Interference between Coulomb Excitation and Resonance Inelastic Scattering in $^{23}$Na + p (\(^*)\).

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In recent years considerable effort has been devoted to the investigation of Coulomb excitation not only in medium-weight and heavy nuclei, but also in the lighter elements. In general, the competition of resonance inelastic scattering makes difficult the unambiguous identification of Coulomb excitation in the light-mass region. In fact, only the experiments of BARNES (\(^1\)) and TEMMER and HEYDENBURG (\(^2\)) have attempted to separate contributions from Coulomb excitation and compound nucleus resonance processes.

BARNES measured the absolute cross-section for the production of 110 and 198 keV \(\gamma\)-rays from the proton bombardment of \(^{19}\)F at two incident proton energies which were well separated from the known resonances for inelastic scattering. The results were in disagreement with cross-section values calculated on the basis of Coulomb excitation and it was concluded that broad resonance structure was responsible for a significant fraction of the measured yield.

The measurements of Temmer and Heydenburg clearly indicated a non-negligible yield of \(\gamma\)-radiation between resonances in the \(^{19}\)F(p, p'\(\gamma\))\(^{19}\)F and the \(^{23}\)Na(p, p'\(\gamma\))\(^{23}\)Na reactions. The energy-dependence of the nonresonant cross-section was found to be consistent with Coulomb excitation, although a discrimination between E1 and E2 excitation could not be made. The 874 keV resonance for the production of 439 keV \(\gamma\)-radiation from the \(^{23}\)Na(p, p'\(\gamma\))\(^{23}\)Na reaction is of particular interest here since this resonance is superimposed on the nonresonant background and exhibits a pronounced asymmetry. The departure from the normal resonance shape is manifested in a long high-energy tail. The observed asymmetry is suggestive of an interference between the resonance process and Coulomb excitation. The theory of such interference has been developed by GRIFFY and BIE-
Dennharn (3) who have calculated the cross-section explicitly in terms of the nuclear resonance parameters, the elastic and inelastic phase shifts, and the Coulomb excitation parameters. The theory has been applied to the 874 keV resonance in $^{23}\text{Na}(p, p'\gamma)^{23}\text{Na}$ and it was found possible to reproduce the asymmetric resonance shape observed by Temmer and Heydenburg.

Fig. 1. - Upper curve: excitation function for all $\gamma$-rays with energy greater than 400 keV obtained with a 4 keV thick NaCl target. Lower curve: extracted yield of 439 keV $\gamma$-rays from the $^{23}\text{Na}(p, p'\gamma)^{23}\text{Na}$ reaction obtained with a NaCl target about 6 keV thick. The normalization of the two curves is different.

Because there were only a few experimental points on the 874 keV resonance and since the high-energy tail could conceivably be the result of target thickness effects, it was decided to investigate in detail the yield of $\gamma$-radiation near this resonance. A 3 in. x 3 in. NaI scintillator was used as the $\gamma$-ray detector and targets of NaCl and NaOH were bombarded with protons in the energy range from 850 to 910 keV. The upper curve in Fig. 1 shows the yield of $\gamma$-rays with energy greater than 400 keV from a 4 keV thick target of NaCl. In the energy range studied there occur two resonances due to proton capture in $^{35}\text{Cl}$ in addition to the 874 keV resonance in the $^{23}\text{Na}(p, p'\gamma)^{23}\text{Na}$ reaction. It is apparent from these data that there is no large asymmetry in the shape of the 874 keV resonance. Similar data obtained with thinner targets confirmed the absence of any pronounced asymmetry. The use of NaOH targets provided quite similar data without the complication of the $^{35}\text{Cl}(p, \gamma)$ resonances.

In order to obtain a yield curve for the 439 keV $\gamma$-ray from the $^{23}\text{Na}(p, p'\gamma)^{23}\text{Na}$ reaction, $\gamma$-ray spectra were measured at 12 different bombarding energies in...