ELECTRIC DIPOLE PHOTON ABSORPTION IN ^{32}S†

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Summary

The particle–hole model has been applied to the calculation of $E1$ photon absorption by ^{32}S. A plausible unperturbed spectrum was obtained from investigation of the results of the ^{32}S(d,p)^{33}S and ^{32}S(p,2p)^{31}P reactions. The results of the calculation are compared with experiment, and suggestions are made with reference to the shortcomings of the calculation.

INTRODUCTION

The particle–hole model, proposed by Brown, Castillejo, and Evans (1961) enjoyed a large measure of success in accounting for the features of photodisintegration cross sections of doubly-magic ^{16}O and ^{40}Ca. This success has been extended to the closed subshell nuclei ^{12}C and ^{28}Si by Vinh-Mau and Brown (1962) and Bolen and Eisenberg (1964) respectively. The existence of a considerable body of data on ^{32}S from direct or inverse photodisintegration reactions has motivated the present calculation of 1^- states in ^{32}S.

CALCULATION AND RESULTS

^{32}S is a closed subshell nucleus, the $2s_{1/2}$ subshell being completed there. The energies of the single-particle states in the unperturbed ^{32}S spectrum are extracted in the usual way from data on ^{33}S and ^{31}P. The known levels of ^{33}S, which are strongly excited in the ^{32}S(d,p) reaction and which have the correct spin and parity, have been taken as the single-particle states of ^{33}S (McFarlane and French 1960). Thus, the ground state of ^{33}S is the $1d_{3/2}$ state, and states at $2\cdot94$, $3\cdot22$, and $5\cdot71$ MeV are taken to be the $1f_{7/2}$, $2p_{3/2}$, and $2p_{1/2}$ single-particle states respectively. These states have reduced widths in the stripping reaction, which support these assignments. The $1f_{5/2}$ state is estimated to be about 6 MeV above the $1f_{7/2}$ state; the approximate value of the separation being taken from data on ^{40}Ca.

The ^{31}P states are more difficult to locate, and it must be done from two studies of the ^{32}S(p,2p) reaction. First, Pugh and Riley (1961) report ^{31}P states corresponding to the ejection of an s-wave proton from ^{32}S, and a non-s-wave proton, which are separated by 5 MeV. These correspond to the ground state of ^{31}P($2s_{1/2}$) and a state which is presumably the $1d_{5/2}$ single-particle state at 5 MeV excitation. Gottschalk (1962) has also given spectra from this (p,2p) reaction and shows that there is an asymmetric peak which could well be due to the two states just mentioned. Also, one can read into his spectra the presence of two smaller "bumps" which should be

due to the $1p_{1/2}$ and $1p_{3/2}$ states in ^{31}P. These are necessary for the calculation, but, as the results show, play a very small part in it. It must be emphasized that large uncertainties should be attached to the energies of these two states. The whole scheme of particle and hole states is shown in Figure 1.

The residual interaction was taken to be of the form

$$V = V_0(1-\eta+\eta\sigma_1 \cdot \sigma_2)\delta(r_1-r_2),$$

where the parameters are taken to be $\eta = 0\cdot 135$ and $V_0 a^3/4\pi = -10\cdot 22$ MeV, a being the harmonic oscillator range parameter. The value of $V_0 a^3/4\pi$ was fixed by interpolating between the successfully used values of this parameter for ^{40}Ca and ^{28}Si, with the proper A-dependence.
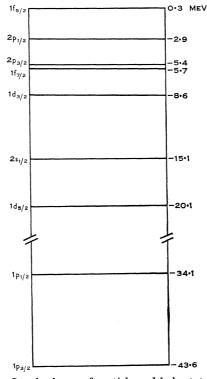

Fig. 1.—Level scheme of particle and hole states in ^{32}S.

The diagonalization of the secular matrices based on the unperturbed spectrum shown in Figure 1, together with the residual interaction indicated, yields the results shown in Table 1 for 1^- states. The calculations were performed under the assumption that isospin is a good quantum number, and results for $T = 0$ and $T = 1$ states are presented. This assumption is not expected to be a good one for states in ^{32}S at such high excitation, and thus considerable isospin mixing is expected to take place.

The lowest $T = 0$ state, given at $1\cdot 76$ MeV and having a very coherent nature, is simply the spurious state of the shell model due to translational motion of the

nuclear centre of mass. The inclusion of ground state correlations in the calculations will place its energy much closer to zero, where it should be, and increase its coherence. These properties are exactly those expected of the $T = 0$, 1^- spurious state.

TABLE 1

ENERGY EIGENVALUES AND EIGENVECTORS FOR 1^- STATES IN ^{32}S

E denotes the transition energy. The numbers in the second row are unperturbed energies in MeV. All eigenvectors are unnormalized.

E (MeV)	$2s_{1/2}^{-1}2p_{3/2}$ 9·7	$1d_{5/2}^{-1}1f_{7/2}$ 14·4	$1d_{5/2}^{-1}2p_{3/2}$ 14·7	$2s_{1/2}^{-1}2p_{1/2}$ 12·2	$1d_{5/2}^{-1}1f_{5/2}$ 20·4	$1p_{1/2}^{-1}1d_{3/2}$ 25·5	$1p_{3/2}^{-1}1d_{3/2}$ 35·0
			$T = 1$				
11·89	1·000	−0·155	0·016	−0·188	0·020	−0·010	0·007
14·07	0·152	−0·234	0·066	1·000	−0·091	−0·024	−0·026
16·77	−0·061	−0·177	1·000	−0·105	−0·096	0·096	0·023
19·07	0·183	1·000	0·254	0·204	0·220	−0·248	0·009
22·26	−0·057	−0·263	0·064	0·028	1·000	−0·133	−0·115
28·29	0·053	0·199	−0·029	0·072	0·159	1·000	−0·255
38·02	0·004	0·010	−0·023	0·048	0·148	0·225	1·000
			$T = 0$				
1·76	0·900	1·000	0·051	0·755	0·136	0·321	0·105
8·34	1·000	−0·702	−0·197	−0·177	−0·073	−0·130	−0·038
11·81	0·148	−0·005	1·000	−0·209	0·016	−0·068	−0·014
13·63	−0·178	−0·507	0·219	1·000	−0·142	−0·227	−0·062
20·86	−0·026	−0·154	−0·001	0·058	1·000	0·001	−0·026
23·59	−0·059	−0·302	0·085	0·041	−0·050	1·000	0·050
35·06	−0·018	−0·072	0·012	0·005	0·014	−0·073	1·000

TABLE 2

DIPOLE TRANSITION STRENGTHS UNDER THREE APPROXIMATIONS

Calculation I $V_0a^3/4\pi = -10·22$ MeV		Calculation II $V_0a^3/4\pi = -9·5$ MeV		Calculation III $V_0a^3/4\pi = -10·22$ MeV*	
E (MeV)	$|M|^2$ (%)	E (MeV)	$|M|^2$ (%)	E (MeV)	$|M|^2$ (%)
11·89	1	11·75	1	11·89	1
14·07	0	13·94	0	14·07	0
16·77	0	16·63	0	16·78	0
19·07	76	18·78	78	19·10	77
22·26	5	22·12	4	23·12	3½
28·29	17	28·09	16	28·07	16
38·02	1	37·76	1	35·34	2½

* Spectrum changed.

The eigenvectors obtained from the diagonalization were also used in the calculation of the dipole strengths of the $T = 1$ states, and these are shown in Table 2 (calculation I). Also shown in Table 2 are the dipole strengths which result from calculations using two variations in the basic assumptions. In calculation II, the

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TABLE 3

COMPARISON OF PRESENT CALCULATION WITH EXPERIMENTAL RESULTS

Author:	Thompson and Taylor*	Firk (1964)	Mutsuro et al. (1963)	Bolen and Whitehead (1963)	Kimura et al. (1963)	Gemmell and Jones (1962)	Present Calculation	
Reaction studied:	$^{32}S(\gamma,n)$	$^{32}S(\gamma,n)$	$^{32}S(\gamma,n)$	$^{32}S(\gamma,n)$	$^{31}P(p,\gamma_0)$	$^{31}P(p,\gamma_0)$	$T = 0$	$T = 1$
								11·89
						13·5	13·62	14·06
						14·3		
						15·0		
	15·6		15·7		15·7	15·6		
	15·9			16·0	16·1	16·0		16·77
	(16·7)		16·8		16·9	16·8		
	17·4	17·4		17·5	17·8	17·6		
	17·6	17·7						
		17·9						
	18·05	18·1	18·0	18·25	18·2	18·1		
	18·4	18·4	18·7		18·8	18·9		
	18·8	18·8	19·3		19·1			19·07
	19·1	19·0						
		19·4						
	19·6	19·8	19·7	19·75	19·75			
		20·2						
	(20·5)	20·6	20·5	21·25	20·5		20·86	
	(21·5)			22·75				22·26
				24·0			23·59	28·28
							35·06	38·02

* Personal communication, 1964.

residual interaction strength was set at $V_0 a^3 / 4\pi = -9 \cdot 5$ instead of $-10 \cdot 22$ MeV. In calculation III, the assumed positions of the $1p_{3/2}$ and $1f_{5\,2}$ states were shifted upward by 3 and 1 MeV respectively, with $V_0 a^3 / 4\pi$ set equal to $-10 \cdot 22$ MeV. It is to be noted that the relative dipole strengths, taken as $|M|^2$ where $M = \int \psi_f^* z \psi_i \, d\tau$, are quite insensitive to these parameter variations. Also, the eigenvectors showed little change due to the two variations. However, it must be emphasized that the wave functions given by a calculation such as this are not considered to be reliable, so that the only firm prediction which can be made is that most of the dipole strength is concentrated in states at 19 and 28 MeV.

COMPARISON WITH EXPERIMENT

The states predicted by this calculation are to be compared with states found in the ^{31}P(p,γ_0)^{32}S reaction (Gemmell and Jones 1962; Kimura *et al*. 1963), in the measurement of the neutron spectra from ^{32}S(γ,n)^{31}S by time-of-flight methods (Firk 1964; Mutsuro *et al*. 1963), and in direct measurements of the ^{32}S(γ,n)^{31}S cross section by yield-curve techniques (Bolen and Whitehead 1963; Thompson and Taylor 1964, personal communication).

The comparison of the calculation with these experimental results is shown in Table 3. It should be noted that only the strong peaks obtained in Firk's measurement are quoted. This is done so that the experimental results may be compared with approximately the same resolution. This approximation in no way removes the necessity for understanding the finer structure.

There exist at present no experimental data above an excitation of 21 MeV, so that the prediction of much cross section at 28 MeV cannot be tested as yet. It is of interest, however, that the possibility exists for the use of the photodisintegration reaction to determine the energies of the two $1p$ states in ^{32}S.

DISCUSSION

It is apparent that there are many more states in the experimental data than are predicted by the present calculation. The extra peaks may be due to $M1$ or $E2$ excitations which were not included in the calculation, or they could be due to a deficiency of the particle–hole model.

This model takes the ground state of the initial nucleus to be the physical vacuum, and does so irrespective of any properties of this ground state. For example, the ^{32}S and ^{28}Si nuclei are expected to be softer against deformation than the doubly-magic ^{16}O and ^{40}Ca nuclei, but the simple model is not able to build in this fact. Perhaps it would show in terms of ground state correlations being much more important for ^{32}S and ^{28}Si, if these correlations should be included in the calculation.

The other limiting feature of the model is that it assumes pure j-j coupling, and thus assumes that all of the single-particle strength is concentrated in one level. This is clearly an idealization, and an alternative much nearer reality was pointed out by Lane, Thomas, and Wigner (1955) to cope with a different situation. If one takes the view that the single-particle nature is concentrated in a given region of excitation, but is spread among many levels with some sort of peaked distribution

about the mean, then in nuclei where the level densities are relatively low there will be more strongly absorbing 1^- states than the simple particle–hole model predicts. This may well be the case in ^{32}S, where, for example, McFarlane and French (1960) state that the $1f_{7/2}$ state is apparently distributed among three or more levels.

ACKNOWLEDGMENTS

REFERENCES

BOLEN, L. N., and EISENBERG, J. M. (1964).—*Phys. Letters* **9**: 52.
BOLEN, L. N., and WHITEHEAD, W. D. (1963).—*Phys. Rev.* **132**: 2251.
BROWN, G. E., CASTILLEJO, L., and EVANS, J. A. (1961).—*Nuclear Phys.* **22**: 1.
FIRK, F. W. K. (1964).—*Nuclear Phys.* **52**: 437.
GEMMELL, D. S., and JONES, G. A. (1962).—Quoted by Kimura *et al.* (1963).
GOTTSCHALK, B. (1962).—Ph.D. Thesis, Harvard University.
KIMURA, M., *et al.* (1963).—*J. Phys. Soc. Japan* **18**: 477.
LANE, A. M., THOMAS, R. G., and WIGNER, E. P. (1955).—*Phys. Rev.* **98**: 1524.
McFARLANE, M. H., and FRENCH, J. B. (1960).—*Rev. Mod. Phys.* **32**: 567.
MUTSURO, N., *et al.* (1963).—*J. Phys. Soc. Japan* **18**: 599.
PUGH, H. G., and RILEY, K. F. (1961).—Proc. Rutherford Jubilee Int. Conf. p. 195. (Academic Press: New York.)
VINH-MAU, N., and BROWN, G. E. (1962).—*Nuclear Phys.* **29**: 89.