Nuclear Physics **A352** (1981) 237–246; © *North-Holland Publishing Co., Amsterdam*

COLLECTIVE EXCITATIONS IN ^{88}Y

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Received 26 February 1980
(Revised 26 August 1980)

Abstract: High-spin states in ^{88}Y were excited through the ^{87}Rb(α, 3n) reaction at energies between 30 and 55 MeV. The population of the previously known 8^+ and 9^+ members of the $\{\pi g_{9/2} \otimes \nu^{-1} g_{9/2}\}$ multiplet carry most of the total cross section. Above the 8^+ state a sequence of 5 levels is observed, which can be interpreted as arising from the coupling of this level with the excitations of the ^{88}Sr core. A similar interpretation is suggested for the 3206.8 keV state which deexcites into the 9^+ state. Only a few of the many low-lying low-spin states previously reported are weakly seen with this reaction. The relative cross sections for the different outgoing channels are compared with those observed in the ^{85}Rb(α, xnypzα) reactions and both sets are in turn combined with earlier data obtained with the Zn isotopes to show that it is possible to attain a systematics for the relative strengths.

E | NUCLEAR REACTION ^{87}Rb(α, 3n), E = 30–55 MeV; measured E_γ, I_γ, $\sigma(E_\alpha, E_\gamma, \theta_\gamma)$, γγ-coin. ^{88}Y deduced levels, J, π. Ge(Li) detectors.

1. Introduction

The nucleus ^{88}Y has been the subject of a considerable number of studies [1–11]. The interest in this nucleus derives from the fact that it lies next to ^{88}Sr and ^{90}Zr, two nuclei which represent relatively good cores. Thus information on this nucleus could not only provide a valuable testing ground for p-n interactions but also for the nature of the core states.

Comfort and Schiffer [4]) studied ^{88}Y using different reactions. They identify many new states below 2.5 MeV with angular momenta ranging up to that of the 9^+ state, described as the highest-spin member of the $\{\pi g_{\frac{9}{2}} \otimes \nu^{-1} g_{\frac{9}{2}}\}$ multiplet. Their data suggest that ^{88}Sr is a better core than ^{90}Zr since in the ground state of this nucleus the $p_{\frac{1}{2}}$ and $g_{\frac{9}{2}}$ orbits are mixed.

† Eellow of the Consejo Nacional de Investigaciones Cientificas y Tecnicas.

In spite of the many investigations carried out until now on ^{88}Y, states of angular momenta larger than 9 have not been reported. In a nucleus like ^{88}Y one expects to find higher angular momentum states originating in the weak coupling of the high-spin members of the $\{\pi g_{\frac{9}{2}} \otimes \nu^{-1} g_{\frac{9}{2}}\}$ multiplet with core excitations. This has been recently found to be the case in ^{89}Y [refs. [12,13]]. These results, as well as those obtained for ^{87}Sr by Arnell *et al.* [14]), stimulate a similar search for these states in ^{88}Y.

2. Experimental procedure

The ^{87}Rb(α, 3n) reaction was chosen as a suitable way to reach large angular momentum states in ^{88}Y. The α-particle beam from the Buenos Aires Synchro-cyclotron was focused onto a target of RbCl enriched to 98 %, and deposited on a 4 μm mylar foil. Energies between 30 and 55 MeV were used. Gamma rays were detected with two Ge(Li) counters of about 7 % efficiency and 2.5 keV energy resolution at 1.33 MeV. The single γ-ray spectrum was investigated between 50 and 3500 keV. A section of it up to 2 MeV, obtained at E_α = 40 MeV is shown in fig. 1. The two prominent lines at 232.1 and 442.8 keV correspond to the well-known two-γ-ray cascade depopulating the 13.9 ms 8^+ isomer into the ground state of ^{88}Y. The strongest line from the ^{87}Rb(α, 2n)^{89}Y reaction [12]) is at 908.6 keV.

The γ-rays assigned to ^{88}Y are labeled by their energy values in keV. Triangles and solid dots indicate lines of ^{89}Y and ^{88}Sr respectively. Most of these ^{88}Y lines are observed for the first time and have been identified mainly through the analysis of their excitation functions. Because these lines correspond to deexcitations into the 8^+ isomer (see below), they are not seen in coincidence with those γ-rays already known, with the exception of the 802.1 keV line which we identify with that of 800.9 keV assigned to ^{88}Y by Baer *et al.* [9]).

The ^{87}Rb(α, 3n)^{88}Y reaction reaches its maximum cross section at 40 MeV while the (α, 2n)^{89}Y and (α, 4n)^{87}Y channels show their maxima below 30 and above 55 MeV, respectively. A similar excitation function to that corresponding to the (α, 3n) reaction is exhibited by the ^{87}Rb(α, 2np)^{88}Sr reaction which is seen to peak at ~ 45 MeV. Other possible channels have been checked in order to ensure the validity of the present identification. In this connection, and also with the purpose of extending a systematic study of relative cross sections carried out a few years ago [15]), we shall discuss the relative cross sections of the different reactions observed in this work and in a previous one [12]) in a later section of this paper.

A measurement of the γ-ray angular distributions was performed by placing a Ge(Li) counter at about 15 cm from the target and at different angles with respect to the beam axis between 90° and 140°. The counts accumulated under the 442.8 keV peak were used to normalize the different spectra as the transition corresponding to this peak is expected to be isotropic. The A_2/A_0 coefficients resulting from a two parameter least-squares fit ($A_4 \equiv 0$) for the stronger lines are listed in table 1,

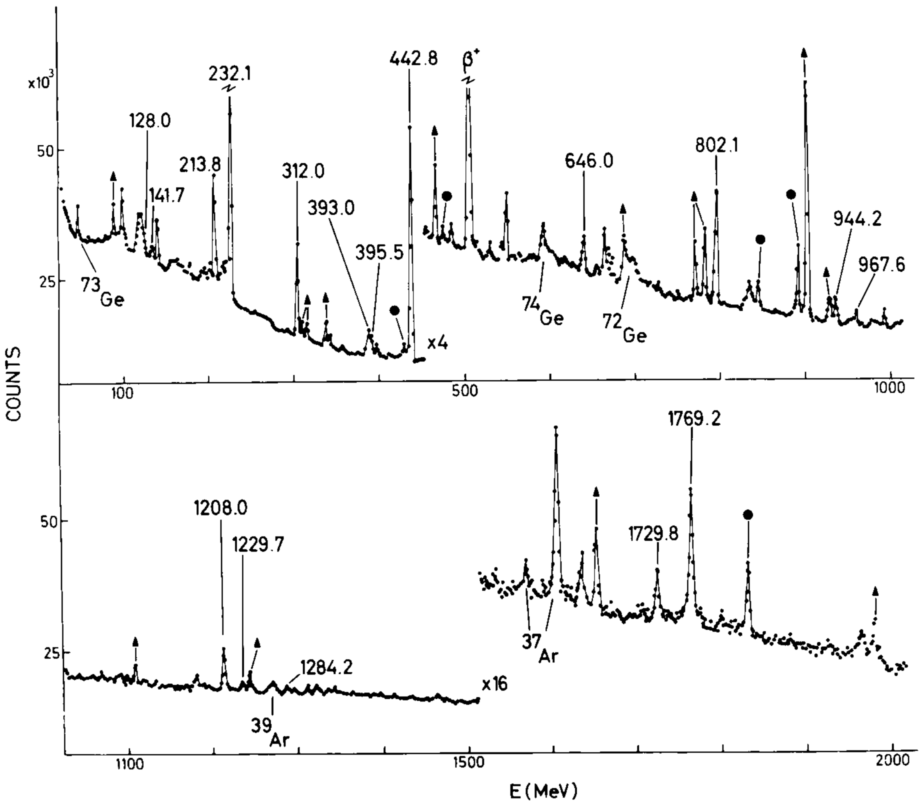

Fig. 1. Singles γ-ray spectrum up to 2 MeV from the $^{87}Rb+\alpha$ reaction at E_α = 40 MeV obtained with a 7 % efficiency Ge(Li) detector. The γ-rays assigned to ^{88}Y are labelled by their energy values in keV. Triangles and solid dots indicate lines of ^{89}Y and ^{88}Sr respectively.

together with energies and intensities for all the γ-rays assigned to ^{88}Y.

For the γ-γ coincidence measurements the two Ge(Li) detectors were placed at 90° and 270° with respect to the beam axis and approximately 2.5 cm from the target. The pulse heights from each ADC and the time-to-amplitude converter signals were recorded on magnetic tapes in the event-by-event mode. A window of approximately 60 ns width was placed on the time spectrum. The covered energy range was approximately from 100 to 2000 keV. In spite of the length of the experiment, the results of these measurements are limited by the maximum current attainable ($\sim$ 0.5 nA) and the duty cycle of $\sim$ 1.15 of the synchrocyclotron. A consistent chart of coincidence intensities for the strong lines was constructed and the results are summarized in table 2, in which the peak areas have been corrected by the counters' efficiencies so that cross combinations can be compared. Examples of coincidence spectra are shown in fig. 2. It should be noted that several runs similar

TABLE 1

Energy, intensity, assignment and angular distribution of γ-rays from the ^{89}Rb(α, 3n)^{88}Y reaction at E_α = 45 MeV

Energy (keV) (± 0.3 keV)	Intensity	Level energy sequence		A_2/A_0
128.0	~2	843.4	715.4	
213.8	8.2±0.8	4177.9	3964.1	−0.45±0.10
232.1	100 ±5.0	232.1	0.0	
312.0	14.3±1.4	3964.1	3652.1	−0.32±0.10
393.0	7.5±0.6	393.0	0.0	
395.5	5.7±0.3			−0.30±0.2
442.8	96.6±4.0	674.9	232.1	normalization
646.0	6.8±0.5	4823.9	4177.9	−1.13±0.21
802.1	21.4±2.1	1477.0	674.9	−0.64±0.11
944.2	8.8±0.6			−1.13±0.21
967.6	5.9±0.5	2444.1	1477.0	
1208.0	18.5±1.6	3652.1	2444.1	0.41±0.15
1229.7	~3	1461.8	232.1	
1284.2	~3	1284.2	0.0	
1729.8	8.7±0.7	3206.8	1477.0	0.77±0.26
1769.2	47.0±3.0	2444.1	674.9	0.38±0.06

to that presented in fig. 2 were carried out in order to increase the confidence level of those coincidences indicated in table 2.

3. Results

As mentioned in the introduction many reaction studies have been carried out

TABLE 2

γ-γ coincidence intensities from the ^{87}Rb(α, 3n)^{88}Y reaction at E_γ = 45 MeV. Errors are about 30 %

E_γ	213.8	232.1	312.0	395.5	442.8	646.0	802.1	944.2	967.6	1208.0	1729.8	1769.2
Gate												
213.8			2.9	1.1		2.1	1.3	1.5	1.5	2.9		2.8
232.1					110							
312.0	5.0			1.1		1.4	1.5		w	2.8		2.3
395.5	0.9		0.8			0.2						
442.8		92										
646.0	2.4		1.4							0.6		w
802.1	1.0		1.0								1.0	
944.2	1.5		0.3									
967.6	w		w									
1208.0	5.0		6.2			1.2						0.8
1729.8							w					
1769.2	2.5		3.3			0.2				w		

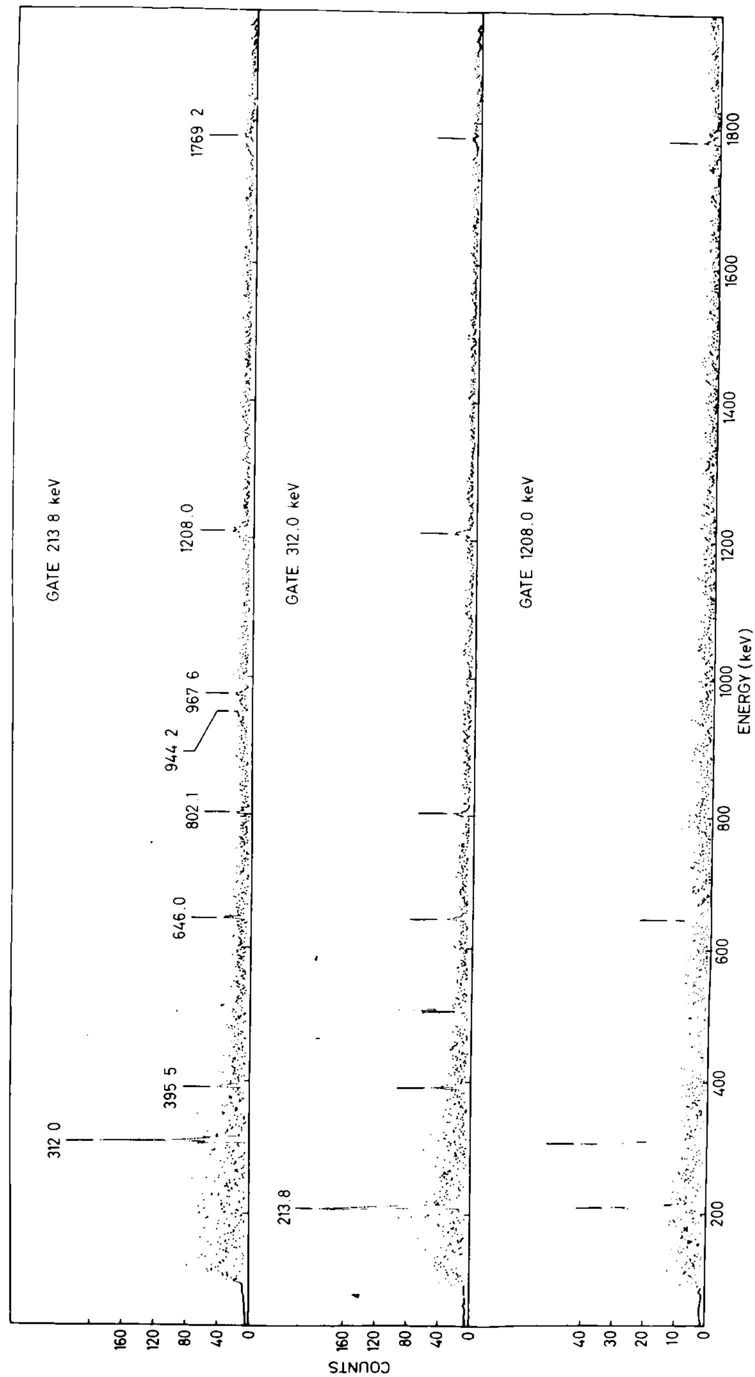

Fig. 2. The γ-ray spectra in coincidence with the 213.8, 312.0 and 1208.0 keV transitions. Counts were accumulated with two 7 % efficiency Ge(Li) detectors.

in the past to investigate the level structure of ^{88}Y, including γ-ray spectroscopy following the ^{85}Rb(α, n) reaction [9]. However, this is the first time that a reaction involving large bombarding energy has been used to reach high-spin states in ^{88}Y. As a result most of the γ-lines observed in this work and assigned to ^{88}Y had not been seen before. New levels are excited and only a few of the many hitherto known states are weakly populated in this work. This is not surprising as one expects to populate the yrast levels above the 8^+ isomer or the 9^+ state which lies 0.8 MeV higher. Whether the main path of decay of the residual nucleus goes through one or the other state, will be determined by the character of the excitations which give rise to the yrast line.

The data presented above allow us to establish the existence of a γ-ray cascade involving the 646.0, 213.8, 312.0, 1208.0 and 1769.2 keV transitions, in order of increasing intensity. This cascade is assigned to ^{88}Y and placed on top of the 8^+ isomer because: (a) the excitation functions are quite similar to those of the known 232.1, 442.8 and 802.1 keV lines; (b) the observation of coincidences between 213.8 and 312.0 keV lines and the 802.1 keV line; (c) the intensity of the strongest member of this cascade, the 1769.2 keV transition is only compatible with the intensities of the 442.8 and 232.1 keV γ-rays, being larger than the intensity of the 802.1 keV γ-ray which depopulates the 9^+ state; (d) other possible reactions such as ^{87}Rb(α, 2np) can be ruled out on the basis of the γ-ray spectroscopic information already available.

In addition to this strong cascade we observe the weak 128.0, 393.0, 1229.7 and 1284.2 keV γ-rays already reported by Baer *et al.* [9], which we place in the level scheme following these authors' work as our data are consistent with their assignment. Finally, a line at 1729.8 keV of moderate intensity (see fig. 1) is also assigned to ^{88}Y on the basis of its excitation function and the fact that there is (weak) evidence that it is in coincidence with the 802.1 keV transition. Because of this and of its intensity this line is placed in the level scheme as depopulating into the 9^+ state at 1477.0 keV.

Fig. 3 summarizes these results in a level scheme. The main cascade mentioned above defines new levels at 2444.1, 3652.1, 3964.1, 4177.9 and 4823.9 keV while the 1729.8 keV transition deexcites the 3206.8 keV level.

Transitions showing negative A_2/A_0 coefficients are interpreted as $\Delta I = 1$ transitions while those with $A_2/A_0 > 0$ may be of $\Delta I = 0$, 1 or 2 character. On this basis and considering that the lack of crossover transitions usually indicates an increasing sequence of angular momenta with excitation energy, we tentatively propose those spin values indicated in parentheses in fig. 3 for the new levels, above 2.4 MeV. Those below are given the values proposed by Baer *et al.* [9]).

If the levels populated by the main cascade are compared to those of ^{88}Sr a remarkable parallelism is found (see fig. 4) which strongly suggests that the sequence of levels observed in this work is likely to originate in core excitations coupled to the $\{\pi g_{\frac{9}{2}} \otimes \nu^{-1} g_{\frac{9}{2}}\}_{I=8^+}$ state. If this is assumed, then the 1769.2 keV γ-ray should

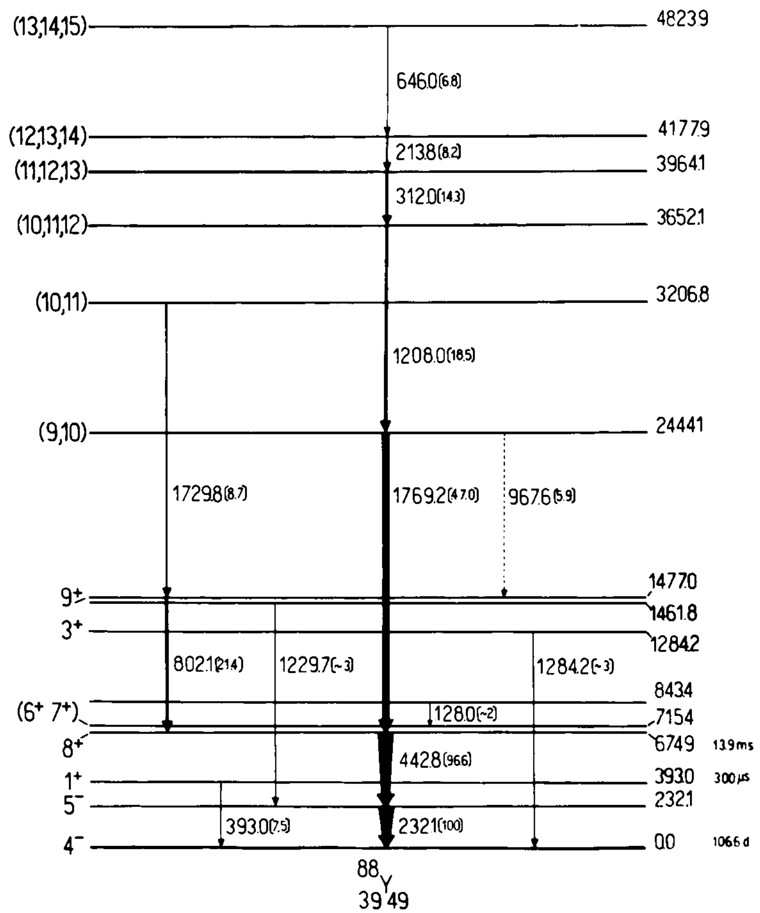

Fig. 3. Level scheme of ^{88}Y proposed in the present work.

correspond to an electric quadrupole $\Delta I = 2$ transition, which is consistent with the measured positive anisotropy of this line, and therefore the spin-parity of the 2444.1 keV level can be tentatively taken as 10^+. Other tentative assignments based on these arguments are also shown in fig. 4. In this connection we interpret the 1729.8 keV γ-ray as the quadrupole transition, analogous to the 1769.2 keV line, which corresponds to the deexcitation of the 11^+ level resulting from the coupling of the 2^+ core state to the $\{\pi g_{\frac{9}{2}} \otimes \nu^{-1} g_{\frac{9}{2}}\}_{I=9^+}$ intrinsic configuration. In such a case the 3206.8 keV level is an yrast state, and we should expect it to capture most of the decaying intensity from the residual nuclei. However if the upper transitions follow the same pattern of the main cascade observed in this work it becomes apparent why this is not the case; the next state on top of the 11^+ should be a 12^- lying at about $\sim$ 0.3 MeV above the 3964.1 keV level.

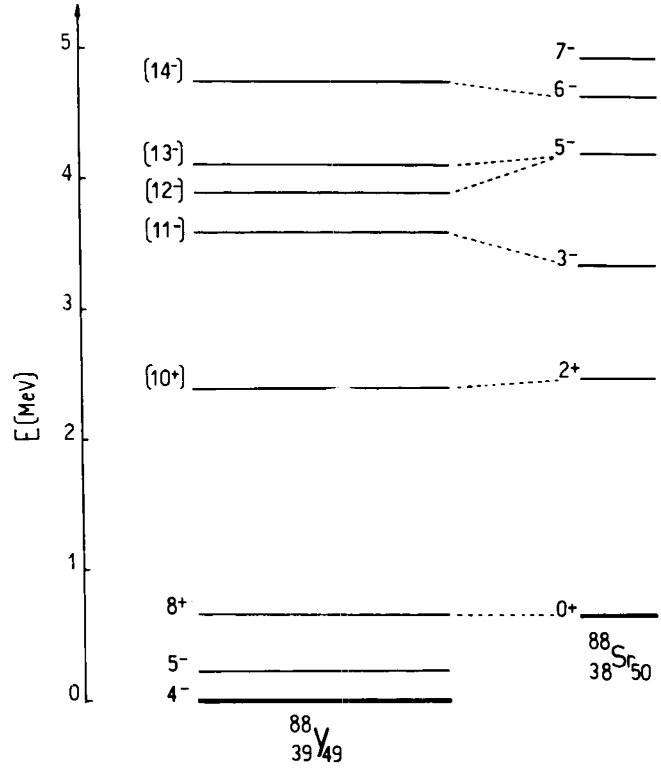

Fig. 4. The levels of ^{88}Y which are populated by the main cascade observed in this work are compared with the yrast states in ^{88}Sr. The scale for the ^{88}Sr has been shifted upwards to facilitate the comparison which supports the interpretation that the high spin states in ^{88}Y are due to core excitations.

4. Systematics of relative cross sections

Pomar *et al.* [15]) have shown that the relative cross sections of the $^{A}Zn(\alpha, xnypz\alpha)$ reactions with $A = 64$, 66, 67 and 68 show a regular behavior when plotted against A. This observation is of particular importance for medium to small A-mass nuclei since in these cases the emission of protons and α-particles strongly compete with the evaporation of neutrons and the systematics may help to identify reaction products and obtain estimates of expected relative cross sections.

By combining the data of this work and of a previous one [12]) using the targets ^{85}Rb and ^{87}Rb it is possible to investigate if the earlier results [15]) obtained for the Zn isotopes also apply for Rb isotopes. Even more significant is to explore the possibility of grouping together both sets of data by using the variable $A-1.7N$ [ref. [16])], which measures the degree of neutron deficiency of the target nuclei, instead A.

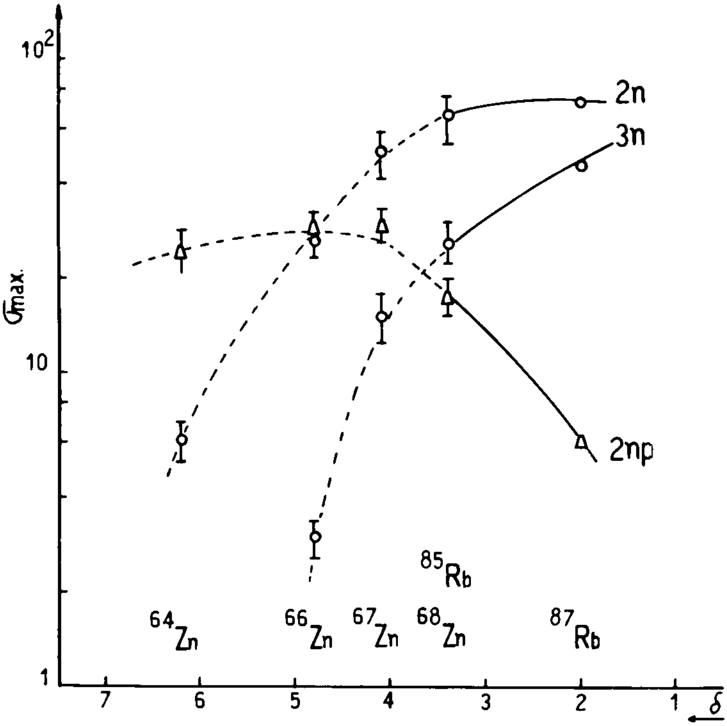

Fig. 5. The maximum cross section σ_{max} versus the degree of neutron deficiency of the target nuclei, as measured by $\delta = A-1.7N$, plotted for the Zn and Rb isotopes.

Fig. 5 shows a plot of the relative cross sections σ_{max} corresponding to the energies at which they reach the maximum. The dashed and solid lines correspond to the data of Pomar *et al.* [15]) and ours, respectively. The data for ^{85}Rb and ^{68}Zn have been used to normalize both groups. It is apparent that a smooth trend is obtained in spite of the mass difference involved between the Zn and Rb isotopes. These results show that one may hope to extend this systematics still further to serve as a guide for experimental work.

A similar systematics has been used also in connection with (^{16}O, $xnypz\alpha$) reactions in this mass region with satisfactory results [17]).

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