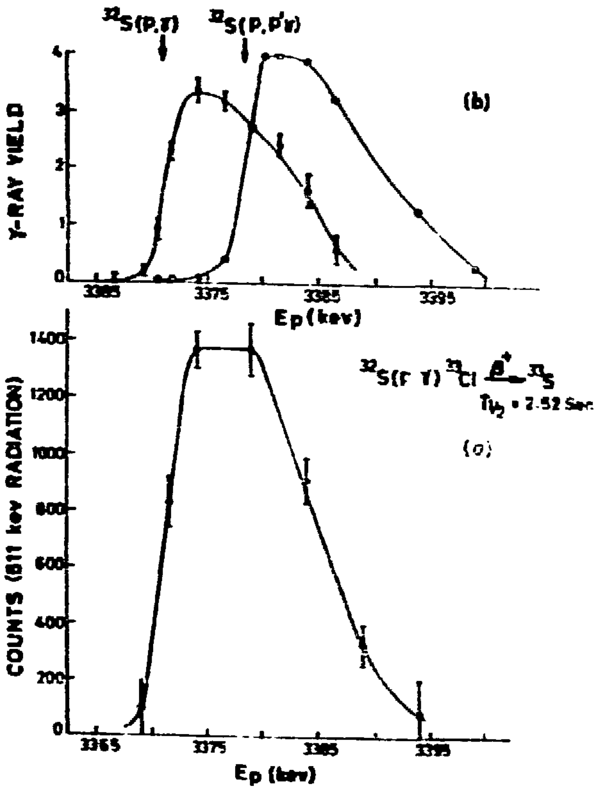


FIG. 10

a) Excitation curve for the reaction $^{32}S(p,\ )^{33}Cl$ measured near the T = 3/2 state by counting the residual activity

b) Excitation curve measured by counting the gamma ray yield for the $^{32}S(p,\ )^{33}Cl$(E = 4.75 MeV) and the $^{32}S(p,p'\ )^{32}S$ (E = 2.237 MeV) reaction showing the T = 3/2 state resonance in the former and the known resonance (T = 1/2) at E_p = 3.379 MeV in the latter.

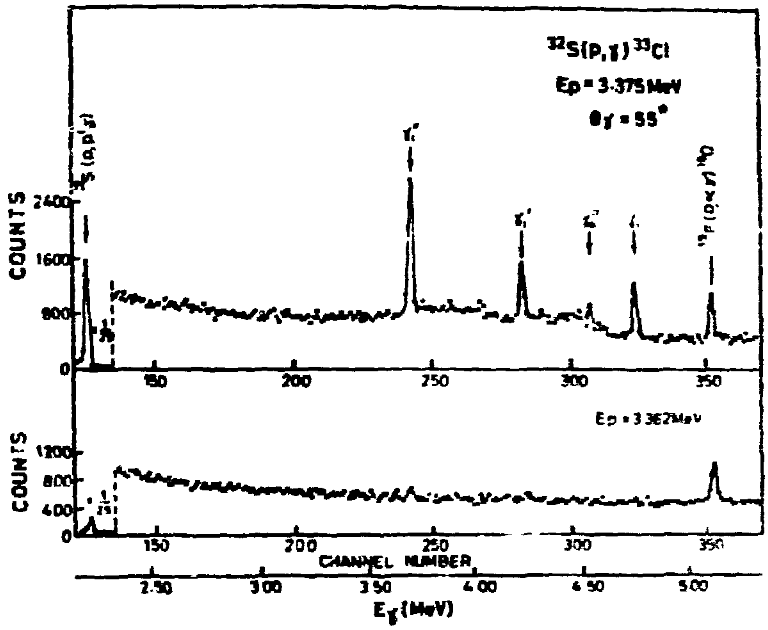
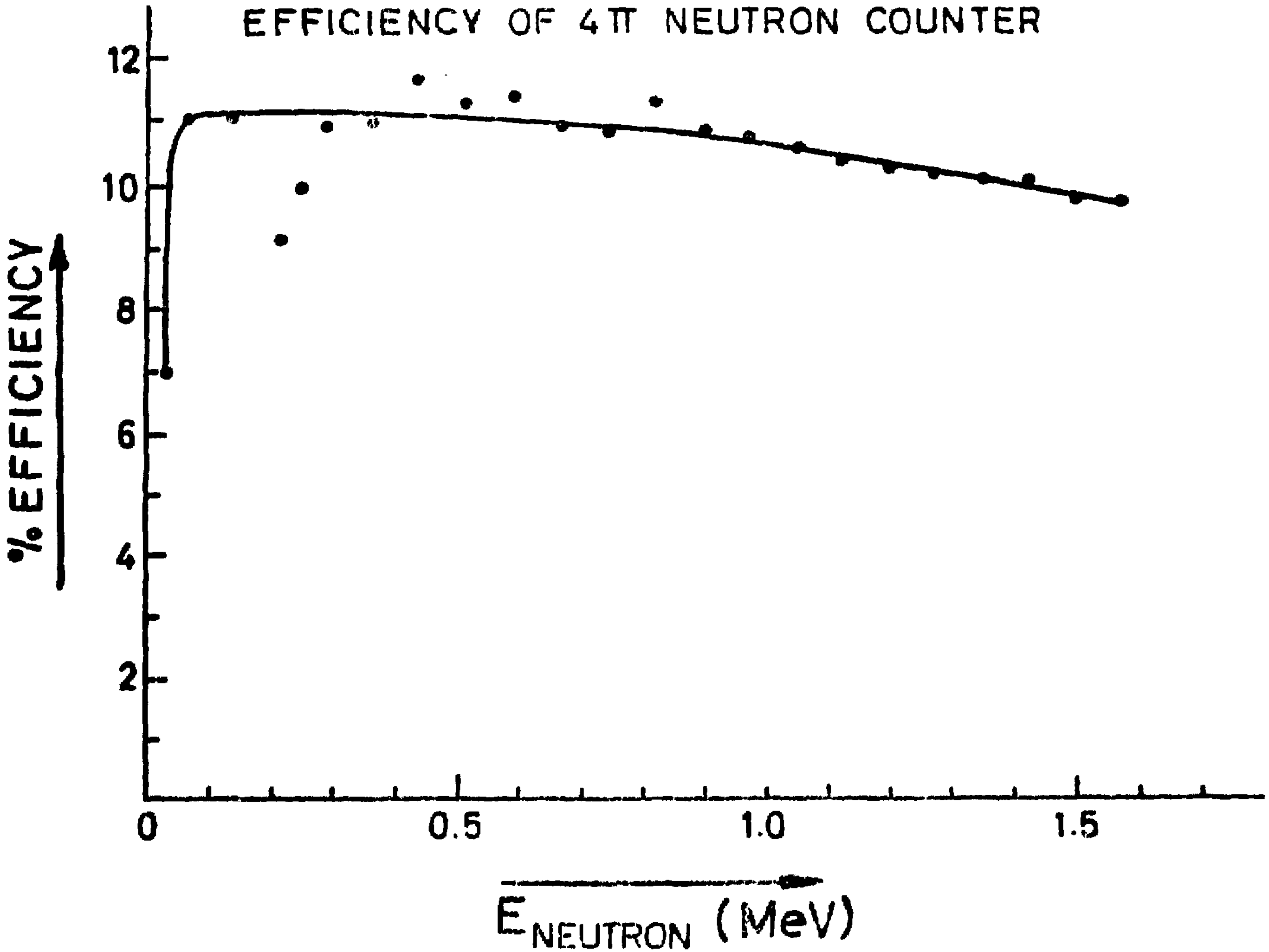


FIG. 11

γ - ray spectra taken on the 3.371 MeV resonance and at an off resonance energy in $^{32}S+p$. The resonance spectrum was measured at a proton energy at which yield was at maximum. The Ge(Li) detector was at 55° to the incident beam.


EFFICIENCY OF 4π NEUTRON COUNTER
12
10
8
6
4
2
% EFFICIENCY
0
0.5
1.0
1.5
E NEUTRON (MeV)
FIG.12

EFFICIENCY OF 30 C.C. GE(LI) DETECTOR

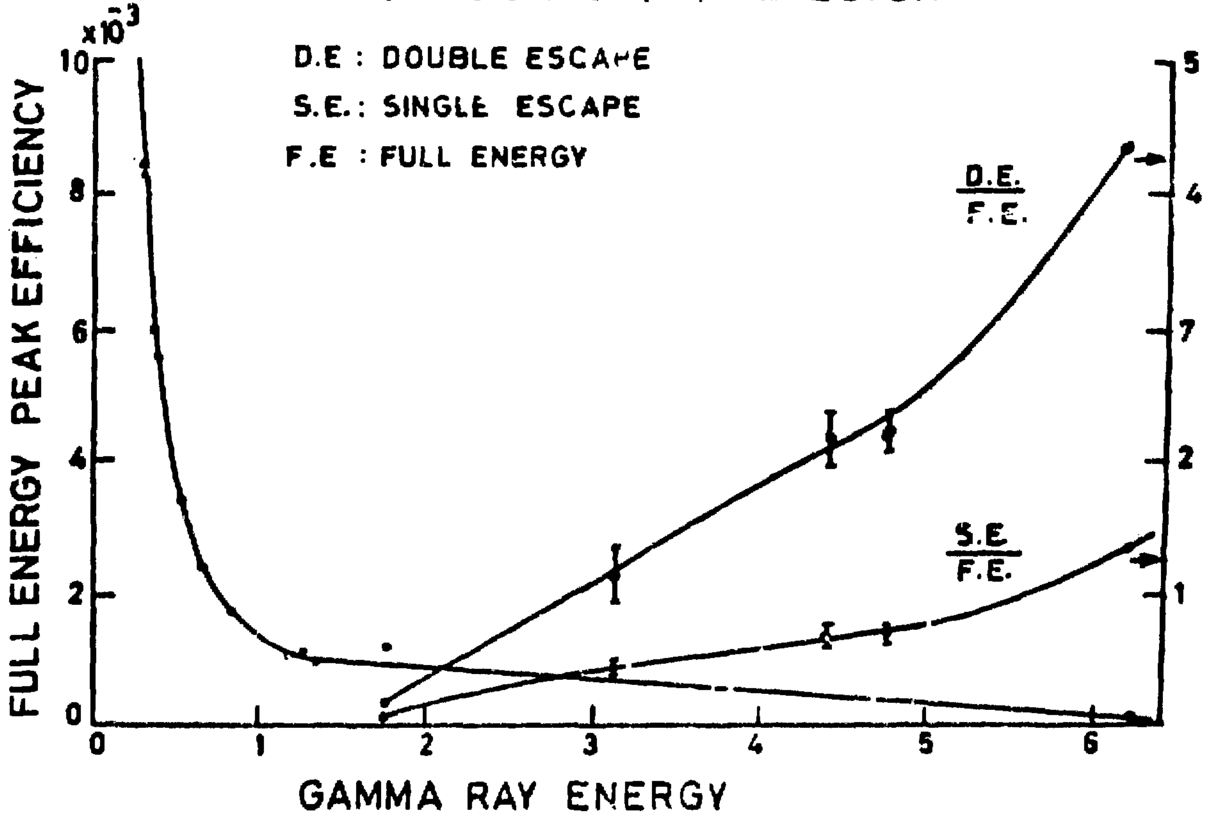


FIG.13