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ABSTRACT

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The cross sections for the (n,2n), (n,p) and (n,α) reactions of the target nuclei ^{85}Rb and ^{87}Rb were measured by the activation method with 14.8 MeV neutrons. (author)

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Abstract

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1. Introduction

The ^{84}Rb isomer at 464 keV is well established since many years. It was first reported by Flamersfeld in 1950 /1/. Two years later Caird and Mitchell /2/ reported that in their experiment they observed an extremely weak line at 890 keV with a half-life of 21 min. This should indicate a weak EC capture from the 463 keV state in ^{84}Rb via some excited states in ^{84}Kr feeding the 882 keV first excited state in ^{84}Kr. In a later work by Kneissl et al. /3/ and in Table of Isotopes /4/ these transitions have been refered to but no further experiments have been reported in which neither the fed states in ^{84}Kr nor the intensities of the transitions have been measured.

In the present experiment we have tried to determine this possible feeding of excited states in ^{84}Kr from ^{84}Rb through the $^{85}Rb(n,2n)^{84}Rb$ reaction. To do this it is necessary to know the cross sections of possible reactions with as good an accuracy as possible.

The cross sections for 14-15 MeV neutrons have been measured both with the mixed powder technique /5/ and with the sample sandwiched with a thin aluminium foil /6/.

The last step in our investigation was to try to avoid producing ^{84}Br and reduce the possible reactions by using the 42 MeV Betatron in Malmö General Hospital.

2. Experimental Procedure

Neutrons were produced via the $^{3}H(d,n)^{4}He$ reaction by bombarding a tritium target (0.021 mm thick Al-backing) with neutrons from the 500 kV Van de Graaff accelerator in the Lund Institute of Technology. The deutron energy was 360 keV.

The sample consisted of natural Rb_2CO_3 placed in a small plexi-glass box. The sample was 1.33 cm^2 in area and 2.65 mm thick. A 0.2 mm thick Al-sheet, 15.0 mm in diameter, was used as neutron flux monitor through the $^{27}Al(n,\alpha)^{24}Na$ reaction and was placed at one end of the plexi-glass box. During the irradiation the Rb_2CO_3 sample was nearest to the tritium target. The deutron beam was about 2 mm in diameter. It is therefore possible to assume that the neutrons come from a point source. The neutron beam had a half angle of 71° for the Rb_2CO_3 sample and 53° for the Al-sheet with respect to the deutron beam direction. The energy of the neutrons reaching the Al-sheet was determined to be 14.9±0.2 MeV by an integration method. At this energy $\sigma(n,\alpha)$ is 112±5 mb for the Al-monitor /7/. The average energy of the neutrons, which hit the Rb_2CO_3 sample, was determined to be 14.8±0.3 MeV. The neutron flux was corrected for flux variations.

In the determination of the cross sections for the $^{85}Rb(n,2n)^{84m,g,m+g}Rb$ reactions the mixed powder method was also used /5/, in order to find systematical faults. Several irradiations were made with either Al-powder or Al_2O_3, mixed in known proportions with Rb_2CO_3.

In the other irradiations when the decay schemas were studied only Rb_2CO_3 were used. The samples were placed in plexi-glass boxes 4.0 cm in diameter and 0.8 cm thick. The samples were positioned close to the tritium target. During the irradiations the neutron flux was about 10^8 neutrons/sec. sterrad.

The samples were irradiated for about one hour and the γ-ray measurements were started 7-15 minutes after the irradiation had been finished.

In another experiment three Rb_2CO_3 samples were irradiated for half an hour at the 42 MeV Betatron in Malmö General Hospital. The Betatron was adjusted to give γ-rays with a maximal energy of 25 MeV. This energy should be too low to produce any considerable amount of ^{84}Br through the $(\gamma,{}^3He)$ reaction. The absence of the 2484.6 keV γ-ray line, which only appears in the decay scheme of ^{84}Br, was taken as a measure of how well this had succeeded. The Rb_2CO_3 powder was placed in a 4.3 cm plastic tube with 1.2 cm in diameter. Before the analysis the powder was transfered to a plexi-glass box.

The γ-ray spectra were measured using a 40 cm^3 Ge(Li) detector with a resolution of about 2.8 keV for 1.33 MeV γ-rays.

The samples were placed just in front of the detector except during the determination of the cross sections, when the samples were placed at a distance of 42 mm in order to prevent summing.

The detector efficiency was determined for the two distances with the aid of a ^{226}Ra source. Gamma energies and intensities were taken from Ref. /8/.

The γ-decay of the product nuclei was observed by measuring three twenty minutes spectra just after the irradiation and a few spectra registered at suitable time intervals were used for the determination of the long-lived activities.

3. Experimental Results

3.1 Decay scheme of ^{84m}Rb

Through the $^{85}Rb(n,2n)^{84}Rb$ and $^{85}Rb(\gamma,n)^{84}Rb$ reactions both the metastable and the ground state of ^{84}Rb are populated. Spin, parity and half-lives have been determined in several previous works /2,3,9,10/. In Fig. 1 is shown the decay scheme of the excited states and of the ground state of ^{84}Rb, which are of interest in the further β^+ and EC decays to ^{84}Kr.

Through neutron irradiation of natural Rb_2CO_3 (72.15% ^{85}Rb and 27.85% ^{87}Rb) we populated the ^{84m}Rb state. The intensities of the 882 keV, 1016 keV and 1898 keV transitions were measured. These intensities were then compared to intensities, which can be obtained assuming a certain feeding, of the excited states in ^{84}Kr from the metastable state and the known feeding from the ground state in ^{84}Rb. The analysis is complicated as many states in ^{84}Kr also are populated in the decays of ^{84m}Br and ^{84g}Br, which are produced in the neutron irradiations via the $^{87}Rb(n,\alpha)^{84}Br$ reaction.

The Rb_2CO_3 samples were also irradiated at the 42 MeV Betatron in Malmö General Hospital. By using the (γ,n) or (γ,2n) reaction we avoided producing ^{84}Br. If the 882 keV level is fed from the ^{84m}Rb state through a cascade involving one or more excited levels in ^{84}Kr some of the following γ-lines should be seen 382, 424, 447, 605, 737, 802, 987, 1016, 1214, 1463, 1740, 1877, 1898 and 2201 keV (see Fig. 1).

In the gamma-ray spectra we observed a small peak, with an energy of 1463 keV, close to the 1460.8 keV ^{40}K background peak. This peak appears in all the three successive 20 min spectra. Therefore a half-life of 6 min is unlikely. There is also no indication of one of the most prominent gamma-line in the ^{84g}Br decay which has an energy of 2485 keV. We therefore conclude that neither ^{84m}Br nor ^{84g}Br are produced in this experiment, through the $^{87}Rb(\gamma,n2p)^{84}Br$ reaction, and that the observed 1463 keV gamma-line may be part of a cascade involved in the decay of the ^{84m}Rb state. The upper limit of the intensity for this line has been calculated to be $2 \cdot 10^{-3}$% relative to the intensity (100%) of the 248 keV transition in ^{84}Rb. If the 1463 keV line is fed directly from the metastable state or through the 424 keV transition, between the 2768 and 2344 keV levels, is not possible to determine with our arrangements, because of the high background in the low energy region. It is not unlikely that the metastable state decays via the 2768 keV level if the spin values are considered.

3.2 Intensity measurements of ^{84}Rb

Spin and parity of the two lowest excited states in ^{84}Rb, the multipole mixing of the gamma transitions and the conversion coefficients are known, through other experiments /3,9,10/. Neglecting a possible weak EC or β^+ from the metastable state we have found the following intensities for the three γ-rays per hundred decays: $I_\gamma(463) = 33.0 \pm 0.7\%$, $I_\gamma(215) = 33.4 \pm 0.7\%$ and $I_\gamma(248) = 63.7 \pm 1.4\%$. In order to compare these results with previous works we have normalized them to $I_\gamma(248) = 100\%$ in Table I. The agreement is good with other results except for those obtained by Pathak et al. /10/.

3.3 Cross section for the ^{85}Rb(n,2n)$^{84m,g,m+g}$Rb reaction

The results for the two different methods which we have used show no systematical differences. Our cross section for the ^{85}Rb(n,2n)^{84m}Rb reaction at 14.8±0.3 MeV is an average of 6 individual values with σ equal to 702±77 mb and with a root mean square deviation of 62 mb. This is in very good agreement with Husain et al. /11/ and Ghorai et al. /12/ but differs a lot from other earlier works. The results have been presented in Table II and in Fig. 2.

Our value for the ^{85}Rb(n,2n)^{84}Rb reaction is 1154±110 mb based on four individual values with a root mean square deviation of 97 mb. This is again in very good agreement with Ghorai et al. /12/ but also with Bormann et al. /13,14/ and Augustyniak et al. /15/. (Table II and Fig. 3).

The different measurements are not performed at exactly the same neutron bombarding energy, but the main difference in the reported cross sections seems to be due to the different experimental set ups.

Our two values give an isomeric ratio for the (n,2n) reaction cross section of 0.64±0.12 which agrees rather well with some earlier works (Table III and Fig. 4).

3.4 Cross section for the ^{87}Rb(n,2n)^{86}Rb reaction

^{86}Rb is produced both through the ^{87}Rb(n,2n)^{86}Rb and the ^{85}Rb(n,γ)^{86}Rb reaction, but the contribution of the last reaction was estimated to be negligible. The only γ-line from these measurements used in determining the cross section is the 1078 keV one, decaying with a half life of 18.66 days and with an intensity of 8.8% /8/. Our cross section is 1206±85 mb, which is in good agreement with earlier works (Table II and Fig. 5).

3.5 Cross section for the ^{85}Rb(n,p)^{85m}Kr and the ^{87}Rb(n,p)^{87}Kr reactions

In order to obtain these two cross sections we have measured the 4.48 h and the 76.31 min /8/ activities of ^{85m}Kr and ^{87}Kr. In the case of ^{85}Rb(n,p)^{85m}Kr reaction we have had to use the 304 keV γ-line with an intensity of 13.5% /8/. This gives us a cross-section value of 5.76±0.4 mb, which is in good agreement with earlier works (Table IV and Fig. 6). For the ^{87}Rb(n,p)^{87}Kr reaction we have used three γ-lines with intensity values from Shihab-Eldin et al. /22/: 403 keV (48.3%), 845 keV (7.25%) and 2554 keV + 2557 keV (12.95%). Our cross section 12.6±0.9 mb agrees with Prasad et al.

/23/, but it is about twice as high as two other works (Table IV and Fig. 7).

3.6 Cross section for the $^{85}Rb(n,\alpha)^{82}Br$ reaction

There are not so many reported cross sections for this reaction and they differ slightly except Ref. /20/. Our cross-section value 6.63±0.5 mb is obtained by using the four γ-lines 554 keV (70.5%), 698 keV (27.9%), 776 keV (83.3%) and 1317 keV (27.5%) with intensity values from Raman /24/ (Table IV and Fig. 8).

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References

1. Flamersfeld,A., Z. Naturforsch 59, 687 (1950).

2. Caird,R.S. and Mitchell,A.C.G., Phys. Rev. 89, 573 (1953).

3. Kneissl,U., Schneider,H., Völpel,R. and Wölcken,K., Nucl. Phys. A135, 395 (1969).

4. Lederer,C.M., Hollander,J.M. and Perlman,I., Table of Isotopes, John Wiley & Sons INC., New York, 1967.

5. Venugopala Rao,P. and Fink,R.W., Phys. Rev. 154, 1023 (1967).

6. Magnusson,G. and Bergqvist,I., Nucl. Technol. 34, 114 (1977).

7. Bormann,M., Neuert,H. and Scobel,W., Handbook on Nuclear Cross-sections, IAEA, Vienna, 1974.

8. Bowman,W.W. and MacMürdo,K.W., Nucl. Data Tables A13, 89 (1974).

9. Cohen,L., Phys. Rev. III, 587 (1958).

10. Pathak,B.P., Murty,K.S.N. and Mukherjee,S.K., Z. Physik 233, 209 (1970).

11. Husain,L., Bari,A. and Kuroda,P.K., Phys. Rev. C1, 1233 (1970).

12. Ghorai,S.K., Vos,R., Cooper,J.R. and Alford,W.L., Nucl. Phys. A223, 118 (1974).

13. Bormann,M., Behrend,A., Riehle,I. and Vogel,O., Nucl. Phys. A115, 309 (1968).

14. Bormann,M., Feddersen,H.-K., Hölscher,H.-H., Scobel,W. and Wagener,H., Z. Physik A227, 203 (1976).

15. Augustyniak,W., Herman,M. and Marcinkowski,A., Acta Phys. Polon. B7, 347 (1976).

16. Minetti,B. and Pasquarelli,A., Nucl. Phys. A118, 449 (1968).

17. Venugopala Rao,P., Wood,R.E., Palms,J.M. and Fink,R.W., Phys. Rev. C3, 629 (1971).

18. Rurarz,E., Chwaszczewska,J., Haratym,Z., Pietrzykowski,M. and Sulik,A., Acta Phys. Polon. B2, 553 (1971).

19. Prestwood,R.J. and Bayhurst,B.P., Phys. Rev. 121, 1438 (1961).

20. Strohal,P., Cindro,N. and Eman,B., Nucl. Phys. 30, 49 (1962).

21. Rieder,R. and Münzer,H., Acta Phys. Austriaca 23, 42 (1966).

22. Shihab-Eldin,A., Prussin,S.G., Bernthal,F.M. and Rasmussen,J.O., Nucl. Phys. A160, 33 (1971).

23. Prasad,R. and Sarkar,D.C., Il Nuovo Cimento 3A, 467 (1971).

24. Raman,S., Phys. Rev. C2, 2176 (1970).

25. Levkovskii,V., Kovel´skaya,G.E., Vinitskaya,G.P., Stepanov,V.M. and Sokol´skii,V.V., Sov. J. Nucl. Phys. 8, 4 (1969).

26. Hattula,T., Andre,S., Schussler,F. and Moussa,A., Nucl. Phys. A158, 625 (1970).

Table I. Relative intensities of gamma radiation from ^{84m}Rb

E_γ (keV)	This work	Ref.10	Ref.9	Ref.3	Ref.8
215	52.5	45	51	50.5	57
248	100	100	100	100	100
464	51.8	82	56	49.8	49

Table II. (n,2n) cross section of Rb

Reaction	σ(expt) This work	σ(expt) Litterature	Ref.	Energy (MeV)
$^{85}Rb(n,2n)^{84m}Rb$	702±77	926±61	16	14.7
		374±28	13	14.88±0.31
		714±50	11	14.8
		412±40	18	14.8
		478±48	17	14.4±0.3
		662±83	12	15.0±0.4
		491±27	15	14.5±0.1
		505±34	14	14.56±0.15
$^{85}Rb(n,2n)^{84}Rb$	1154±110	1530±77	19	14.81±0.31
		687±74	20	14.6
		1430±71	21	14.7±0.1
		1682±222	16	14.7
		1174±94	13	14.88±0.31
		1335±90	11	14.8
		892±63	17	14.4±0.3
		1125±141	12	15.0±0.4
		1205±69	15	14.5±0.1
		1093±79	14	14.56±0.15
$^{87}Rb(n,2n)^{86}Rb$	1206±85	1191±60	19	14.81±0.31
		838±136	20	14.6
		1560±156	21	14.7±0.1
		2551±350	16	14.7
		1417±72	11	14.8
		995±99	17	14.4±0.3
		1336±168	12	15.0±0.4
		1307±140	15	14.5±0.1

Table III. Isomeric cross-section ratio for the $^{85}Rb(n,2n)^{84}Rb$ reaction

(expt) This work	(expt) Literature	Ref.	Energy (MeV)
0.64±0.12	0.8±0.2	16	14.7
	2.14±0.29	13	14.88±0.31
	0.87±0.12	11	14.8
	0.87±0.12	17	14.4±0.3
	0.70±0.15	12	15.0±0.4
	1.45±0.14	15	14.5±0.1
	1.16±0.16	14	14.56±0.15

Table IV. (n,p) and (n,α) cross section of Rb

Reaction	σ(expt) This work	σ(expt) Literature	Ref.	Energy (MeV)
$^{85}Rb(n,p)^{85m}Kr$	5.76±0.4	6±1	11	14.8
		4.1±0.4	17	14.4±0.3
		3.7±0.8	15	14.5±0.1
$^{87}Rb(n,p)^{87}Kr$	12.6±0.9	7±1	11	14.8
		4.9±0.5	17	14.4±0.3
		13±2	23	14.8±0.5
$^{85}Rb(n,\alpha)^{82}Br$	6.63±0.5	142±9	20	14.6
		6.1±0.9	25	14.8
		4.9±0.5	17	14.4±0.3
		5.3±0.5	15	14.5±0.1

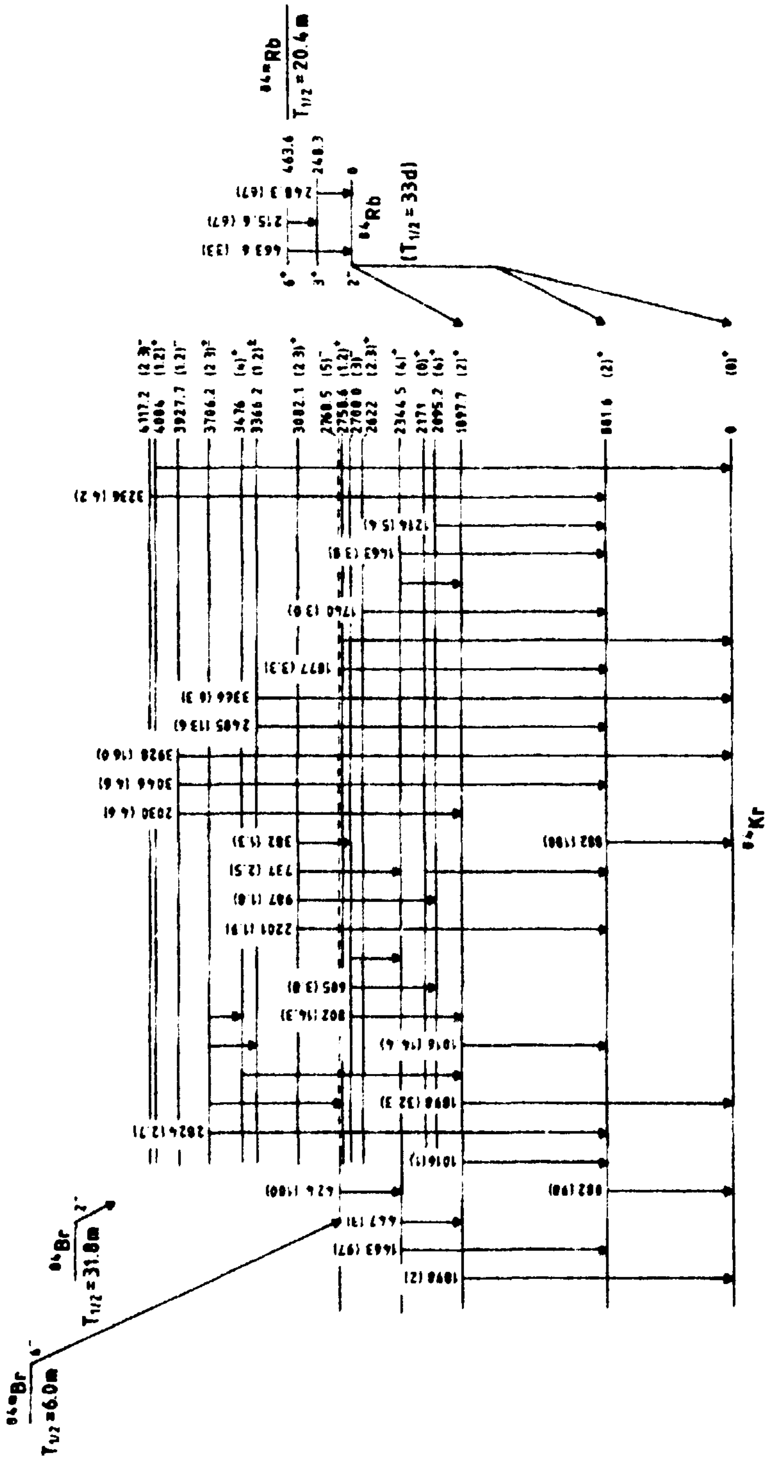

Fig. 1 Decay scheme of $^{84m,g}Br$ based upon the works of Hattula et al. [26]. Intensities which are less than 1% are not given in the figure. The deexcitation of $^{84m,g}Rb$ are also included in the figure.

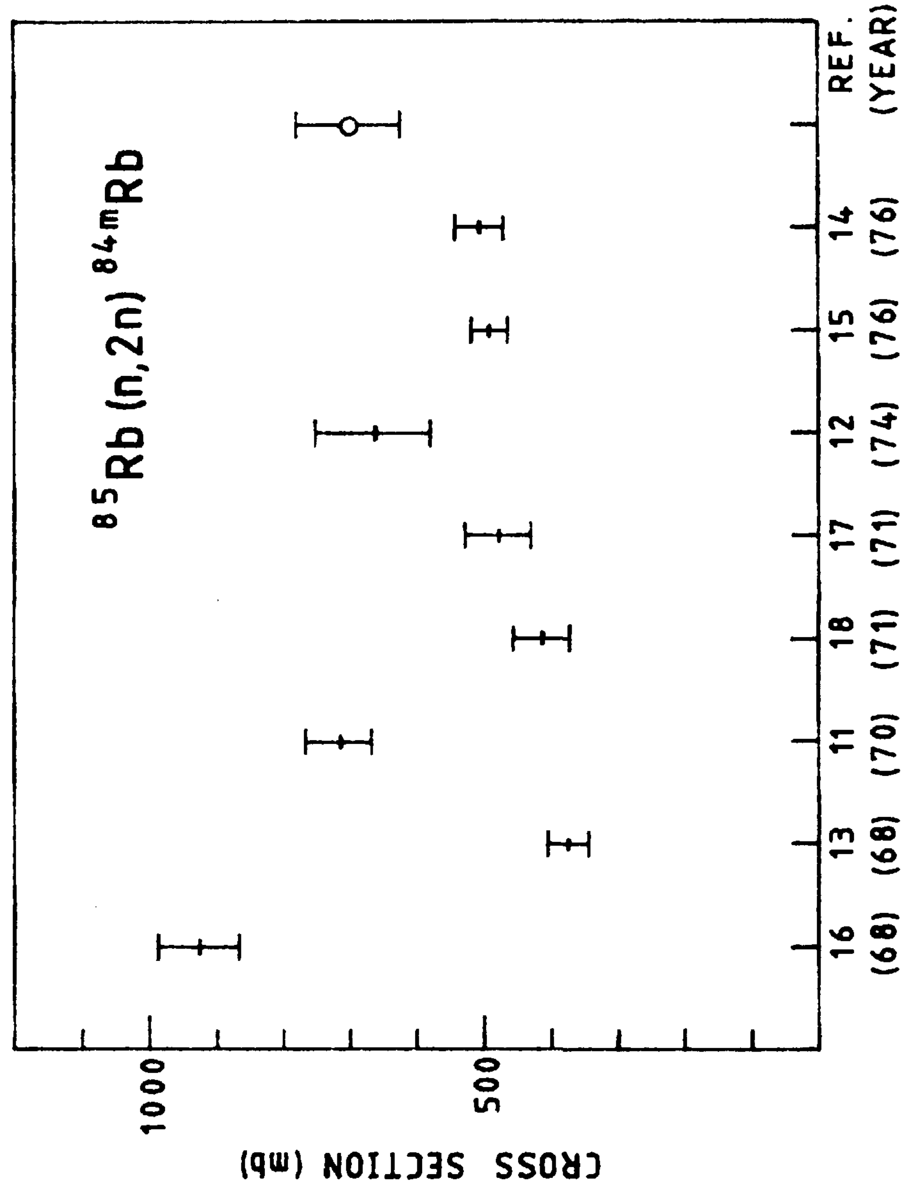

Fig. 2 Comparison of experimental cross sections for the $^{85}Rb(n,2n)^{84m}Rb$ reaction for different references with their publication year in parantheses. Error bars are marked with vertical lines. Present results are marked with an open circle.

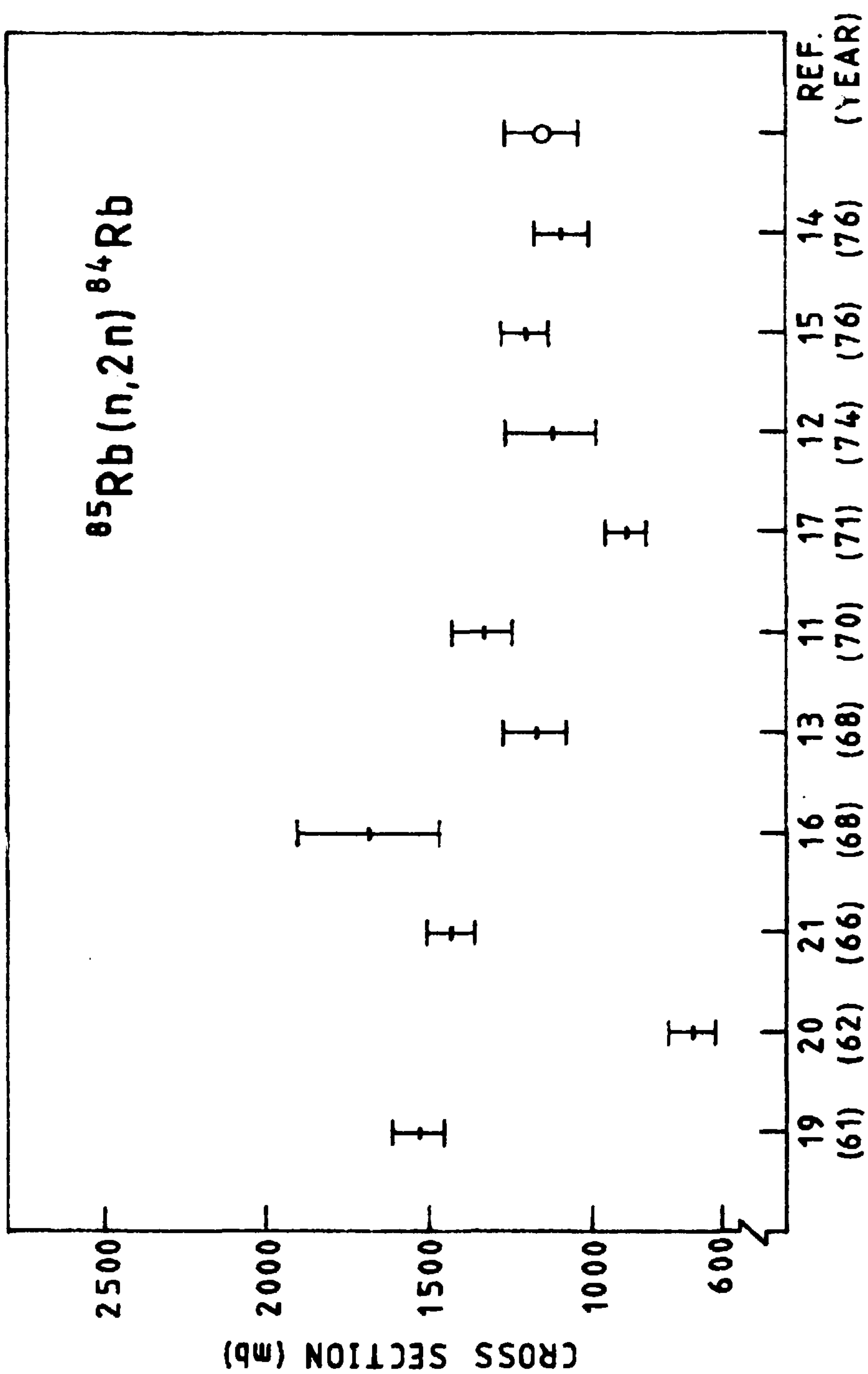

Fig. 3 Comparison of experimental cross sections for the ^{85}Rb(n,2n)^{84}Rb reaction.

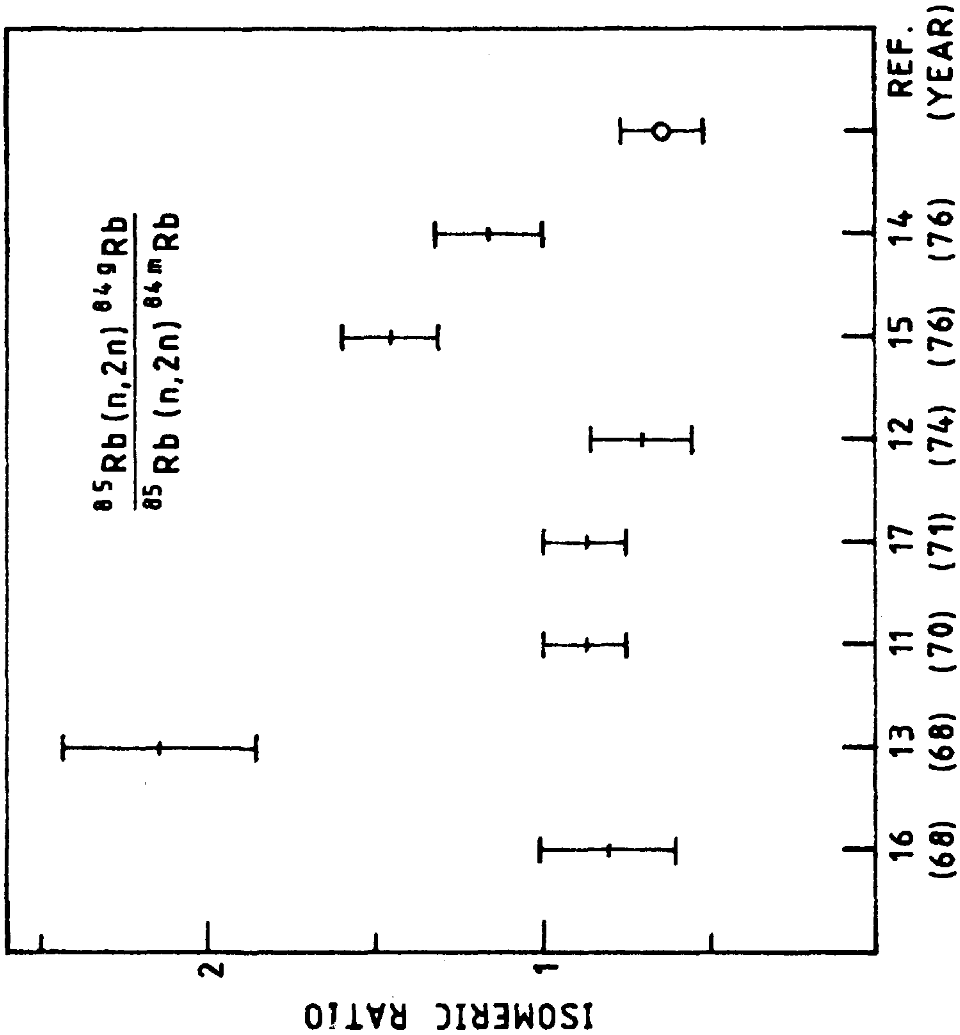

Fig. 4 Comparison of experimental isomeric ratio for the ^{85}Rb(n,2n)^{84g,m}Rb reaction.

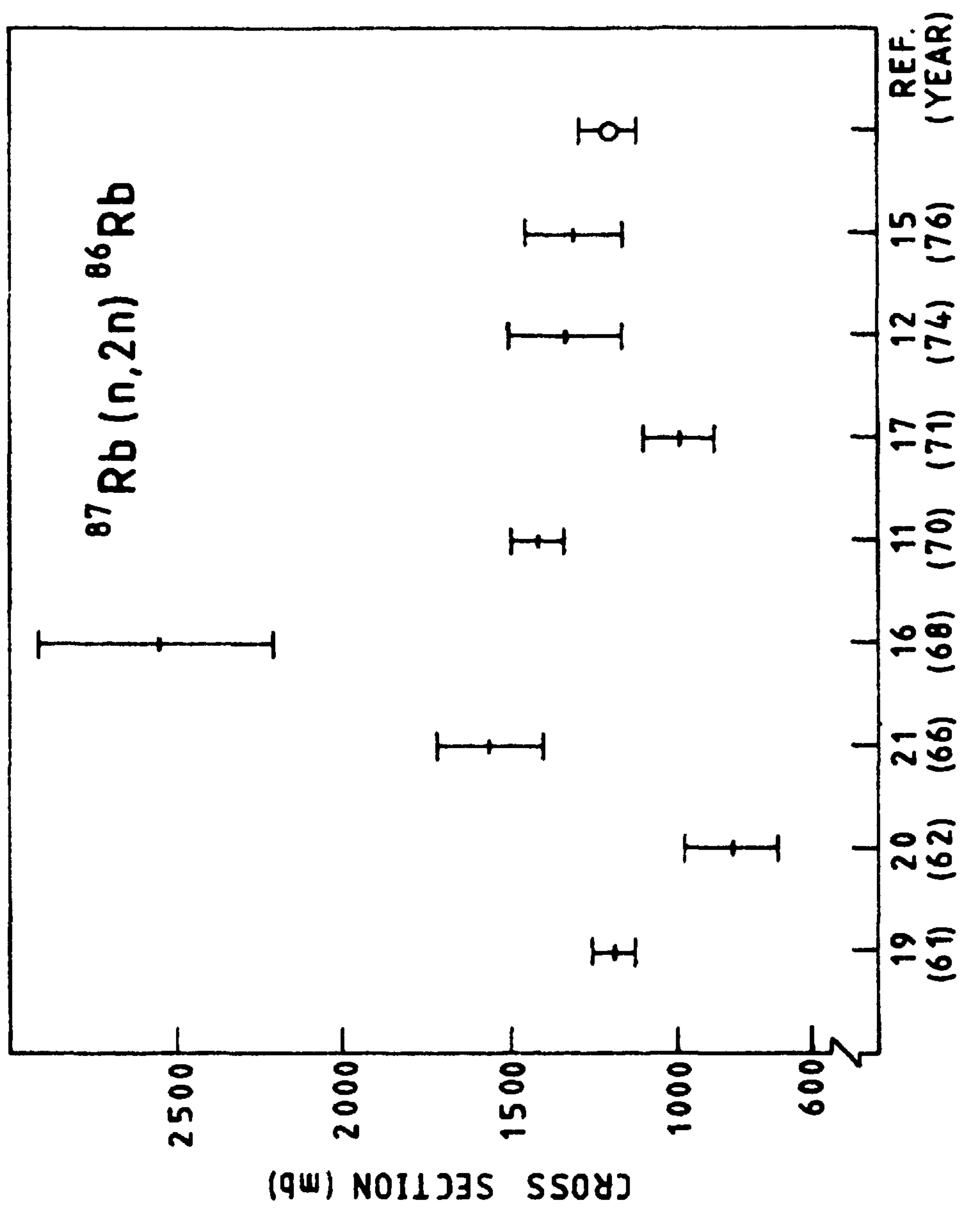

Fig. 5 Comparison of experimental cross sections for the $^{87}Rb(n,2n)^{86}Rb$ reaction.

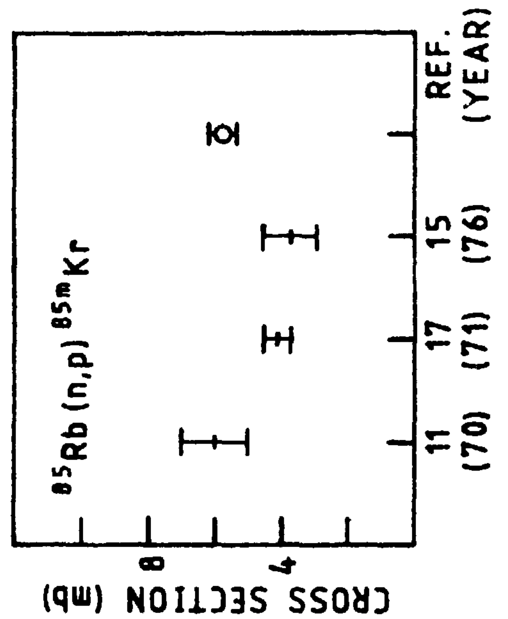

Fig. 6 Comparison of experimental cross sections for the ^{85}(n,p)^{85m}Kr reaction.

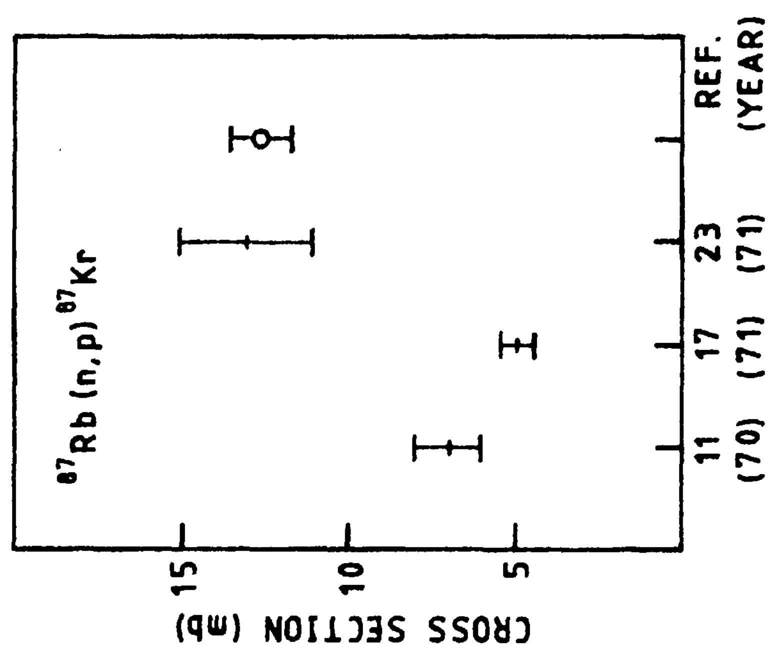

Fig. 7 Comparison of experimental cross sections for the ^{87}Rb(n,p)^{87}Kr reaction.

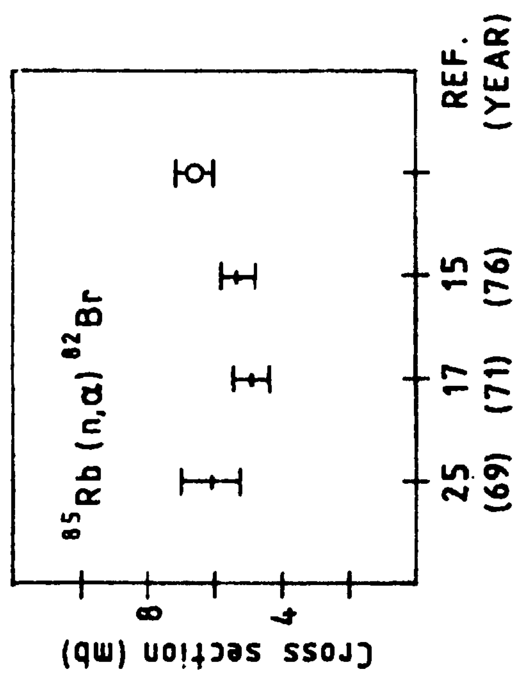

Fig. 8 Comparison of experimental cross sections for the $^{85}Rb(n,\alpha)^{82}Br$ reaction.