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Cross sections for $^{18}O(\alpha, n_{3,4}\gamma)^{21}Ne$ reactions populating the $(1/2^-, 1/2^+)$ doublet

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Cross sections have been measured for the $^{18}O(\alpha, n_{3,4}\gamma)^{21}Ne$ reactions which populate the $J^\pi = 1/2^-, 1/2^+$ doublet at 2.8 MeV excitation in ^{21}Ne. These states are possible candidates for the study of nuclear parity mixing. Data are presented for α-particle energies in the range 4.3 to 6.5 MeV.

[NUCLEAR REACTIONS $^{18}O(\alpha, n\gamma)$, $E = 4.3$–6.5 MeV; measured $\sigma(E)$ for (α, n_3) and (α, n_4). Enriched target.]

Among the low-lying states of ^{21}Ne is a doublet with $J^\pi = \frac{1}{2}^-, \frac{1}{2}^+$ whose excitation energies are 2.789 and 2.796 MeV, respectively. A portion of the ^{21}Ne level scheme[1] is shown in Fig. 1. It has recently been suggested[2] that these states which are of the same spin, opposite parity, and only 7 keV apart may be candidates for the study of parity mixing. The transition of interest is the 2.789 MeV $(\frac{1}{2}^-) \rightarrow$ ground state $(\frac{3}{2}^+)$ of ^{21}Ne, a very strongly inhibited $E1$ transition. A small admixture of the nearby 2.796 MeV $(\frac{1}{2}^+)$ level results in a an $M1$-$E1$ interference giving rise to a circular polarization of the 2.789 MeV γ ray. So far most experimental studies of parity mixing have relied upon the measurement of such a circular polarization. Preliminary calculations[2] suggest that for the ^{21}Ne example the circular polarization may be $\gtrsim 10^{-2}$. This predicted magnitude is much greater than that for the (ground state, 110 keV) doublet of states in ^{19}F (which is a closely related example) experimentally studied by Adelberger *et al.*[3] and the (1.04, 1.08 MeV) doublet of ^{18}F for which calculations have been made by Gari, McGrory, and Offermann.[4]

Before embarking on an experimental study of the γ-ray circular polarization in a spirit similar to Adelberger *et al.*,[5] it is necessary to identify a suitable nuclear reaction for the production of the $\frac{1}{2}^-$ state and then to select a bombarding energy at which the yield is optimum. One possible reaction is $^{18}O(\alpha, n)^{21}Ne$, which on the basis of the simplest of structure arguments should populate both "particle" and "hole" states. The total neutron yield from this reaction has been reported previously,[6] but partial cross section data for the levels of interest are not available. Whilst the $^{18}O(\alpha, n_3)$ yield is the essential information for determining the optimum conditions for the circular polariza-

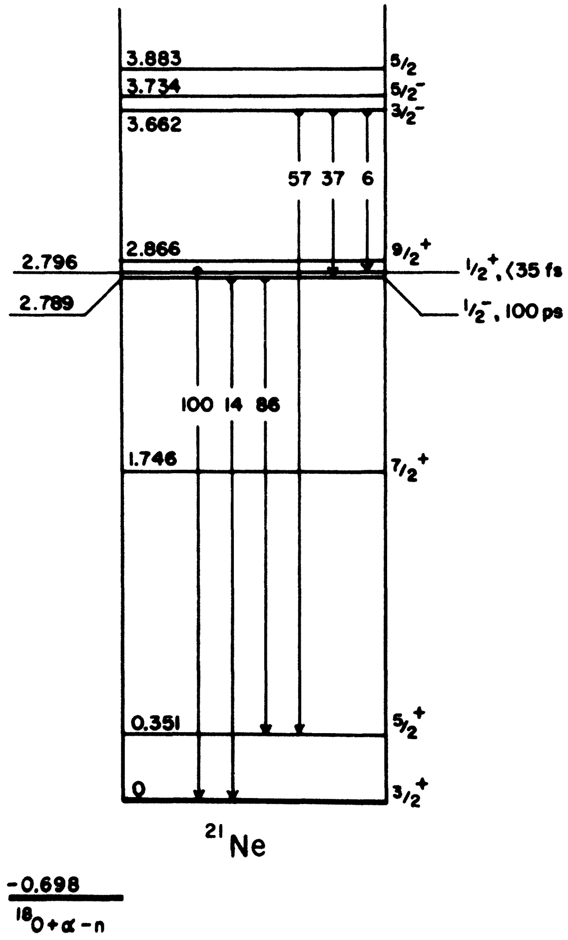

FIG. 1. Partial level scheme of ^{21}Ne. Transitions are displayed which populate or deexcite the $\frac{1}{2}^-$, $\frac{1}{2}^+$ doublet near 2.8 MeV excitation. All data are taken from Ref. 1, except for the decay of the $\frac{1}{2}^-$ level which was studied in the present experiment.

tion measurement, the $^{18}O(\alpha, n_4)$ yield is also interesting because the circular polarization of the 2.796 MeV γ ray will be negligibly small, and therefore this γ ray may be used as a control to check any instrumental asymmetries.

In this communication, we report measurements of the $^{18}O(\alpha, n_3)$ and $^{18}O(\alpha, n_4)$ partial cross sections as a function of α-particle bombarding energy.

The ^{18}O targets were prepared by anodizing 0.125 mm tantalum blanks in water enriched to 50 at.% in ^{18}O. Two Ta_2O_5 targets of different thicknesses were prepared. The thicker target was of a thickness that could be determined by two methods: (i) from a measurement of the mass change of the tantalum blank after anodizing, and (ii) from a study of the $^{18}O(p, \alpha_0)^{15}N$ reaction. For the latter method, the Ta_2O_5 target was bombarded with 730 keV protons and the α particles detected with a surface barrier detector located at 150°. At this bombarding energy, the (p, α_0) cross section is known,[7] it is relatively insensitive to energy[7] and the emitted α particles have an isotropic angular distribution.[8] The results of the two techniques were completely consistent. The Ta_2O_5 film thickness was 205 ± 20 $\mu g/cm^2$ which corresponds to 70 keV for 5 MeV α particles. This thicker target then served as a standard against which the thickness of the thin target was calibrated. This was done by observation of the 1.982 MeV γ rays from the $^{18}O(\alpha, \alpha_1)$ reaction at $E_\alpha = 5.90$ MeV, an energy where the inelastic scattering cross section was constant over a 150 keV range in beam energy. This thin target contained $(1.0 \pm 0.1) \times 10^{17}$ ^{18}O atom/cm^2 and corresponded to an energy loss of 10 keV for 5 MeV α particles.

Both the thick and thin Ta_2O_5 targets were mounted on a target ladder in one arm of a stainless steel tee which constituted the target chamber. The excitation functions for the production of the two states of the 2.8 MeV doublet in ^{21}Ne were measured by observing the deexcitation γ rays from these states when the thin Ta_2O_5 target was

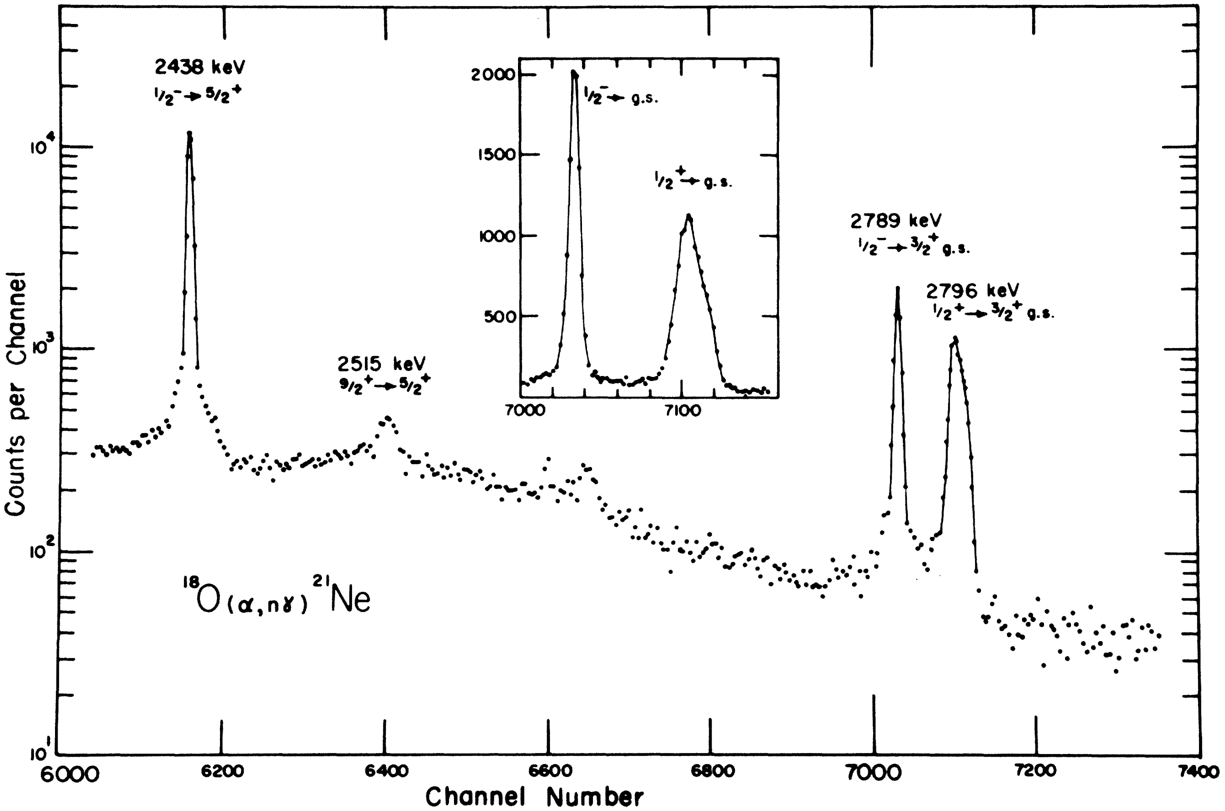

FIG. 2. Portion of an $^{18}O(\alpha,n\gamma)^{21}Ne$ reaction γ-ray spectrum. This spectrum was acquired for α particles of energy 4.98 MeV bombarding the thicker (70 keV) ^{18}O-enriched Ta_2O_5 target. Integrated charge of $^4He^{++}$ for this run was 700 μC. Only every fourth channel has been plotted except in the vicinity of the peaks where every second channel is shown. The dispersion is 0.4 keV/channel. The inset displays, on a linear scale, the γ-ray spectrum around the photopeaks corresponding to the ground state decays of the $(\frac{1}{2}^-, \frac{1}{2}^+)$ doublet of states at 2.8 MeV is ^{21}Ne. Every second channel is plotted.

bombarded with α particles. A beam of 150 nA of doubly charged ^{4}He ions was delivered by the University of Melbourne 5U Pelletron accelerator. γ-ray spectra were recorded with a 67 cm^3 Ge(Li) detector. The angular distribution of the γ rays from deexcitation of the spin-$\frac{1}{2}$ levels is isotropic. The energy separation of the two states is only 7 keV. However, since the lifetime of the 2.789 MeV state is as long as 100 ps,[1] it decays essentially from rest. The higher energy level has a much shorter lifetime (<35 fs[1]), so that the recoiling ^{21}Ne nucleus excited in this state decays in flight and the γ ray is Doppler-shifted. To take advantage of this Doppler shift, the detector was located at 0° with its front face about 2 cm behind the target. The energy separation of the two γ rays in the detector was then 25 keV for $E_\alpha = 5.0$ MeV. The full width at half maximum of the 2.789 MeV photopeak was 3.6 keV, which is equal to the detector resolution.

γ-ray spectra were acquired over the α-particle energy range 4.3 to 6.5 MeV in intervals of 20 keV, $E_\alpha = 4.3$ MeV being the threshold for the $(\alpha, n_{3,4})$ reactions. In the energy region near $E_\alpha = 5.9$ MeV the steps in beam energy were reduced to 10 keV to explore the possibility of fine structure in the γ-ray yield curve. No significant narrow fluctuation was observed. γ-ray spectra were acquired for 70 μC of integrated charge at each bombarding energy and were analyzed with an 8000-word analog-to-digital converter and PDP-11/40 computer. The most prominent peaks in the spectra arose from $(\alpha, n\gamma)$ reactions, the ^{18}O(α, $\alpha_1\gamma$)^{18}O* (1.982 MeV) reaction and the low-energy Coulomb excitation lines from the ^{181}Ta backing. An example of a γ-ray energy spectrum in the vicinity of the 2.8 MeV doublet photopeaks is shown in Fig. 2.

The $(\alpha, n\gamma)$ cross sections were inferred from the measured photopeak yields. The Ge(Li) detector efficiency was determined using standard radioactive sources. The measured excitation functions are shown in Fig. 3. The uncertainty in the absolute cross section is ±15%. The structures evi-

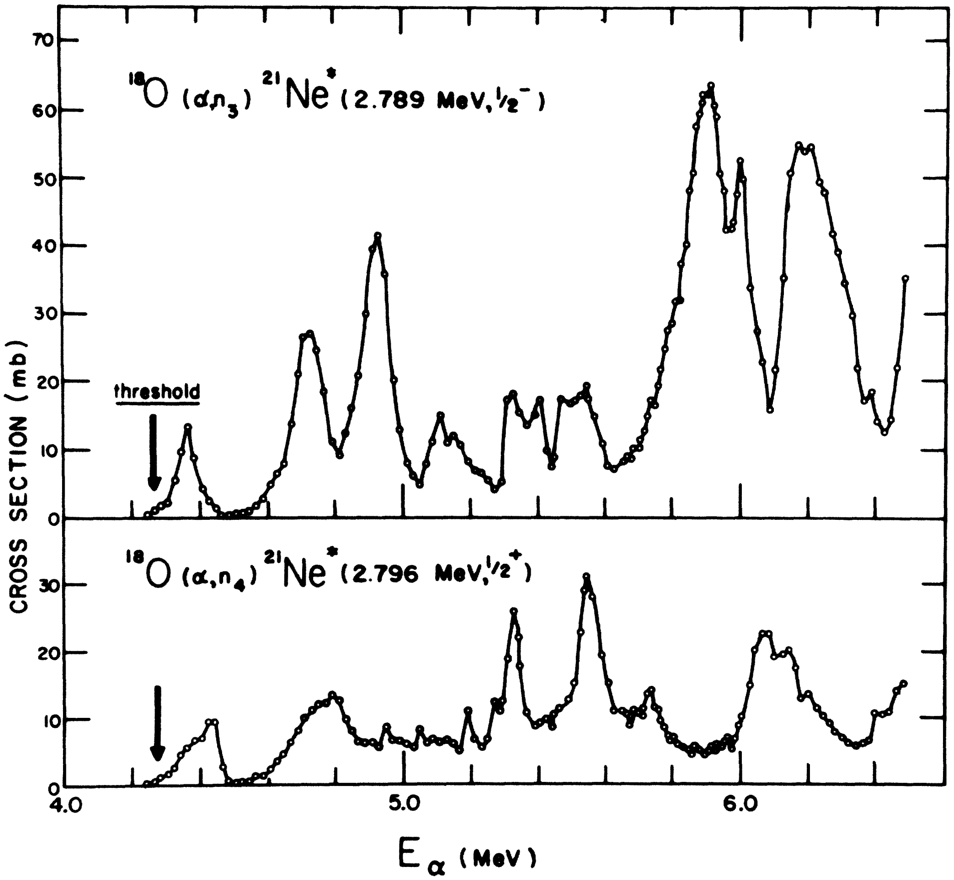

FIG. 3. Excitation function for the ^{18}O$(\alpha,n)^{21}$Ne reaction. Total cross sections for the population of the two spin-$\frac{1}{2}$ states are shown as a function of the α-particle energy at the center of the target. Target thickness was 10 keV. Statistical uncertainties are approximately the size of the points. The uncertainty in the absolute cross sections is ±15%. The solid line joining the points is only to guide the eye.

dent in the two excitation functions appear only weakly correlated. Widths lie in the range 40–100 keV and this is consistent with an analysis of the total (α, n) cross section.[6] From analysis of the γ-ray spectra, the branching ratio of the 2.789 keV level was found to be 86% and 14% to the first excited state and ground state, respectively, and the decay of the 2796 keV state was consistent with a 100% branch to the ground state. These values are in agreement with the results of Rolfs *et al.*[9] The cross sections shown in Fig. 3 are for the production of the $\frac{1}{2}^-$ and $\frac{1}{2}^+$ states by $(\alpha, n_{3,4})$ reactions directly and, for $E_\alpha > 5.33$ MeV, feeding from higher lying states, the only likely candidate for this feeding being the decay of the 3.662 MeV level of ${}^{21}Ne$. The energy $E_\alpha = 5.33$ MeV corresponds to the threshold for formation of the 3.662 MeV state by the (α, n_6) reaction. The decay of this level has a 37% branch to the 2.789 MeV state[1] (see Fig. 1). The associated 873 keV primary γ-ray yield was monitored during the experiment and found to be negligibly small below $E_\alpha = 5.85$ MeV. Thereafter, however, it was found that the feeding from the 3.662 MeV level contributed up to 30% of the population of the 2.789 MeV state and was totally responsible for the narrow peak in the yield curve at 6.0 MeV.

When considered in conjunction with the availability of suitable α-particle beams and optimum ${}^{18}O$ target thickness, the excitation function data presented herein will permit more reasonable decisions to be made in the pursuit of the fundamental parity mixing measurements.

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