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Nuclear Physics A111 (1968) 652—656; © North-Holland Publishing Co., Amsterdam

THE EFFECT OF THE ISOSPIN SELECTION RULE ON DIPOLE TRANSITIONS IN ^{24}Mg AND ^{28}Si

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Received 11 December 1967

Abstract: We have estimated absolute γ-ray transition rates for levels found as resonanced in (p, γ) reactions on ^{23}Na and ^{27}Al and identified 37 (in ^{24}Mg) and 54 (in ^{28}Si) cases of dipole radiation between levels with known J, π and T quantum numbers. Forbidden E1 transitions between levels with $\Delta T = 0$ are indeed retarded with respect to the allowed $\Delta T = 1$ transitions. However, the existence of these forbidden transitions indicates a small amount of isospin admixture in the high-lying $T = 0$ levels. The average rate of forbidden E1 transitions is similar to that in lighter nuclei, while the average rate of allowed is ≈ 15 times slower here than in lighter nuclei. We suggest that this is a consequence of the increased level density in the heavier nuclei and the presence of isospin mixtures among the radiating levels.

1. Introduction

Two isospin selection rules apply to dipole radiation in self-conjugate nuclei [1,2])

(i) E1 radiation $\Delta T = 0$ transitions are forbidden,

$\Delta T = 1$ transitions are allowed;

(ii) M1 radiation $\Delta T = 0$ transitions are, on the average,

≈ 100 times weaker than $\Delta T = 1$ transitions.

For actual nuclei, where some isospin admixtures are present, rule (i) will be relaxed. The effectiveness of (i), in fact, provides an estimate of the amount of foreign T-components in the wave functions of levels taking part in the γ-transition. The rules can only be properly tested on a statistical aggregate of transition rates which allows us to average over many combinations of quantum numbers (other than T) that also influence transition rates. Naturally in the process of averaging we also obtain the average isospin admixture.

This approach to the analysis of transition rates was pioneered by Wilkinson [3]) who applied it to nuclei with $A \leq 20$. One of the problems in extending the surveys to nuclei in the d-s shell has been the lack of information on T-values for the relevant self-conjugate nuclei. However in the previous paper [5]), we established the isospin values for levels in ^{20}Ne, ^{24}Mg and ^{28}Si and that information - combined with the

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measured widths of the (p, γ) reaction leading to mass 20, 24 and 28 nuclei - will be used for a survey similar to Wilkinson's. Quite a large number of transitions have been measured and there is adequate statistics to study ^{24}Mg and ^{28}Si individually so as to reveal the possible mass dependence of isospin admixtures.

2. The data

It is convenient to extract the intrinsic transition probability of the measured decay by comparing it to the Weisskopf single-particle transition [3]) estimate. We define

$$|M|^2 = \Gamma_{\text{exp}}/\Gamma_{\text{Weisskopf}}. \quad (1)$$

The lifetimes were taken from the (p, γ) reactions [6-8]) used in the previous paper [5]). If we make the simplifying assumption, $\Gamma_p \gg \Gamma_\gamma$, the (p, γ) yield is proportional to $(2J+1)\Gamma_\gamma$. We only consider the cases where the J-values of the resonances are known. The absolute lifetimes obtained in this way are probably only within a factor of two of the true partial γ-decay lifetime, since the γ-ray width may not necessarily be much smaller than the particle decay width.

The data for the γ-ray decay of highly excited states of ^{20}Ne are very scanty and do not permit a meaningful statistical treatment. On the other hand, many transitions have been measured on ^{24}Mg and ^{28}Si; we include 37 and 54 cases, respectively, where we consider the J- and T-values, total γ-ray widths and branching ratios accurately determined. Both the ^{24}Mg and ^{28}Si nuclei have a large number of states between 6 and 10 MeV excitation. Weak transitions to those states may easily be lost in a γ-ray spectrum recorded in NaI(Tl) detectors. However, this probably does not bias the sample in any *specific* way since the levels also have small Γ_W. We have only used the listed [7,8]) γ-ray branches except in two cases where dipole transitions to the ground and first excited state were not observed and we instead estimated reasonable $|M|^2$ values. We have omitted transitions [7]) like $11.98 \rightarrow (10.08 \pm 0.02)$ MeV at the 308 keV resonance in the ^{23}Na(p, γ) reaction where the energy resolution is insufficient to determine if the final state is the $T = 1$ state at 10.077 ± 0.01 MeV or an adjacent state with $T = 0$. In fact, no transition from a resonance level to a $T = 1$ state has been included in this survey †.

Since the number of data points available is comparatively large, we may display the results for each nucleus separately as in fig. 1. In this figure we have also included earlier results of Wilkinson [3]) for light nuclei with $A < 20$ (i.e. not merely self-conjugate nuclei). One may summarize the data in fig. 1.

(i) Forbidden E1 transitions are observed but they are, on the average, impeded by a factor of 2 (in ^{24}Mg) and 7 (in ^{28}Si) as compared to average of the allowed transitions in these nuclei. Similarly, M1 transitions involving no change of isospin are, on the average, 5 and 10 times retarded, respectively, as compared to other M1 transitions.

† A recent [9]) study of the ^{26}Mg(p, γ)^{27}Al has indeed demonstrated that Li-Ge counters are essential for the identification of γ-ray decay to high-lying levels in the final nucleus.

(ii) Dipole transitions with $\Delta T = 1$ in ^{24}Mg and ^{28}Si are, on the whole, ≈ 15 times slower than in nuclei with $A < 20$, whereas dipole transitions with $\Delta T = 0$ have the same speed as in nuclei with $A \leqq 20$.

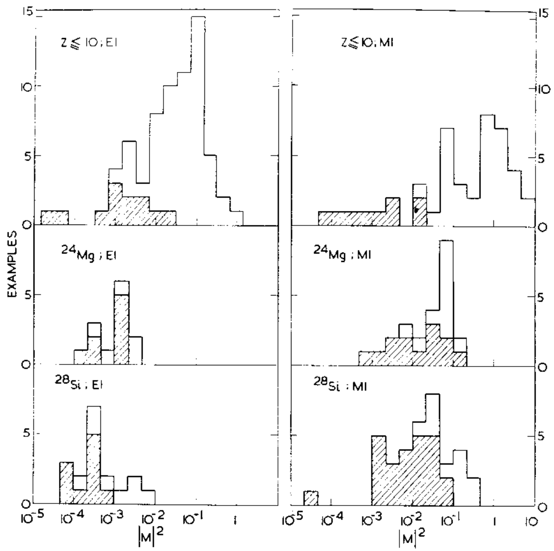

Fig. 1. Distribution of γ-ray transition rates.

3. Discussion of E1 transitions

Property (*i*) is similar to the trend found by Wilkinson [3]) among the nuclei with $A \leqq 20$. The presence of the same trend in our data gives some further support to our T-assignments.

Forbidden E1 transitions may occur as a result of T-admixtures in the wave function (Φ) of the (initial) state. We call the amplitude of this admixture α and write in an obvious notation:

$$\Phi = \psi(T) + \sum \alpha_T(T')\psi(T').$$

The admixture may arise from the Coulomb perturbation $H^{C}_{TT'}$ between this level with chief isospin T and an adjacent state of isospin T' at an energy separation of $\Delta_{TT'}$. Then, in first-order perturbation theory

$$\alpha_T(T') = \frac{H^{C}_{TT'}}{\Delta_{TT'}}.$$

Following Wilkinson's procedure [3]), we deduce the average values of these quantities (see table 1). The separation energies $\Delta_{TT'}$ are determined from positions of the de-exciting levels used in this paper and also from the estimated positions of other $T = 1$ states as guided by the level systematics of ^{24}Na and ^{28}Al. We find that $\Delta_{10} \approx \Delta_{01}$ and $\alpha_0(1) \approx \alpha_1(0)$. The Coulomb interaction in ^{24}Mg and ^{28}Si at ≈ 12.5 MeV excitation is then of the same order as those of lighter elements [3]); but the spread in the values of $H^{C}_{TT'}$ for $A < 20$ is quite considerable. Since however the level spacing is less here than for lighter nuclei, the T-admixtures $\alpha^2_T(T')$ are larger.

Table 1

Average values of experimentally derived nuclear parameters defined in the text

Nucleus	E1 $\lvert\Delta_{TT'}\rvert$ (keV)	$\alpha^2_T(T')$	M1 $H^{C}_{TT'}$ (keV)	$\langle G\rangle$
^{24}Mg	60	0.5	30	−3.8
^{28}Si	40	0.15	15	−3.7

Property (*ii*), in the summary of fig. 1, may be the result of an increased configuration mixing in mass 24 and 28 nuclei as compared to nuclei with $A \leqq 20$. In other words, the Weisskopf single-particle radiative strength is spread over many highly excited states [10]). The radiating levels are typically at ≈ 12 MeV excitation in ^{24}Mg and ^{28}Si. The bulk of reported [3]) dipole transitions in nuclei with $A \leqq 20$ emerge from similar excitation energies, although there is a large spread in the sample. From a rough estimate based on the statistical model, we obtain a factor 10-20 as the ratio between level densities in mass-28 and mass-16 nuclei at $E_x = 12$ MeV. The level density is roughly proportional to number of highly excited states that may radiate via dipole transitions to low-lying levels. This mechanism would thus account for the considerable slowing up the transition rates in nuclei with mass 24 and 28 as compared to lighter nuclei.

We may explain the observed difference in the rate of allowed and forbidden E1 transitions as being due to the combined effects of the increased level density and the isospin mixing. In this argument, the admixture of $T = 0$ components into the $T = 1$ states can significantly effect the rate of the allowed E1 transitions. Thus, the allowed transitions will be *slower* here than in lighter nuclei (with $A \leqq 20$) where the average admixture is less. On the same grounds, the forbidden transitions become *faster* in ^{24}Mg and ^{28}Si than in the lighter nuclei. If we finally take into account the retarding effect of the increased level density we arrive at a net result in conformity with property (ii).

4. Discussion of M1 transitions

Warburton [1]) has given a treatment of the ratio (R) of reduced rates of M1 transitions with $\Delta T = 0$ and $\Delta T = 1$, respectively. After certain simplifying assumptions (ref. [4])), one has

$$R = \left\{ - \frac{1.8 + \langle G_0 \rangle}{9.4 + \langle G_1 \rangle} \right\}^2 ,$$

where $G_{\Delta T}$ is a statistical factor which contains the angular and spin dependence of the M1 transition matrix element. If we further simplify and put $\langle G_0 \rangle = \langle G_1 \rangle$, we obtain the experimental values given in table 1.

We may obtain a rough estimate of the theoretically expected value of G by taking an average of the G-values for some likely transitions in ^{24}Mg and ^{28}Si, i.e. all possible combinations of single-particle transitions between the $1d_{\frac{5}{2}}$, $1d_{\frac{3}{2}}$ and $2s_{\frac{1}{2}}$ states. This average is $\langle G \rangle = -2$ in good agreement with the value deduced from fig. 1.

5. Conclusions

We have shown that the evidence of γ-ray transition rates support the T-assignments of ref. [5]). The $T = 1$ states have apparently only small admixtures of foreign isospin components, and the main features of the transition rates may be understood if one allows quite small $T = 0$ components in the $T = 1$ states and vice versa.

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Nuclear Physics **A111** (1968) 657—677; © *North-Holland Publishing Co., Amsterdam*

ANGULAR CORRELATION STUDIES IN ^{50}Cr

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Received 5 February 1968

tract: Proton-gamma angular correlation measurements have been used to determine spins and establish modes of decay for some of the low-lying levels in ^{50}Cr. The spins of the 3.317, 3.621 and 3.786 MeV states are found to be 4, 1 and 5, respectively. Confirmation of previous spin assignments to the 2.922, 3.156 and 3.692 MeV states are reported together with multipole mixing ratios of relevant gamma rays from all six states. Branching ratios were measured for the above states and those at 3.838, 3.888, 3.927 and 4.123 MeV. The results are discussed in relation to ^{46}Ti, a cross-conjugate nucleus in an $(f_{\frac{7}{2}})^n$ description, and the theoretical predictions of McCullen, Bayman and Zamick.

NUCLEAR REACTIONS ^{50}Cr(p, p'γ), $E = 6.33$ and 6.45 MeV; measured $\sigma(E_{p'}, E_\gamma, \theta_{p'\gamma})$. ^{50}Cr deduced levels, J, multipole mixing ratios. Enriched target.

1. Introduction

This investigation is one of a series on the even nuclei in the $1f_{\frac{7}{2}}$ shell. Assuming the quivalence of nucleons and holes, both ^{46}Ti and ^{50}Cr have six nucleons in the $1f_{\frac{7}{2}}$ ell. Therefore levels of predominantly $(f_{\frac{7}{2}})^6$ configuration should occur at the same ergy in both nuclei. Recent work [1,2]) in this laboratory on ^{46}Ti has shown the istence of interesting levels at 3.158 MeV (spin 1), 3.048 MeV and 3.430 MeV. he latter level has a major decay branch via the 3.048 MeV, 2.000 MeV (4^+) and 885 MeV (2^+) levels to the ground states. The spins of the 3.048 and 3.430 MeV vels are probably 4 and 5, respectively. All these levels can be fitted into the theoretal level scheme of McCullen *et al.* [3]), even though the levels of spins 1 and 5 are uch lower in energy than predicted. McCullen has assumed a pure $(f_{\frac{7}{2}})^6$ configuration for these two nuclei and has determined the $1f_{\frac{7}{2}}$ nucleon-nucleon interaction rom the observed levels of ^{42}Sc.

Previous work on ^{50}Cr has been the triple angular correlation measurements of Twin and Willmott [4,5]). Above 3.5 MeV excitation energy, the levels of ^{50}Cr are often less than 100 keV apart, and therefore the (p, p'$\gamma\gamma$) measurements are extremely difficult due to the poor resolution of the NaI(Tl) crystals. We have used the technique of proton-gamma angular correlations and hence have been able to utilise the resolution of the solid-state proton detector (approximately 50 keV) to enable more of

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