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1972 J. Phys. A: Gen. Phys. 5 1524

(http://iopscience.iop.org/0022-3689/5/10/018)

J. Phys. A: Gen. Phys., Vol. 5, October 1972. Printed in Great Britain. © 1972

Analogue resonances of low lying levels of ^{52}V in the $^{51}V(p, \gamma)^{52}Cr$ reaction

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MS received 29 March 1972

Abstract. The analogues of the ^{52}V levels at 0·793 and 0·846 MeV have been examined as resonances in the $^{51}V(p, \gamma)^{52}Cr$ reaction at proton energies of 1·567 and 1·629 MeV. The resonance at 1·567 MeV and hence the 0·793 MeV ^{52}V level has been assigned J^{π} of 3^+ and the most probable J^{π} value for the 1·629 MeV resonance and hence the 0·846 MeV ^{52}V level is shown to be 4^+. These results are consistent with previous theoretical calculations of the ^{52}V levels.

1. Introduction

The low lying levels of ^{52}V have been previously studied with the $^{51}V(d, p)^{52}V$ and $^{51}V(n, \gamma)^{52}V$ reactions and the information summarized by Rapaport (1970). The ground and 0·142 MeV states have been definitely assigned J^{π} of 3^+ and 1^+ respectively and other levels have spins limited to two possibilities. Calculations have been made (Pellegrini 1966, Vervier 1966) by considering ^{52}V as three protons and a neutron outside a ^{48}Ca core. In the work of Pellegrini (1966) the neutron is restricted to the $p_{3/2}$ shell, while Vervier (1966) allows the neutron to occupy the $p_{3/2}$, $p_{1/2}$ and $f_{5/2}$ shells, the protons occupying the $f_{7/2}$ shell. Both calculations produce the five lower levels with approximately the correct level spacing but in a different order. The spacing of the next three levels is predicted correctly by Vervier with J^{π} of 2^+, 3^+ and 4^+ but Pellegrini predicts only two levels with J^{π} of 4^+ and 2^+. These data are summarized in figure 1. Higher excited states of ^{52}V predicted by both theories do not occur until about 1·2 MeV in agreement with experiment except for a state at 0·875 MeV, excited very weakly in the $^{51}V(d, p)^{52}V$ reaction, which must have a more complicated structure than the four particle configurations considered. The present work yields more information on the spins of the levels at 0·793 and 0·846 MeV, to facilitate a better comparison between experiment and theory, by examining their analogues as resonances in the (p, γ) reaction which favours the analogues of levels excited in the (d, p) reaction.

2. Experimental results

The analogue resonances of the low lying levels of ^{52}V have been identified by Teranishi and Furubayashi (1966) in ^{52}Cr. In the present work the analogue resonances of the states at 0·793 and 0·846 MeV were examined with the $^{51}V(p, \gamma)^{52}Cr$ reaction at proton

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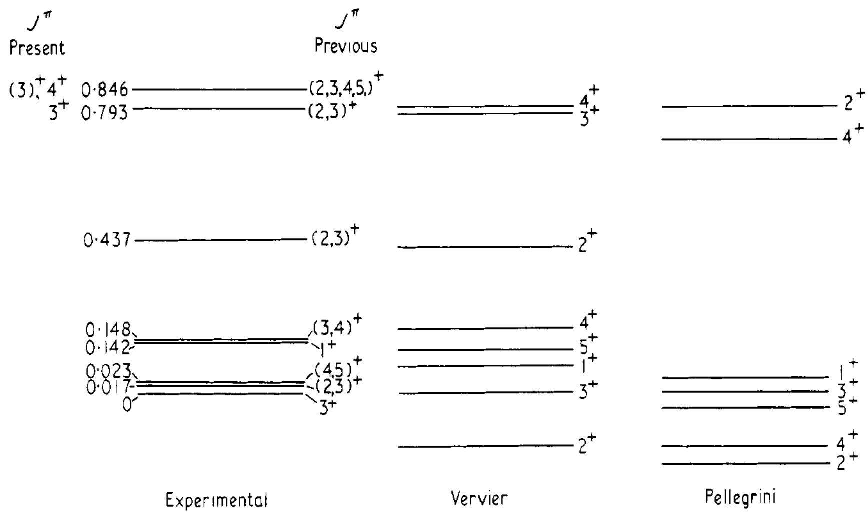

Figure 1. The experimental level scheme of ^{52}V showing the present and previous spin assignments. The theoretical level schemes of Vervier and Pellegrini are also shown in which the levels are displayed so that the lowest 3^+ states have the same energy as the ^{52}V ground state. All the states shown, except the 1^+ state, are seen strongly in ^{51}V(d, p)^{52}V with $l = 1$ neutron transfer, as predicted theoretically.

energies of 1·567 and 1·629 MeV respectively. Targets of 20 μg cm^{-2} natural vanadium evaporated onto thick gold backing were bombarded with protons from the UKAERE Harwell 6MV Van de Graaff accelerator and the gamma rays observed with 30 cm^3 Ge(Li) detectors. The efficiencies of the Ge(Li) detectors were determined using radioactive sources and the well known ^{27}Al(p, γ)^{28}Si resonances at proton energies of 0·992 and 2·489 MeV.

The gamma ray spectra indicated that the resonances also occurred in the ^{51}V(p, p′γ)^{51}V reaction to the 0·320 MeV ($5/2^-$) first excited state of ^{51}V and previous experiments (Teranishi and Farubayashi 1966, Gibbons *et al* 1955) had shown them resonating in the ^{51}V(p, n)^{51}Cr reaction. The (p, γ) resonance strengths $S_{p,\gamma} = (2J+1)\Gamma_p\Gamma_\gamma/\Gamma$ were determined from the absolute yield of the 1·434 MeV gamma ray from the first excited state of ^{52}Cr through which all gamma ray transitions from both resonances eventually cascade. The (p, p′γ) resonance strengths $S_{p,p'} = (2J+1)\ \Gamma_p\Gamma_{p'}/\Gamma$ were determined from the absolute yield of the 0·320 MeV gamma ray, and the (p, n) resonance strengths $S_{p,n} = (2J+1)\ \Gamma_p\Gamma_n/\Gamma$ were deduced from the absolute neutron yields given by Gibbons *et al* (1955). For the 1·567 MeV resonance, the experimental strengths were $S_{p,\gamma} = 0{\cdot}65 \pm 0{\cdot}15$ eV, $S_{p,p'} = 1{\cdot}0 \pm 0{\cdot}3$ eV, $S_{p,n} = 1{\cdot}3 \pm 0{\cdot}1$ eV and for the 1·629 MeV resonance $S_{p,\gamma} = 5{\cdot}4 \pm 1{\cdot}1$ eV, $S_{p,p'} = 3{\cdot}6 \pm 0{\cdot}9$ eV and $S_{p,n} = 26{\cdot}1 \pm 2{\cdot}6$ eV. It can be seen that for both resonances the three strengths are of the same order of magnitude. This means that Γ_γ, $\Gamma_{p'}$ and Γ_n are of the same order of magnitude. The 0·793 and 0·846 MeV ^{52}V levels are observed strongly in the ^{51}V(d, p)^{52}V reaction with $l = 1$ neutron transfer. This means that their predominant configuration is probably $p_{3/2,1/2}\,(f_{7/2})^3_{7/2^-}$. A calculation of the proton width of their analogue resonances assuming that the corresponding ^{52}V levels have pure $p_{3/2,1/2}\,(f_{7/2})^3_{7/2^-}$ configurations gives widths of 900 eV and 960 eV respectively. This means $\Gamma_p = \Gamma$ would probably be a reasonable assumption for the resonances in question. If this assumption is invalid then of course the gamma ray widths quoted in table 1 should be regarded as lower limits. Values for the branching ratios, gamma ray widths and coefficients of the angular distributions for the major decay modes of the resonances are shown in table 1. The weaker branches to higher excited states of ^{52}Cr have not been shown.

Table 1. Gamma decay data of the 1·567 and 1·629 MeV resonances showing the major decay modes. Weaker transitions to higher excited states have not been shown

Resonances (MeV)	Final state (MeV)	J_f^π†	A_2	A_4	Branching ratio	$(2J+1)\Gamma_\gamma$ (eV)	Γ_γ(M1) (mWu)‡
1·567	1·434	2^+	0·00 ± 0·11	0·01 ± 0·12	22 ± 3	0·98 ± 0·22	5·6
	2·370	4^+	−0·15 ± 0·03	−0·01 ± 0·03	28 ± 3	1·33 ± 0·30	9·6
	2·768	4^+	0·28 ± 0·13	0·05 ± 0·14	8 ± 1	0·35 ± 0·08	3·1
	2·965	2^+	−0·02 ± 0·15	0·06 ± 0·16	7 ± 1	0·35 ± 0·08	3·0
	3·163	2^+	−0·18 ± 0·11	−0·03 ± 0·14	14 ± 2	0·63 ± 0·14	6·1
	3·414	4^+	0·34 ± 0·17	0·09 ± 0·20	5·0 ± 0·6	0·21 ± 0·05	2·2
1·629	2·370	4^+	0·20 ± 0·03	−0·02 ± 0·03	38 ± 5	1·89 ± 0·38	10·6
	3·414	4^+	0·44 ± 0·12	0·00 ± 0·13	10 ± 1	0·48 ± 0·10	3·8
	3·472	$(3, 5^+)$	−0·03 ± 0·11	0·05 ± 0·12	4·0 ± 0·6	0·21 ± 0·04	1·7
	3·609	5^+	−0·01 ± 0·20	0·05 ± 0·23	7 ± 1	0·35 ± 0·07	3·1
	3·935		0·18 ± 0·16	−0·01 ± 0·18	5·0 ± 0·6	0·23 ± 0·04	2·1
	4·015	5^+	−0·01 ± 0·26	0·10 ± 0·30	3·0 ± 0·5	0·24 ± 0·05	1·5
	4·034	4^+	−0·05 ± 0·17	0·05 ± 0·20	7 ± 1	0·34 ± 0·07	3·4
	4·611	$(3, 4)^+$	0·36 ± 0·10	0·04 ± 0·10	11 ± 2	0·53 ± 0·11	6·5

† Spins and parities taken from Rapaport (1970) and Sprague *et al* (1971).
‡ M1 strengths calculated with the assumption that the transitions are purely M1.

The 0·793 MeV level and hence the 1·567 MeV analogue resonance has a J^π limited to 2^+ or 3^+ (Rapaport 1970). If the resonance J^π is assumed to be 2^+, the measured widths show that any M3 admixture in the transitions to the 4^+ levels must be very small. This implies that the two angular distributions must be identical which is contrary to the experimental observation (see table 1) that they differ significantly at the 0·1 % confidence level. Furthermore since the 0·793 MeV level was observed strongly with $l = 1$ neutron transfer in the $^{51}V(d, p)^{52}V$ reaction and no $l = 3$ contribution was observed then this would imply that the reduced width for $l = 3$ formation of the analogue resonance would be at least an order of magnitude less than the reduced width for $l = 1$ formation. This coupled with the fact that $l = 3$ proton penetrability is at least two orders of magnitude less than $l = 1$ proton penetrability at these bombarding energies implies that the width for formation by $l = 3$ protons would be at least three orders of magnitude less than the width for formation by $l = 1$ protons. It is thus reasonable to assume that formation by $l = 3$ protons is negligible so that if the resonance has a J^π of 2^+, it can only be formed by a channel spin of 3 for $l = 1$ protons and the substate population of the resonance is determined. Thus the angular distribution of the gamma ray transition to the 2·370 MeV (4^+) state, which must be pure E2, can be calculated and gives $1 + 0{\cdot}04\ P_2(\cos\theta)$. This is contrary to the experimental angular distribution of $1 - (0{\cdot}15 \pm 0{\cdot}03)\ P_2(\cos\theta)$. These considerations thereby exclude the 2^+

spin possibility giving a unique J^π of 3^+ for the resonance and hence the 0·793 MeV ^{52}V level.

The 0·846 MeV ^{52}V level has been excited strongly in the ^{51}V(d, p)^{52}V reaction with $l = 1$ neutron transfer and so can have spins ranging from 2^+ to 5^+. Since the analogue of this level is seen quite strongly in inelastic scattering to the 0·320 MeV ^{51}V state, which has an almost pure $(f_{7/2})^3_{5/2^-}$ configuration (Horoshko *et al* 1970), then a 5^+ assignment would mean that the ^{52}V level would have to be predominantly an $f_{5/2}(f_{7/2})^3_{5/2^-}$ configuration to explain the observed inelastic scattering width because of the extremely low penetrability of the emitted $l = 3$ protons. ^{51}V(d, p)^{52}V indicates that the predominant configuration is probably $p_{3/2}, {}_{1/2}(f_{7/2})^3_{7/2^-}$, so that the 5^+ possibility would be inconsistent with the observed inelastic scattering in the present experiment. The 2^+ possibility can also be excluded for the same reasons as for the previous resonance (see table 1) together with the fact that a 2^+ assignment would imply an M3 strength of 10^4 Wu to the 3·609 MeV (5^+) state of ^{52}Cr. The spin possibilities are thus reduced to 3^+ or 4^+. Unfortunately, in this case, because of the two possible channel spins 3 and 4 for $l = 1$ protons forming the resonance, no further distinction between the two spin possibilities can be made from the angular distribution. However if the resonance had a J^π assignment of 3^+ then the transition to the 3·609 MeV (5^+) and 4·015 MeV (5^+) levels would have quite strong E2 strengths of 0·1 Wu while, unlike the previous resonance shown to have a J^π of 3^+, no transitions to the 2^+ levels of ^{52}Cr have been observed. It would thus seem that a resonance J^π of 4^+ would be favoured, although of course a 3^+ assignment cannot be excluded.

3. Discussion

It can be seen from figure 1 that these spin assignments agree better with Vervier's theoretical predictions for these levels. This indicates the probable existence of an $f_{5/2}(f_{7/2})^3$ component in the configurations as this is included in Vervier's calculation. Further evidence of this could be indicated by the main decay modes of the analogue resonances to the ^{52}Cr levels at 1·434 MeV (2^+), 2·370 MeV (4^+) and 3·609 MeV (5^+) which are chiefly of the $(f_{7/2})^4$ configuration (Auerbach 1967). If these transitions are predominantly M1, then this could imply an $f_{5/2}(f_{7/2})^3$ component in the resonance wavefunctions since M1 transitions involving the single particle transitions $p_{3/2}$ or $p_{1/2} \rightarrow f_{7/2}$ are forbidden. However since Auerbach's calculations also indicate small admixtures of the configuration $p_{3/2}(f_{7/2})^3$ in the low lying ^{52}Cr levels mentioned above, then it could be possible that this component is responsible for the transition.

The 0·320 MeV ($5/2^-$) ^{51}V level is predominantly an $(f_{7/2})^3$ configuration (Horashko *et al* 1970). Thus the appearance of the resonances in inelastic scattering can be explained by a $p_{3/2}, {}_{1/2}(f_{7/2})^3_{5/2^-}$ component in the resonance wavefunctions. This experiment thus shows the importance of configurations other than $p_{3/2}(f_{7/2})^3_{7/2^-}$ indicated by the ^{51}V(d, p)^{52}V reaction.

Acknowledgments

I would like to thank Dr G A Jones for many helpful discussions and Mr D Hossain, Dr E P Jones, Dr J Domingos and Dr C W Cottrell who assisted in taking the data. Many thanks are also due to the staff of the Harwell Van de Graaff accelerator.

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