On the Mechanism of the Reactions $^{24,25,26}\text{Mg}(n,\alpha)^{21,22,23}\text{Ne}$ at Neutron Energies Near 14 MeV

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Differential cross sections of the reactions $^{24}\text{Mg}(n,\alpha)^{21}\text{Ne}$, $^{25}\text{Mg}(n,\alpha)^{22}\text{Ne}$, and $^{26}\text{Mg}(n,\alpha)^{23}\text{Ne}$ have been measured at neutron energies of 13.19, 13.93 and 14.33 MeV, at 13.93 and 14.33 MeV, and at 13.47 and 13.93 MeV, respectively. In forward direction, differential excitation functions of those reactions have been measured at energies between 12.67 and 16.05 MeV. The results are analysed in terms of direct-reaction and compound-nucleus theories.

I. Introduction

Up to now, the experimental data on the reactions $^{24,25,26}\text{Mg}(n,\alpha)^{21,22,23}\text{Ne}$ have been rather scarce. Besides some activation studies [1–3] on the reaction $^{26}\text{Mg}(n,\alpha)^{23}\text{Ne}$ at neutron energies near 15 MeV, measurements of excitation functions and angular distributions of the inverse reactions $^{21,22}\text{Ne}(\alpha,n)^{24,25}\text{Mg}$ have been published by Tanner [4], Ashery [5], and Haas and Bair [6]. The reactions were found to proceed mainly through compound-nucleus resonances. Even at the maximum excitation energies of 14.2 and 14.6 MeV, the mean distance $D$ of the resonances was of the same order of magnitude as their mean width $\Gamma$ was. At neutron energies near 14 MeV, however, the $^{25}\text{Mg}$, $^{26}\text{Mg}$, and $^{27}\text{Mg}$ excitation energies amount to 20.8, 24.6, and 19.9 MeV, respectively. Much more exit channels are open, and $\Gamma$ is much greater than $D$. So no conclusions can be drawn from the low-energy ($\alpha,n$)-data on the ($n,\alpha$)-reaction mechanism at neutron energies above 10 MeV.

More data have been published on ($n,\alpha$)-reactions on the neighbour nuclei $^{26}\text{Ne}$, $^{23}\text{Na}$, $^{27}\text{Al}$ and $^{28}\text{Si}$ at neutron energies near 14 MeV.

Angular distributions of the $^{26}\text{Ne}(n,\alpha)^{17}\text{O}$ reaction have been measured by Cevolani et al. [7], Mc Dicken and Jack [8], Karge [9], Bachinger and Uhl [10], and Lin et al. [11]. With the exception of Lin et al., who analyse their data in terms of the statistical theory, and of Bachinger and Uhl, who resign to draw any conclusion on the reaction mechanism, the authors agree in interpreting those reactions as direct processes. Due to heavy discrepancies with respect to the shape of the angular distributions, however, different direct mechanisms must be evoked to explain the data.

The ($n,\alpha$)-reaction on $^{23}\text{Na}$ has been investigated by Kaul [12]. Due to the emulsion-plate technique used, the data are subjected to considerable errors. They were analysed by Kaul according to the statistical theory. A contrary interpretation, however, was given by Massot et al. [13], who explained an angular distribution published by Kaul assuming direct reaction mechanisms only.

Energy spectra and angular distributions of alpha particles from the reaction $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ have been measured by Kumabe et al. [14], Cevolani et al. [15], Patzak and Vonach [16], Irfan and Jack [17], and Seebeck and Bormann [18]. Different energy resolutions may account for the different shapes of the energy spectra. There are discrepancies between the angular distributions, too; but the investigators agree in interpreting those reactions by mainly compound-nucleus processes with $\Gamma \gg D$. Then, according to the statistical theory, the excitation functions are expected to fluctuate. Indeed, fluctuations were reported by Cindro et al. [19]. Their results,
however, were called in question by Ferguson and Albergotti [20], Bormann and Riehle [21], Vonach et al. [22], and Boschung et al. [23]. Recently, fluctuations were found again by Gardner and Gardner [24]. Angular distributions of alpha particles from the reaction $^{28}\text{Si}(n,\alpha)^{25}\text{Mg}$ have been measured by Leroux et al. [25], Morgenstern et al. [26], and Forti et al. [27]. At least the angular distribution of the ground state transition was found to be very asymmetric. Hence the authors conclude that reaction proceeds mainly by direct processes. They disagree, however, on the sign of that asymmetry. So their interpretations must be based on different direct mechanisms.

On the other hand, distinct fluctuations of the excitations functions measured by Colli et al. [28, 29], Miller and Kavanagh [30], Mingay et al. [31], and Grimes [32] indicate the presence of compound-nucleus processes. From a detailed fluctuation analysis, Grimes concludes direct processes to play a minor role only.

At neutron energies near 14 MeV, the empirical data on $(n,\alpha)$-reactions on nuclei with $20 < A < 28$ seem to be inconsistent in many cases. There are many contradictions between conclusions drawn with respect to the reaction mechanisms by different authors. Experimental data allowing definite conclusions on the mechanisms of the $^{24,25,26}\text{Mg}(n,\alpha)^{21,22,23}\text{Ne}$ reactions are lacking. For those reasons, an experimental study of the latter reactions seemed to be useful.

II. Experimental Procedure

To produce neutrons, the reaction $^3\text{H}(d,n)^4\text{He}$ was used. A tritium-titanium target was bombarded with deuterons accelerated by means of a 2 MV Van-de-Graaff generator. To keep the background consisting of scattered neutrons low, a low-mass tritium-target chamber was constructed according to design rules we owe to Tornow. The tritium target was cooled by forced air for the same reason.

Up to 4 magnesium targets were irradiated simultaneously. Each was contained in a separate chamber together with a counter telescope to detect alpha particles (Fig. 1).

For mean neutron energies from 12.67 to 16.05 MeV, the magnesium targets were positioned under 10 different angles from $37.5^\circ$ to $150.0^\circ$ with respect to the neutron source and the deuteron direction. 6 different deuteron energies from 0.40 to 1.15 MeV were used. For each parameter set, the neutron energy spectra at the magnesium-target positions were computed by means of a Monte-Carlo program. The spectrum widths ranged from 50 keV to 350 keV (FWHM).

A stilbene proton-recoil scintillation counter monitored the neutron yield continuously. Low-energy neutron events were discriminated by pulse height, gamma events by pulse shape. Gain stabilization was achieved by a microprocessor controller [33]. The detecting efficiency was calculated according to rules given by Borman et al. [34]. Magnesium target foils with isotope concentrations of 99.9\% $^{24}\text{Mg}$, 95.7\% $^{25}\text{Mg}$, and 99.7\% $^{26}\text{Mg}$ were prepared by A.E.R.E. Harwell (G.B.). Thicknesses of about 1 mg/cm$^2$ were chosen as a compromise be-