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REPUBLIC OF SOUTH AFRICA

PROGRESS REPORT TO THE INDC

1969

Compiled by D. Reitmann

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IAEA NUCLEAR DATA SECTION, KÄRNTNER RING 11, A-1010 VIENNA

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1. Southern Universities Nuclear Institute, Faure, Cape Province

Towards the end of 1969 a new pulsing and bunching system was installed in the 5.5 MV van de Graaff accelerator in order to obtain shorter and more intense beam pulses. This modification should enhance the capabilities of this facility in the field of time-of-flight studies. Relevant research projects carried out during 1969 include the following:

1.1 The level structure of ^{51}V from $(n,n'\gamma)$ measurements

I.J. van Heerden and W.R. McMurray

The low energy levels of ^{51}V have been successfully described by considering the nucleus as three protons with residual interactions moving in orbitals around an inert ^{48}Ca core. Such shell model calculations[1] predict the order of the lowest five states of ^{51}V. Experimental information on the level structure has been obtained from the $^{50}Ti(^{3}He,d)^{51}V$, $^{50}V(d,p)^{51}V$, and $^{51}V(n,n')^{51}V$ reactions[2 - 5], but the picture is still incomplete.

A Ge(Li) detector with time-of-flight gating to discriminate against neutron induced γ-rays has been used to resolve the level structure of ^{51}V by observing the de-excitation γ-rays from neutron scattering. Spectra were obtained using incident neutron energies of 2000, 2125, 2250, 2500 and 2750 keV. The ^{51}V scattering sample, in the form of a hollow cylinder was positioned vertically at 0^{o} at a distance of 7.5 cm from a lithium target bombarded by protons. The Ge(Li) detector was placed at

a distance of 34 cm from the scatterer and was shielded from the neutron source by a mallory wedge.

The γ-rays observed have been fitted into an energy level scheme. The energy values of the levels as obtained from the present $(n,n'\gamma)$ measurements, namely 319.8, 928.3, 1608.6, (1719.6), 1812.6, 2411.9 and 2707.0 keV, are in excellent agreement with those obtained from neutron scattering. No γ-rays have been observed that could have resulted from the decay of the 2544 keV level observed in neutron scattering at an incident neutron energy of 3.2 MeV and above. However, a very low cross section for the formation of this state could explain why it was not observed in the present measurements.

1) J.D. McCullen et al., Phys. Rev. 134 (1964) B515
2) B.J. O'Brien et al., Nucl. Phys. A104 (1967) 609
3) M.E. de Lopez et al., Nucl. Phys. A94 (1967) 673
4) M. Mazari et al., Phys. Rev. 112 (1958) 1691
5) J.H. Towle, Nucl. Phys. A117 (1968) 657

1.2 The levels of ^{75}As

P. Celliers, W.R. McMurray, I.J. van Heerden and W.L. Mouton

A study of ^{75}As has been initiated using the $(n,n'\gamma)$ reaction to determine the level energies. Several spectra have been obtained and a start has been made on the analysis of the ^{75}As decay scheme. As a large number of levels are involved, more detailed measurements will be required.

1.3 The level structure of ^{89}Y from $(n,n'\gamma)$ measurements

I.J. van Heerden and W.R. McMurray

Measurements using neutrons in the energy region 1.5 to 2.75 MeV have confirmed levels at 909.0, 1506.8, 1744.1, 2221.9, 2529.7, 2566.2 and 2621.4 keV, in excellent agreement with the energy values formed by Buchanan and Williams[1]. In the (n,n') results[2] no sign of the 2.57 MeV level was observed but this can be explained by its low

cross section.

1) P.S. Buchanan and G.H. Williams, Bull.A.P.S.13(1968)873
2) J.H. Towle, Nucl.Phys.A131(1969)561

1.4 The level structure of ^{93}Nb from (n,n'γ) measurements

I.J. van Heerden and W.R. McMurray

In order to obtain more information about the energies and possibly also of the spins of levels of ^{93}Nb, the γ-ray transitions following inelastic scattering of neutrons have been studied. A large number of γ-ray spectra were obtained for incident neutron energies between 1000 and 2750 keV in energy steps not greater than 75 keV. From the relative excitation cross sections and threshold energies of the observed gammas it has been possible to deduce a level scheme consisting of levels at 29, 743.7, 808.4, 949.6, 978.7, 1082.1, 1296.6, 1315.4, 1334.3, 1367.9, 1393.6, 1482.6, (1519.8), (1528.5), 1602.9, 1679.4, 1682.6, 1715.1, 1729.9, 1789.5, (1913.8),(1918.2), (1939.4) and (2004.0) keV. The inelastic neutron scattering results of Reitmann et al.[1] have provided cross sections for the excitation by inelastic neutron scattering of 740, 810, 960 and 1030 keV levels in ^{93}Nb.

The 808.4 keV γ-ray is about twice as intense as the 779.4 keV γ-ray, but if it is assumed that they originate from a single line at 808.4 keV, no spin assignment would be able to reproduce their relative intensities. It must therefore be assumed that the 808.4 keV line is in fact a doublet. Similarly no single spin assignment could satisfy their relative intensities if it was assumed that the 949.6 and 978.7 keV γ-rays originate from a single level at 978.7 keV decaying to the ground and first excited state at 29 keV. The level structure is clearly more complex than has previously been proposed. The present measurements have not yet been fully analysed, and further work is being planned to resolve the uncertainties which still exist.

1) D. Reitmann et al. Nucl.Phys.48(1963)593.

1.5 The level structure of ^{115}In

I.J. van Heerden and W.R. McMurray

The $(n,n'\gamma)$ reaction on a natural In sample (4.28% ^{113}In, 95.72% ^{115}In) has been studied over the neutron energy range 300 to 2575 keV. The results are being analysed. Previous work on the ^{115}In nucleus is summarised by J. McDonald et al.[1].

1) J. McDonald, D. Porter and D.T. Stewart, Nucl.Phys. A104 (1967) 177

1.6 The levels of ^{232}Th from $(n,n'\gamma)$ measurements

I.J. van Heerden, W.R. McMurray, L.M. Spitz and P. van der Merwe

A 40 cc Ge(Li) detector with time-of-flight gating has been used in a continuation of an earlier study[1] of the level structure of ^{232}Th. A large number of γ-ray spectra were obtained for incident neutron energies between 750 and 1500 keV in energy steps of about 50 keV. In addition to the annihilation peak at 511.0 keV and the background γ-ray peaks from neutron-induced events in the Ge(Li) detector, γ-ray peaks which originate from natural ^{232}Th radioactivity were observed. At neutron energies of 750 and 800 keV, a γ-ray peak is observed at 729.9 keV which is clearly a γ-ray peak from the decay of ^{232}Th. At a neutron energy of 850 keV two other γ-rays at 724.9 and 728.0 keV appear, and their intensities increase with increasing neutron energy.

Energy levels in ^{232}Th at 49.5, 163.0, 714.5, 730.5, 774.6, 776.8, 785.3, 829.7, 873.0, 969.5, 1053.3, 1072.6, 1078.0, 1094.8, 1106.1, 1143.8 and 1182.4 keV were deduced from the relative excitation cross sections and threshold energies of the observed γ-rays. This level scheme contains more levels, especially at high energies, than were obtained from Coulomb excitation[2] and from inelastic neutron scattering[3]. It is obvious that, except for states with high spin

values unlikely to be excited in neutron scattering, all the well-known collective states are observed in the present measurements, and that the present energies agree very well with those obtained in Coulomb excitation studies. Additional levels have been deduced at 714.5, 776.8, 959.5, 1053.3, 1072.6, 1078.0, 1106.1, 1143.8 and 1182.4 keV. The neutron scattering results[3] are not very informative about the existence of levels at these energies. The existence of the 776.8 keV level is deduced from the appearance of γ-rays with energies of 728.0 and 776.0 keV at neutron energies of 850 keV and above. The 829.7 keV level, deduced from the appearance of a 780.2 keV γ-ray above an incident neutron energy of 850 keV, is presumably due to the same level observed at 820 keV in neutron scattering. The strength of this γ-ray cannot result from the de-excitation of the 10^+ rotational state[1] at 828 keV, and is therefore indicative of a close lying doublet at this energy.

1) W.R. McMurray, I.J. van Heerden and P. van der Merwe SUNI Annual Report (1968), item 2.3

2) F.S. Stephens et al., Proc.Int.Conf. Reactions between Complex Nuclei, Asilomar (1963) p. 303

3) A.B. Smith, Phys.Rev. 126(1962)718

1.7 The levels of ^{238}U from $(n,n'\gamma)$ measurements

W.R. McMurray, I.J. van Heerden, L.M. Spitz and P. van der Merwe

The previously reported study[1] of the ^{238}U nucleus has been continued with larger Ge(Li) detectors[2] with incident neutron energies between 750 and 1500 keV.

The ^{238}U level scheme, consisting of levels at 44.9, 148.4, 680.0, 731.9, 835.4, 926.7, 930.8, 950.1, 966.1, 997.3, 1037.1, 1060.1, 1105.9, 1128.7, 1167.7, 1179, 1201, 1215.6, 1223.3 and 1278.5 keV, deduced from the present work is in qualitative agreement with inelastic neutron scattering results[3]. The level energies are progressively lower at higher excitation energies but the relative intensities of the de-excitation gammas are consistent with the (n,n') cross sections.

The agreement with levels deduced from coulomb excitation studies[4] is generally good. An exception is the 0^+ state at 993 keV which has not been observed in the present work. The state found at 997.3 keV is well outside the combined energy uncertainties. This level corresponds to that observed with the (n,n') reaction at 1006 keV for which Hauser-Feshbach analysis[3] indicated a J^π of 1^+; the measured (n,n') cross sections were too large to be consistent with a 0^+. The anomaly is not explicable with the present data.

1) W.R. McMurray, I.J. van Heerden and P. van der Merwe, SUNI Annual Report (1968) item 2.4

2) W.R. McMurray, I.J. van Heerden, L.M. Spitz and P. van der Merwe, Contribution 2.33 to the Int. Conference on Properties of Nuclear States, Montreal, August 1969.

3) E. Barnard, A.T.G. Ferguson, W.R. McMurray and I.J. van Heerden, Nucl.Phys.80(1966)46

4) F.S. Stephens, B. Elbek and R.M. Diamond, Proc.Int.Conf. on Reactions between Complex Nuclei, Asilomar (1963)p.303

1.8 (n,γ) study of the levels of ^{116}Sn

W.R. McMurray and I.J. van Heerden

Fast neutron capture in ^{115}In excited an isomeric state of ^{116}In with a 54 minute half-life. Subsequent β-decay populated levels in ^{116}Sn. The decay gammas were observed with a Ge(Li) detector and a decay scheme deduced from the relative intensities of the observed gammas. There are some discrepancies with results obtained by R.K. Girgis and R. van Lieshout[1].

1) R.K. Girgis and R. van Lieshout, Physica 25(1959)590

2. Atomic Energy Board, Pelindaba, Transvaal

Neutron physics research was continued both at the 3 MV pulsed van de Graaff and the 20 MW research reactor, Safari I. A small computer was installed at the accelerator for data processing and eventual data collection. Pertinent research projects during 1969 included the following:

2.1 Neutron cross section measurements

2.1.1 Inelastic scattering of fast neutrons from ^{209}Bi

TOP

E. Barnard, J.A.M. de Villiers and D. Reitmann

Differential cross sections at 90^{o} for the excitation of the level at 896 keV by inelastic neutron scattering were measured in the energy range of 1020 to 1500 keV. Good incident energy definition and steps of 5 or 10 keV were employed and a considerable amount of structure was observed in the excitation curve. The results were combined with elastic and total cross sections, measured by Smith and Whalen at ANL, into a paper which will be published in Nuclear Science and Engineering.

2.1.2 Fast neutron interactions with Sc

E. Barnard, J.A.M. de Villiers, D. Reitmann and J.W. Tépel

A complete study of the interactions between fast neutrons and ^{45}Sc has been carried out. High resolution total cross sections between 200 and 1400 keV were measured by the thick target time-of-flight technique. Elastic scattering angular distributions were measured in steps of 20 keV from 200 to 1400 keV. Inelastic scattering cross sections were measured in steps of about 10 keV for the levels at 376, 543, 720 and 972 keV and a considerable amount of structure was observed in each case. Accurate energy determinations for these levels were obtained from Ge(Li) studies of the $(n,n'\gamma)$ reaction. This results of the $(n,n'\gamma)$ studies agree well with those of Rogers et al.[1].

1) V.C. Rogers, L.E. Beghian and F.M. Clikeman, Nucl.Phys. A137(1969)85

2.1.3 Fast neutron interactions with Cs and Rb

N. Coetzee

Total, elastic- and inelastic scattering cross sections up to about 1200 keV were determined for natural samples of Cs and Rb and supplemented with $(n,n'\gamma)$ studies. Excitation curves were

measured for levels at 152, 283, 514 and 733 keV in ^{85}Rb, at 403 and 847 keV in ^{87}Rb and at 81, 161, 384, 436, 633, 706, 788 and 819 keV in ^{133}Cs. Level energies and the allocation of levels to either of the isotopes of Rb were based on the (n,n'γ) measurements.

2.1.4 Inelastic scattering of fast neutrons from Ti

E. Barnard, J.A.M. de Villiers and D. Reitmann

Differential cross sections at 90^{o} for the excitation of levels at 889 keV in ^{46}Ti and 893 keV in ^{48}Ti by inelastic neutron scattering were measured in steps of 5 keV and a considerable amount of structure was observed. These results will be combined with total and elastic scattering cross sections measured by Smith at ANL into a joint publication.

2.2 Nuclear structure from neutron reactions

2.2.1 Levels in ^{197}Au from (n,n'γ) studies

E. Barnard, J.A.M. de Villiers, C.A. Engelbrecht and D. Reitmann

An earlier study of the energy levels in ^{197}Au by the inelastic scattering of neutrons[1] revealed a number of new levels. These were further investigated by means of (n,n'γ) reactions. Levels were found at 77.4 ($\frac{1}{2}$+), 268.6($\frac{1}{2}$+), 278.8($\frac{5}{2}$+), 409.5($\frac{11}{2}$ -), 502.5($\frac{3}{2}$ +), 547.5($\frac{7}{2}$+) 736.6($\frac{5}{2}$+), 855.3($\frac{9}{2}$+), 883.1($\frac{1}{2}$+), 936.0($\frac{5}{2}$+), 948.5($\frac{13}{2}$ -), (966.2($\frac{11}{2}$ +)), 1037.9($\frac{3}{2}$+), 1045.0($\frac{5}{2}$+), (1147.9($\frac{3}{2}$+)), 1150.5($\frac{5}{2}$+), 1217.4($\frac{3}{2}$+) and 1242.1($\frac{1}{2}$+) keV. Spins and parities were assigned to them on the basis of their excitation cross sections and decay modes as well as structure considerations.

1) E. Barnard, J.A.M. de Villiers, C.A. Engelbrecht and D. Reitmann, Nucl.Phys.A107(1968)612

2.2.2 The level structure of ^{71}Ge from neutron capture in ^{70}Ge

C. Hofmeyr and B.C. Winkler

The (n,γ) experiment on ^{70}Ge was performed with subthermal

neutrons from a tangential beam tube in Safari I. The γ-rays from a sample of germanium oxide, containing 1 gram of 91.4% enriched ^{70}Ge, were detected in a 30 cc. Ge(Li) detector. A large number of γ-rays from the $\frac{1}{2}^+$ capture state at 7420.5 $\pm$ 0.6 keV were fitted into a level scheme. Complimentary information about low-lying levels in ^{71}Ge was obtained from (p,n) and (p,nγ)-studies on ^{71}Ga, performed on the 3 MV van de Graaff accelerator. A preliminary report on these results was presented at the conference on "Neutron Capture Gamma-ray Spectroscopy" (Studsvik, 1969) and a detailed report has been accepted for publication in Nuclear Physics.