AN INTERPRETATION OF DE-EXCITATION GAMMA RAY MEASUREMENTS FOLLOWING THE PHOTODISINTEGRATION OF ^{12}C, ^{16}O, AND ^{40}Ca†

By B. M. Spicer‡

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Abstract

The relative populations of final states in photonuclear reactions for ^{12}C, ^{16}O, and ^{40}Ca are examined in the light of information on the known major configurations present in the wavefunctions of those final states, with the assumption that the nucleon excited in the radiation absorption process is in fact the one emitted. This assumption is investigated and found to be reasonable for ^{12}C and ^{16}O but not for ^{40}Ca. The data on relative populations of final states are interpreted to give information on the relative strengths of configurations in the wavefunctions of the ground states of the three nuclei.

I. Introduction

The single-particle, single-hole model of electric dipole states of closed shell and closed subshell nuclei makes implicit predictions regarding the nature of the final residual states available. For example, in ^{12}C the dominant E1 excitations involve, in the pure *jj*-coupling model, the promotion of a single nucleon from the $1p_{3/2}$ state to an excited $2s_{1/2}$ or 1d state. In the absence of residual interactions which could recouple the excited nucleon to the core, the final state must have a pure $(1p_{3/2})^{-1}$ configuration, that is, it is the ground state of ^{11}B or ^{11}C.

In the case of ^{16}O, nucleons may be excited from either the $1p_{1/2}$ or the $1p_{3/2}$ state, so that (again assuming no residual interactions to couple the excited nucleon to the core) the final state must have a $(1p_{1/2})^{-1}$ or $(1p_{3/2})^{-1}$ hole configuration. Experiments measuring spectra of the de-excitation γ-rays in ^{15}N and ^{15}O (Owens and Baglin 1966; Ullrich and Krauth 1969; Horowitz *et al.* 1970) have shown that more states are populated than just the $1p_{3/2}$ hole state, which is at an excitation of 6·32 MeV in ^{15}N and 6·18 MeV in ^{15}O. In particular, the doublet of states at approximately 5 MeV excitation in both ^{15}N and ^{15}O has been shown to be quite strongly populated, as well as other states at higher excitation energies. The more strongly populated final states, as well as their dominant configurations, are listed in Table 1.

The observation of population of the even parity states indicates the need to consider dipole states whose configurations contain at least two-particle, two-hole excitations. Indeed, the nature of the configurations of the even parity states of ^{15}N and ^{15}O, listed in Table 1, makes it mandatory to consider at least two-particle, two-hole excitations in the dipole states (see Owens and Baglin 1966).

† Work carried out while the author was a National Science Foundation Senior Foreign Scientist Fellow at the Physics Department, Catholic University of America, and the Center for Radiation Research, National Bureau of Standards, Washington D.C., U.S.A.

‡ School of Physics, University of Melbourne, Parkville, Vic. 3052.

The present paper investigates the proposition that the relative intensities of de-excitation γ-rays can give quantitative information regarding admixtures in the ground state wavefunction of the target nucleus.

The population of even parity residual states, and the observation made above, raises some interesting questions. Firstly, how correct is the assumption that the residual interactions can be neglected? In other words, how correct is the assumption that the excited particle in a dipole state configuration is in fact the particle emitted? The answer of course is found in the lifetime of the dipole state—the longer the lifetime the more likely that the residual interaction has caused mixing in the dipole state.

TABLE 1

FINAL STATES OBSERVED IN PHOTODISINTEGRATION OF ^{16}O

^{15}N E_f (MeV)	^{15}O E_f (MeV)	J^{π}	Dominant configuration
0	0	$1/2^-$	$(1p_{1/2})^{-1}$
5·27	5·24	$5/2^+$	$(1d_{5/2})(1p_{1/2})^{-2}$
5·30	5·18	$1/2^+$	$(2s_{1/2})(1p_{1/2})^{-2}$
6·32	6·18	$3/2^-$	$(1p_{3/2})^{-1}$
7·30	6·79	$3/2^+$	$(1d_{3/2})(1p_{1/2})^{-2}$

For the ^{16}O and ^{12}C nuclei the widths of the dipole states are approximately 1 MeV or more, and during the characteristic lifetime corresponding to this width a nucleon is able to make up to 10 transits across the nucleus. In this case the assumption of no interactions occurring may well be valid. For ^{40}Ca, however, the width of structure is of the order of 0·3 MeV or so and the characteristic lifetime is long enough for 20 or 30 transits of the nucleus. In this case, one may suppose that interactions will occur and that the nucleon emitted in a photonuclear reaction may well not be the one excited in the radiative absorption. This proposition is supported by the work of Singh *et al.* (1965) on the reaction $^{27}Al(p, \gamma_0)^{28}Si$. They found that the angular distribution of emitted γ-rays was consistent with the absorption of p-wave protons, while the particle–hole model for ^{28}Si indicates that the dominant transition is $1d_{5/2} \rightarrow 1f_{7/2}$. One may thus infer that interactions took place between the proton absorption and photon emission in this case.

The second question that arises is just how the multiparticle, multihole dipole states are formed in the photonuclear reaction. Since it has been shown that there are significant $2p$–$2h$ and $4p$–$4h$ admixtures in the ground states of all three nuclei under consideration here, we shall take as a basis for discussion that the np–nh dipole states arise from the excitation of a nucleon from a correlated pair or quartet in the ground state. What is neglected in this assumption is the possibility that $T = 1, 1^-$ states, of unperturbed energy $3\hbar\omega$, may be forced down into the relevant energy region by the residual interaction. Such states are $2p$–$2h$ in nature, and may be formed by exciting two nucleons from a pure ground state. If such a situation pertains, there must be significant mixing of $2p$–$2h$ dipole configurations with those which are $1p$–$1h$ in nature in order to allow significant radiative absorption in the states so formed. For there to be any mixing, certain conditions must be satisfied (see Eisenberg *et al.* 1965), and these will reduce to some extent the degree of mixing of $1p$–$1h$ and $2p$–$2h$ $T = 1$ dipole states. Thus, it is considered more likely that the ground state correlations are the source of transitions which lead to the formation of final states not predicted by the simple particle–hole model. We shall proceed with this assumption, knowing that the effect of any error so introduced will be to overestimate the admixtures of higher particle–hole configurations in the ground state wavefunction.

One other condition must be noted. As a general rule, nuclear energy levels decay by γ-ray emission only if their excitation energy is less than the nucleon binding energy. Thus the population in the photoreaction of final states above the nucleon emission energy will not be reflected in the de-excitation γ-ray spectrum and will tend to cause the analysis to underestimate the contributions of higher configurations.

II. A Specific Example

Consider the reactions $^{16}O(\gamma, p)^{15}N$ and $^{16}O(\gamma, n)^{15}O$ feeding the $1/2^+$ state (at 5·30 MeV in ^{15}N and at 5·18 MeV in ^{15}O). The dominant configuration for this state must be taken to be $(2s_{1/2})(1p_{1/2})^{-2}_{J=0,T=1}$. The coupling of the $1p_{1/2}$ holes is written as $J = 0$, $T = 1$ since both the $^{14}N(d, p)$ reaction studies and the calculation of Halbert and French (1957) indicate that the ^{14}N ground state is not a parent of the ^{15}N state at 5·30 MeV, but rather the 2·31 MeV state of ^{14}N (0^+, $T = 1$) is the dominant parent state. Given such a configuration, the only two dipole states that can be formed in ^{16}O, if we accept the hypothesis of no residual interactions, must be of the form

$$(2p_{1/2})(2s_{1/2})(1p_{1/2})^{-2}_{0,1} \qquad \text{or} \qquad (2p_{3/2})(2s_{1/2})(1p_{1/2})^{-2}_{0,1},$$

where the two subscripts refer to the J, T to which the two $1p_{1/2}$ holes are coupled.

For the $5/2^+$ final state in mass-15 nuclei, the dominant configuration is $(1d_{5/2})(1p_{1/2})^{-2}_{0,1}$, and the dipole states must then be of the form

$$(2p_{3/2})\,(1d_{5/2})(1p_{1/2})^{-2}_{0,1},$$

or

$$(1f_{7/2})\,(1d_{5/2})(1p_{1/2})^{-2}_{0,1},$$

or

$$(1f_{5/2})\,(1d_{5/2})(1p_{1/2})^{-2}_{0,1}.$$

Now, remembering that the radiative transition operator is a single-particle operator, we note that the most likely initial states able to give rise to these two groups of dipole states are

$$(2s_{1/2})^2(1p_{1/2})^{-2} \qquad \text{or} \qquad (1d_{5/2})^2(1p_{1/2})^{-2}$$

in the ^{16}O ground state. This means that we speak of a radiative transition of $1\hbar\omega$ energy, namely

$$2s_{1/2} \rightarrow 2p_{1/2} \quad \text{or} \quad 2p_{3/2}$$

or

$$1d_{5/2} \rightarrow 1f_{7/2} \quad \text{or} \quad 1f_{5/2} \quad \text{or} \quad 2p_{3/2}.$$

It should be pointed out that this type of argument provides no way of distinguishing between a $2p$–$2h$ and a $4p$–$4h$ admixture in the ground state. The latter would be favoured by the arguments of Gillet and Danos (see Gillet 1968), but it is expected that both $1p$–$2h$ and $3p$–$4h$ configurations will be present in these even parity states of the mass-15 nuclei, as is borne out by the calculation of Zuker *et al.* (1968).

The preceding comments indicate that an analysis such as the present one can, at best, only be approximate. To be strictly correct, the ground state of ^{15}N should be considered as a $1p_{1/2}$ hole in the actual ^{16}O ground state and not, as is done in this paper, as a $1p_{1/2}$ hole in the pure shell model ^{16}O ground state. This means that the proper configurations specifying the ^{15}N ground state should be $1h$ plus $2p$–$3h$ plus $4p$–$5h$ .... The proper way to approach this ideal situation is by iteration, that is, first assume a pure ground state and deduce an admixed ground state by the type of analysis shown below, and then use this admixed ground state as input for a second analysis step to deduce a better approximation to the intensities of admixed configurations in the ground state of the target nucleus. On convergence of such an iterative process, the correct configuration admixtures presumably will be found. The present work considers only the first step of this iterative procedure.

TABLE 2

FINAL STATES POPULATED IN PHOTODISINTEGRATION OF ^{12}C

Data from Medicus *et al.* (1970)

E_f (MeV) ^{11}B	^{11}C	J^π	Relative population (%) ^{11}B	^{11}C	Mean	
0	0	$3/2^-$	88·6	88·3	88·5	
2·12	2·00	$1/2^-$	4·5	5·7	5·1	10·1
4·44	4·30	$5/2^-$	1·8	1·8	1·8	
5·02	4·79	$3/2^-$	2·5	2·7	2·6	
6·74	6·48	$7/2^-$	0·7	0·5	0·6	
6·79	6·34	$1/2^+$	0·5	0·5	0·5	1·25
7·30	6·91	$5/2^+$	0·5	0·5	0·5	
8·00	7·51	$3/2^+$	0·5	—	0·25	
8·57	8·11	$<5/2^-$	0·4	—	0·2	

III. COMPARISON WITH EXPERIMENTAL DATA

(*a*) *Results for ^{12}C*

In considering the results of γ-ray de-excitation measurements, we require that the bremsstrahlung spectrum used should more than adequately cover the energy region of the giant dipole resonance. For the case of ^{12}C we take the measurements of Medicus *et al.* (1970) for the 42 MeV bremsstrahlung bombardment, which was the highest energy they used. The results are shown in Table 2. The relative populations of the analogue states in ^{11}B and ^{11}C can give information on the average isospin purity of the dipole states. However, a mean value is taken here as we wish to note the percentage population of residual states following nucleon emission.

The ground states of ^{11}B and ^{11}C are predominantly $(1p_{3/2})^{-1}$ and this is assumed to be their nature. These residual states are the ones predicted in the $1p$–$1h$ theory of the dipole states of ^{12}C.

The next four odd parity states can all be formed from the configuration $(1p_{1/2})(1p_{3/2})^{-2}$ or $(1p_{1/2})^3(1p_{3/2})^{-4}$. Final states of this form are involved in 10% of the reactions. Within the framework given in Section II above, the presence of these states among the final states in the reaction is in terms of an admixture in the ground state of ^{12}C of the form $(1p_{1/2})^2(1p_{3/2})^{-2}$ or $(1p_{1/2})^4(1p_{3/2})^{-4}$.

The appearance of the $1/2^+$, $5/2^+$, and $3/2^+$ states among the final states in this reaction is similarly taken to indicate admixtures in the ground state of ^{12}C of the form:

$$(2s_{1/2})^2(1p_{3/2})^{-2} \quad \text{or} \quad (2s_{1/2})^4(1p_{3/2})^{-4}, \quad 0\cdot5\% \text{ intensity;}$$

$$(1d_{5/2})^2(1p_{3/2})^{-2} \quad \text{or} \quad (1d_{5/2})^4(1p_{3/2})^{-4}, \quad 0\cdot5\% \text{ intensity;}$$

$$(1d_{3/2})^2(1p_{3/2})^{-2} \quad \text{or} \quad (1d_{3/2})^4(1p_{3/2})^{-4}, \quad 0\cdot25\% \text{ intensity.}$$

Thus we deduce that the ^{12}C ground state is 88% $(1p_{1/2})^0$, $10\frac{1}{2}$% $(1p_{3/2})^{-2}(1p_{1/2})^2$ or $(1p_{3/2})^{-4}(1p_{1/2})^4$, and $1\frac{1}{2}$% $(1p_{3/2})^{-2}$(2s–1d)^2 or $(1p_{3/2})^{-4}$(2s–1d)^4. In arriving at this conclusion, we have ignored any difference between the probabilities of exciting a $1p_{3/2}$ nucleon and a $1p_{1/2}$ nucleon. The present result is to be compared with that given by Rowe and Wong (1970), which also agrees with Cohen and Kurath's (1967) result, namely $80\frac{1}{2}$% $(1p_{1/2})^0$ and $19\frac{1}{2}$% $(1p_{1/2})^2(1p_{3/2})^{-2}$. The 2s–1d shell nucleons were not included in the basis for either of these calculations.

It is to be noted that the wavefunctions of the two lowest $J^\pi = 3/2^-$ states of the mass-11 nuclei will be dominated by the configurations $(1p_{3/2})^{-1}$ and $(1p_{1/2})^2(1p_{3/2})^{-3}$. These two states are the ground state and the 5·02 MeV state in ^{11}B (4·79 MeV in ^{11}C). The population of the latter states is anomalously high and may therefore represent an underestimate of up to 2% for the intensity of the $(1p_{1/2})^0$ component in the ground state wavefunction. However, such a value is certainly less than the size of the experimental errors. The overall agreement is considered satisfactory.

TABLE 3

FINAL STATES POPULATED IN PHOTODISINTEGRATION OF ^{16}O

Data from Caldwell *et al.* (1967) and Ullrich and Krauth (1969)

E_f (MeV) ^{15}N	^{15}O	J^π	Relative population (%) ^{15}N	^{15}O	Sum
0	0	$1/2^-$	28·7	22·3	51·0
5·27	5·24	$5/2^+$	3·6	1·9	5·5
5·30	5·18	$1/2^+$	0·5	1·0	1·5
6·32	6·18	$3/2^-$	18·5	7·9	26·4
7·30	6·79	$3/2^+$	4·7	3·8	8·5
8·31*		$1/2^+$			
9·05		$1/2^+$	1·7	—	1·7
9·22		$3/2^+$	1·3	—	1·3
9·93		$1/2^+$	2·0	—	2·0
10·7		$3/2^+$	2·0	—	2·0

* Yields probably not separable from 7·30 MeV results.

(*b*) *Results for* ^{16}O

For the case of ^{16}O, the results in Table 3 are those of Caldwell *et al.* (1967) and Ullrich and Krauth (1969). These experiments covered respectively an energy range from 16 to 29 MeV using monoenergetic photons and a bremsstrahlung spectrum of 32 MeV. The data of Caldwell *et al.* include information on transitions to the ground states of ^{15}N and ^{15}O.

There is an existing discrepancy regarding the relative yields of 5 and 6 MeV γ-rays as a function of bremsstrahlung energy. Maison *et al.* (1965) found that the relative populations of these γ-rays stayed essentially constant with change of bremsstrahlung energy from 21 to 31 MeV. (They also derived relative populations in disagreement with the results quoted in Table 3.) On the other hand, Owens and Baglin (1966) indicated that the 5 MeV states were populated mainly in the region of 23 MeV excitation. The results of Caldwell *et al.* (1967), as quoted, indicate 77·4% of the total decays of ^{16}O dipole states lead to $1/2^-$ and $3/2^-$ states. This compares with 80 ± 8 % found by Horowitz *et al.* (1970) using bremsstrahlung with an end-point energy of 27 MeV. It is to be noted that $1/2^-$ and $3/2^-$ final states (or, more correctly, $1p_{1/2}$ and $1p_{3/2}$ single-hole strengths) are the only final states available if the ^{16}O ground state is considered as a pure $0p$–$0h$ state.

The results of Caldwell *et al.* (1967) and Horowitz *et al.* (1970) then indicate that:

$1/2^-$ and $3/2^-$	states are populated in 77·4% of the reactions,
$1/2^+$	states are populated in 5·2% of the reactions,
$5/2^+$	states are populated in 5·5% of the reactions,
$3/2^+$	states are populated in 11·8% of the reactions.

Once more it has been assumed that nucleons may be excited from all single-particle orbitals with the same probability. It is of interest to compare these results with a theoretical calculation by Brown (1966), who found

$$\psi(0_1^+, 0\ \mathrm{MeV}) = 0\cdot 87(0p\text{–}0h) + 0\cdot 47(2p\text{–}2h) + 0\cdot 13(4p\text{–}4h).$$

This gives an intensity of 76% for the $0p$–$0h$ component in the ground state and 24% for higher particle–hole configurations, which is in fortuitously good agreement with the experimental values quoted above.

Ellis and Zamick (1969) have compared several different methods of calculating the $2p$–$2h$ admixtures in the ^{16}O ground state. They indicate that their best value for the $2p$–$2h$ admixture in this state is 22%, although differing methods of calculation give results from 14% to 43%. It is worth noting that the "best" value given by Ellis and Zamick is very close to that of Brown (1966) quoted above.

A different value for the intensity of the $2p$–$2h$ admixture is the 33% given by the calculation of Zuker *et al.* (1968). However, as noted by Green and Rho (1969), this value is obtained as the result of diagonalization of a very large matrix and such a process always brings with it large uncertainties in the energies of single-particle levels.

(*c*) *Results for* ^{40}*Ca*

In the case of ^{40}Ca, the data in Table 4 on the spectrum of de-excitation γ-rays are taken from the work of Ullrich and Krauth (1969). Their experiment involved bombardment of a calcium target with 32 MeV bremsstrahlung. Here, there is no reference to the cross sections for neutron and proton emission to the ground states of the residual nuclei as there was in the cases of ^{12}C (Medicus *et al.* 1970) and ^{16}O (Caldwell *et al.* 1967).

Wu *et al.* (1969) measured both the (γ, p_0) and (γ, n_0) reaction cross sections for 90° angle of emission and found $\sigma(\gamma, p_0)/\sigma(\gamma, n_0) = 2\cdot 2$ independent of energy. This is in conflict with the ratio of 3·5 for the populations of the first excited states of ^{39}K and ^{39}Ca given in Table 4. Unfortunately, neither of these values can be relied upon to any high accuracy. Although the de-excitation γ-ray measurements have evidently been corrected for the effect of cascades, the major problem is in normalization of yields to that of the 6·32 MeV γ-ray produced in the reaction $^{16}O(\gamma, p\gamma')^{15}N$. This normalization tacitly assumes that the shapes of the photoreaction cross sections in ^{16}O and ^{40}Ca are the same, an assumption which is not correct. In the case of the experiment of Wu *et al.*, the value for the ratio of the (γ, n) to (γ, p) cross sections is dependent on independently derived data for the absolute efficiencies of proton and neutron detection.

TABLE 4

FINAL STATES POPULATED IN PHOTODISINTEGRATION OF ^{40}Ca

Data from Ullrich and Krauth (1969)

E_f (MeV) ^{39}K	^{39}Ca	J^π	Relative populations (%) ^{39}K	^{39}Ca	Sum
0	0	$3/2^+$	53·2	15·2	68·4
2·53	2·47	$1/2^+$	15·6	4·4	20·0
2·82	2·79	$7/2^-$			4·2
3·02	3·03	$3/2^-$			2·0
3·88	(3·88)	$7/2^-$			0·4
3·94	3·94*	$1/2^-$ or $3/2^-$			0·7
4·93	—	?	0·6	—	0·6
5·17	—	?	0·7	—	0·7
5·28	5·13	$(3/2^+)$ or $5/2^+$			1·3
5·62	—	$(3/2^+)$ or $5/2^+$	0·5	—	0·5
5·96†	—	$1/2^-$ or $3/2^-$	0·3	—	0·3
—	6·15	$(3/2^+)$ or $5/2^+$	—	0·3	0·3
—	6·35	$(3/2^+)$ or $5/2^+$	—	0·6	0·6

* The ^{39}Ca state shows $l_n = 1$ pick-up in the reaction $^{40}Ca(^3He, \alpha)$.
† The ^{39}K state shows $l_p = 1$ pick-up in the reaction $^{40}Ca(t, \alpha)$.

Because of the above uncertainties, it is necessary to check back to other measurements of, for example, the (γ, n) reaction cross section integrated to 30 MeV. Baglin and Spicer (1964) quoted for that quantity a value of 81 ± 4 MeV mb, while Min *et al.* (1963) gave 76 MeV mb for cross section integration to 28 MeV. Lindenberger and Scheer (1960) gave 116 ± 7 MeV mb for the sum of the integrated cross sections for (γ, n), (γ, pn), and $(\gamma, 2n)$ reactions to 33 MeV. The work of Bramanis (1971) indicates that the integrated (γ, pn) cross section to 33 MeV is about 36 MeV mb, which, if the $(\gamma, 2n)$ reaction makes a negligible contribution, leaves close to 80 MeV mb as the integrated cross section for the (γ, n) reaction. We assume this value.

We also take the ratio of the (γ, p) to (γ, n) cross sections, independent of energy, to be 3·5. This is supported by the measurement of Ratner (1964) who gives the integrated (γ, p) cross section as 280 MeV mb, more than three times the value for the (γ, n) reaction. This value of 3·5 is in much better agreement with the experimental ratio of 3·5 (Ullrich and Krauth 1969) than with the 2·2 given by Wu *et al.* (1969).

The integrated cross sections from Table 4 indicate that (γ, n) and (γ, p) reactions to excited states of the residual nuclei contribute a total of 113 MeV mb. This implies that the (γ, n) and (γ, p) reactions leading to the ground states of ^{39}Ca and ^{39}K respectively contribute a total of 250 MeV mb, integrated to 30 MeV. The values indicate that 91% of the transitions populate even parity final states, that is, they populate states which are consistent with a pure configuration in the ^{40}Ca ground state. For the odd parity final states, 4·6% of the transitions populate $7/2^-$ states, 2·0% populate $3/2^-$ states, and 1·0% populate $1/2^-$ states. These states would be populated by virtue of having wavefunction components of the form

$$(1f_{7/2})^{2n-1}(1d_{3/2})^{-2n}$$
$$(2p_{3/2})\quad(1d_{3/2})^{-2n}$$
$$(2p_{1/2})\quad(1d_{3/2})^{-2n},$$

where $n = 1$ or 2 (see Section II). The percentages turn out to be very much the same whatever value is taken for the ratio $\sigma(\gamma, p)/\sigma(\gamma, n)$.

The implication of the results is that the wavefunction for the ground state of ^{40}Ca is rather more pure than was given by the calculation of Gerace and Green (1967). They found

$$\psi(0^+, 0\text{ MeV}) = 0\cdot904(0p\text{–}0h) + 0\cdot414(2p\text{–}2h) + 0\cdot111(4p\text{–}4h),$$

that is, the ^{40}Ca ground state has an intensity component 82% $0p$–$0h$ and 18% of higher particle–hole configurations. The interpretation of the de-excitation γ-ray experiment in ^{40}Ca is that the ground state of that nucleus has 9% of intensity of ground state correlations. The Gerace and Green calculation gives 18%.

It should also be noted that the random phase approximation calculation of Agassi *et al.* (1969) predicts very large amounts of shell breaking in all three of the nuclei considered here. However, the investigations of Rowe (1968) and Ellis and Zamick (1969) seem to indicate that the random phase approximation overestimates the shell breaking, at least in the case of ^{16}O by approximately a factor of two.

IV. Conclusions

This paper has investigated the proposition that the relative populations of final states in photonuclear reactions can give quantitative information not only about the nature of the dipole states but also about the intensity of multiparticle, multihole components in the wavefunction of the ground state of the target nucleus. The proposition has been based upon two assumptions: (1) that the excited particle is in fact the one emitted and (2) that the formation of multiparticle, multihole dipole states reflects the presence of correlations in the ground state of the target nucleus. Both assumptions appear to be justified in the cases of ^{12}C and ^{16}O targets, but the first assumption seems unlikely to be correct for ^{40}Ca.

It is in fact probable that the failure of the first assumption for ^{40}Ca causes the discrepancy between the calculated impurity in the ground state wavefunction and its intensity as deduced from γ-ray de-excitation measurements. The likelihood of collisions between the nucleons during the lifetime of the dipole state increases the probability that the angular momentum barrier will control the l-value of the nucleon emitted, and accounts for the emission of p-wave rather than f-wave nucleons in ^{28}Si (as noted in Section I). In such a case, the excited nucleon is the one most likely to be scattered (see Quirk and Spicer 1964) while the most probable nucleon energy after scattering is one which is close to the initial nucleon energy. Small changes in energy during scattering consequently imply small changes in the l-value of the nucleon, if it is assumed that only single-particle states are involved.

The dominant dipole transition from a pure shell model ^{40}Ca ground state is $1d_{5/2} \rightarrow 1f_{7/2}$ while the dominant transition from a $(1d_{3/2})^{-2n}(1f_{7/2})^{2n}$ ground state component is $1f_{7/2} \rightarrow 1g_{9/2}$. The scattering process referred to above will readily remove one unit of orbital angular momentum from the g-wave particle, a change which will tend to make each process (originating in a multiparticle, multihole component in the ground state) similar to that which originates in a pure shell model ground state. Thus, it is expected that the effect of nucleon–nucleon scattering during the lifetime of the dipole state will tend to cause the population of final states to appear like that expected from a purer ground state than actually exists. This accounts qualitatively for the discrepancy between the calculation and experimental results for ^{40}Ca.

In the cases where scattering during the lifetime of the dipole state is not a major effect, as in ^{12}C and ^{16}O, the agreement between calculations and de-excitation γ-ray results is good. That is, given the two assumptions noted above, de-excitation γ-ray measurements can indeed give quantitative information regarding the wavefunction of the ground state of the target nucleus.

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