DE-EXCITATION GAMMA RAYS FOLLOWING PHOTODISINTEGRATION OF ^{28}Si†

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Abstract

Integrated cross sections for the population of excited states of ^{27}Al and ^{27}Si following photodisintegration of ^{28}Si are presented. Consistency with particle pickup reactions is claimed as evidence of the single-particle nature of the photonuclear reaction in the giant resonance region.

Experimental Details

The population strength of the states formed in a residual nucleus following photodisintegration depends on the degree of similarity that the residual state configuration bears to the giant resonance states. Since in particular reactions the residual state configurations are often well known, the measurement of de-excitation γ-rays yields information on the character of the giant resonance states and on the reaction mechanism. In this paper a study of the reaction $^{28}\text{Si}(\gamma, x\gamma')$ is reported.

A 600 g target of natural silicon was irradiated by 28 MeV bremsstrahlung from the Melbourne University betatron. Observations of the prompt de-excitation γ-rays were made using a well-shielded 35 cm^3 Ge(Li) detector. In order to minimize the background due to Compton scattering the detector was placed at the maximum possible backward angle to the primary beam. This angle was limited by the size of our shielding to 140°. The detector efficiency was determined as a function of γ-ray energy by using a radium source in equilibrium with its decay products.

Results

Figure 1 shows the observed spectrum. The various peaks are assigned to decays from residual states. Energy agreement is generally better than 3 keV, with the exception of the peak at 2924 keV. This is tentatively identified as the double escape peak from the 3956 keV state in ^{27}Al, but there is an energy discrepancy of 12 keV. Two significantly better energy assignments for the first and second excited states of ^{27}Si have been made, namely $783\cdot6\pm1\cdot0$ and 954 ± 2 keV respectively. These assignments are possible because of the close proximity of de-excitation lines at $842\cdot9$ and $1013\cdot0$ keV from ^{27}Al, which were used as calibrations.

Two spectral lines have been observed which appear to be due to sources other than ^{27}Si and ^{27}Al. One at 1368 keV is assumed to be from the decay of the first excited state of ^{24}Mg which would be produced following photoalpha emission. The

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integrated cross section (up to 28 MeV) for this reaction as determined from the present data is 6 ± 2 MeV mb. This is considerably larger than the value of 2·7 MeV mb for the integrated cross section from 17·4 to 22·3 MeV as reported by Matsumoto *et al.* (1965). The difference implies considerable cross section strength to this excited state of ^{24}Mg from the region above 22·3 MeV in ^{28}Si, and this should be investigated further.

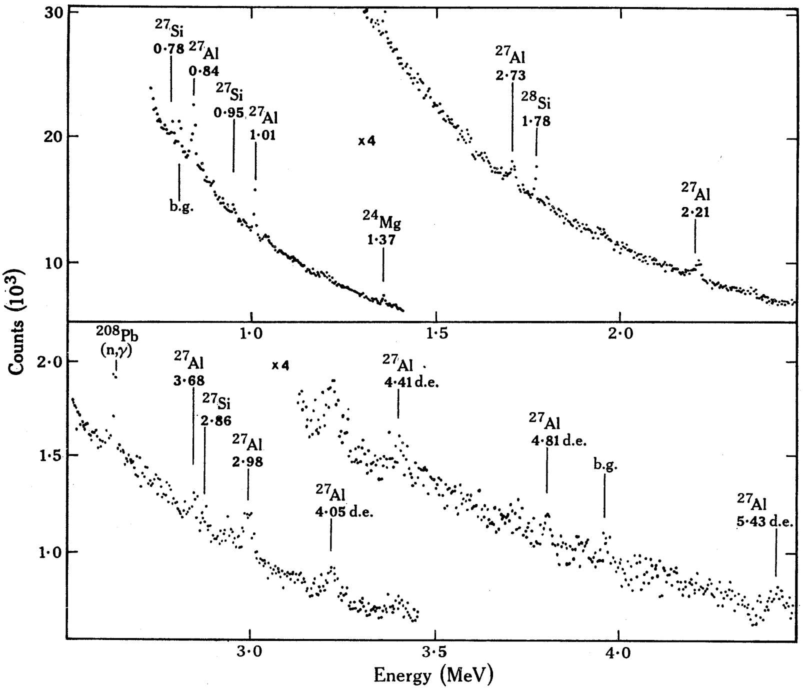

Fig. 1.—Spectrum of γ-rays obtained using a silicon target irradiated with 28 MeV bremsstrahlung. Unless otherwise indicated, the energies shown are those of the originating states.

The second line not due to a decay in ^{27}Al or ^{27}Si is at 1780 keV and is ascribed to the decay of the first excited state in ^{28}Si. This state is most likely populated from the ^{29}Si(γ, n) reaction involving the 4·7% ^{29}Si impurity in the natural silicon target. When the cross section is corrected for this percentage of ^{29}Si in the target, we estimate an integrated cross section of 140 ± 35 MeV mb for the photoneutron reaction in ^{29}Si which leads to the first state in ^{28}Si.

The integrated cross section for reaction leading to each of the residual states was normalized to that for the reaction ^{16}O(γ, p)^{15}N* leading to the 6·30 MeV state in ^{15}N, as reported by Caldwell, Fultz, and Bramblett (1967). This normalization was determined in a separate experiment using an SiO_2 target. In analyzing the data from this ^{16}O intercalibration, allowance was made for the different observation angles used in this experiment and that of Caldwell, Fultz, and Bramblett (1967) by using an angular distribution measurement obtained by Baglin and Benz (personal communication).

Discussion

For the purpose of comparison with cross sections to the ground states of ^{27}Al and ^{27}Si, it would be convenient to have a measure of the total cross section rather than the differential cross section at 140°. An approximate estimate of this can be obtained from the present data. Assuming an angular distribution for the de-excitation γ-rays

TABLE 1

RESULTS FOR STATES POPULATED IN ^{27}Si AND ^{27}Al

(a) ^{27}Si

E (MeV)	$J\pi$	$\int_0^{28} \sigma\, dE$ (MeV mb)	Spectroscopic factor C^2S (^3He, α)*	(p, d)†
0	5/2+	53±1‡	2·99	2·14
0·784	1/2+	14	0·42	0·65
0·954	3/2+	7	0·38	0·37
2·17	7/2+	—	—	—
2·65	5/2	<2·3	0·78	0·23
2·86	—	3·4	1·43	0·82
2·91	—	—	—	—

(b) ^{27}Al

E (MeV)	$J\pi$	$\int_0^{28} \sigma\, dE$ (MeV mb)	(d, ^3He)§ l	C^2S
0	5/2+	50±5‡	2	3·1
0·843	1/2+	32	0	0·58
1·013	3/2+	19	2	0·60
2·21	7/2+	<2	—	—
2·73	5/2+	12	2	0·63
2·98	3/2+	13	(2)	<0·3
3·001	9/2+	—	—	—
3·68	1/2+	8	—	—
3·96	(3/2)	(3)	—	—
4·05	(1/2, 3/2)−	9	1	—

* Data from Swenson, Zurmuhle, and Fou (1967).
† Data from Jones, Johnson, and Griffiths (1968).
‡ See text for derivations of ground state integrated cross sections.
§ Averages of the data from Gove *et al.* (1968) and Wildenthal and Newman (1968).

of the form $1+AP_2(\cos\theta)$, a measurement at 125° would yield the average differential cross section. By taking the differential cross section measured at 140° as being the average value, an overestimation of less than 15% (depending on the size of the coefficient A) is made in the total cross section value. Hence the total integrated cross section values listed in Table 1 include this overestimate. The relative populations are correct to within 20%, but the absolute uncertainties in these values vary from ±20% for the strongly populated states to ±40% for the weaker ones.

The total integrated photoneutron strength to excited states is found to be 27±7 MeV mb. Since the total photoneutron cross section is 80 MeV mb (average of the values from Bolen and Whitehead (1964), Goryachev *et al.* (1966), and Webb, Muirhead, and Spicer (1970)), it is concluded that $34 \pm 13\%$ of the neutron decays lead to excited states in ^{27}Si. In the case of photoproton emission, the total integrated cross section to excited states is determined as 100 ± 25 MeV mb, compared with a ground state integrated cross section of 50 ± 5 MeV mb extrapolated from the work of Cannington *et al.* (1965). Thus $67 \pm 8\%$ of the photoproton reactions lead to excited states of ^{27}Al.

For comparison, spectroscopic factors for the states formed in ^{27}Al and ^{27}Si following particle pickup reactions are also listed in Table 1. This shows that those states populated in photonuclear reactions are also the states that are assigned large spectroscopic factors from pickup reactions. The implication is that in both reactions hole states in ^{27}Al and ^{27}Si are populated when a single nucleon is removed from the ground state of ^{28}Si. Strong evidence for this type of mechanism has been provided by the de-excitation γ-ray studies of ^{32}S by Thompson, Stewart, and Thomson (1970) and of ^{16}O by Caldwell, Fultz, and Bramblett (1967). Further evidence for this mechanism is provided by the fact that proton pickup reactions (Gove *et al.* 1968; Wildenthal and Newman 1968) populate the $9/2^+$ level at $3 \cdot 001$ MeV in ^{27}Al quite strongly, yet no unique l value of the pickup, and consequently no spectroscopic factor, can be assigned. It is suggested by Gove *et al.* (1968) that in pickup reactions this state is produced by some two-step core-excitation process. The absence of any population of this state in the photoproton reaction reported here implies that this complex process cannot be initiated by photons.

The observed population of the $1/2^+$ level at $0 \cdot 843$ MeV in ^{27}Al implies a proton excitation from the $2s_{\frac{1}{2}}$ admixtures in the ^{28}Si ground state since the $l = 0$ nature of this excited state is well established by the pickup reactions referred to above. Population of the $(1/2^-, 3/2^-)$ level at $4 \cdot 052$ MeV in ^{27}Al must involve excitation of an $l = 1$ proton from either the 1p shell or from a significant $(2p)^2$ admixture in the ground state of ^{28}Si.

Overall it is concluded that the reaction mechanism for photo-absorption in ^{28}Si can best be described as the excitation of a single nucleon from the ^{28}Si ground state in which considerable $(2s_{\frac{1}{2}})^2$ as well as possible $(2p)^2$ admixture are present.

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