(n, α) REACTIONS ON Hf178 AND Hf180 INDUCED BY 14.8 MeV NEUTRONS

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The energy spectra of the (n, α) reactions on Hf178 and Hf180 isotopes at 0° ($E_n = 14.8$ MeV) were measured by use of a counter telescope and the method of a two-dimensional analysis. The interpretation of the measured spectra was performed in the framework of the preequilibrium statistical model of nuclear reactions. It appears that the emission can be attributed to the preformed α-particles, which is in agreement with other results for the (n, α) reactions on heavy nuclei induced by fast neutrons.

I. INTRODUCTION

Although the measurements [1—5] and the interpretation of the (n, α) reactions induced by ∼14 MeV neutrons has been a field of constant interest in nuclear physics, the existing data are still incomplete and suffer from large uncertainties, especially in the energy and angular distributions. On the theoretical side the main interest is connected with the reaction mechanism and its mass dependence. Special attention is paid to the region $A>80$, where the equilibrium statistical theories appear to be in serious disagreement with the experimental data.

II. EXPERIMENTAL METHOD

A counter telescope [6] consisting of two proportional counters (dE and ΔE) filled with CO_2 (60 mm Hg) and a semiconductor E-detector was used to identify α-particles and measure their energies. Pulses from the detectors were fed into an electronic system consisting principally of coincidence units and a 256×256 channel pulse-height analyzer. The block diagram of the electronics is shown in Fig. 1.

The targets were made from enriched hafnium oxides Hf178O2 (enriched up to 95.9 %) and Hf180O2 (enriched up to 97.2 %) by means of sedimentation on Al-backings in isopropyl alcohol. In order to decrease the background, the telescope was lined with graphite, which has a negative Q-value for the (n, α) reaction ($Q = -5.7$ MeV), while the Q-values for the measured isotopes are positive (for Hf178 (n, α), $Q = 8.2$ MeV; for Hf180 (n, α), $Q = 6.97$ MeV).

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The energy of the α-particles was obtained after corrections for energy losses in the targets and in the counter gas. The distance between the neutron source and the Hf targets was 9.5 cm and between the target and the E-detector, 6 cm.

Neutrons with an energy of 14.8 MeV were obtained by use of a 150 keV deuteron beam accelerated in the 300 kV Cockcroft-Walton accelerator of the "Rudjer Bošković" Institute in Zagreb. The effective time of measurement for both spectra was about 300 hours.
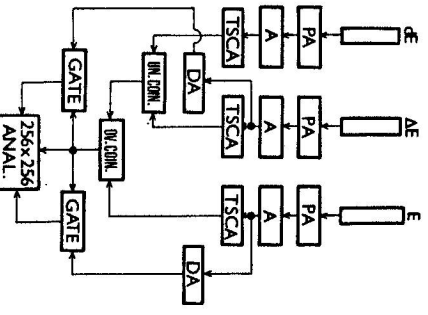

Fig. 1. Block diagram of the electronic circuit.

III. RESULTS AND DISCUSSION

The measured spectra are shown in Figs. 2 and 3. They begin at 17—18 MeV, reach a maximum at 19—20 MeV, and have an end point consistent with the Q-values taken from the literature. The differential cross sections determined from the total number of detected particles, neutron flux and geometrical conditions are:

$$\sigma(0°) = (0.49 \pm 0.17) \text{ mb/sr for Hf}^{178} (n, \alpha) \text{ Yb}^{175}$$
$$\sigma(0°) = (0.28 \pm 0.11) \text{ mb/sr for Hf}^{180} (n, \alpha) \text{ Yb}^{177}.$$

The fits of the spectral shapes shown with dashed lines in Figs. 2 and 3 are calculated using the following formula (the only really important term is $n_0 = 3$):

$$\left(\frac{d\sigma}{d\varepsilon}\right)_{\text{pre-eq. preformed}} \sim \sigma_C \frac{\mu_\alpha \varepsilon_\alpha \sigma_{inv}(\varepsilon_\alpha)(2s+1)}{2\pi^3 \hbar^2 |M|^2 g^4 E^3} \times \sum_{\substack{n=n_0 \\ \Delta n=2}}^{n} \left(\frac{U}{E}\right)^{n-2} (n+1)(n^2-1). \qquad (1)$$

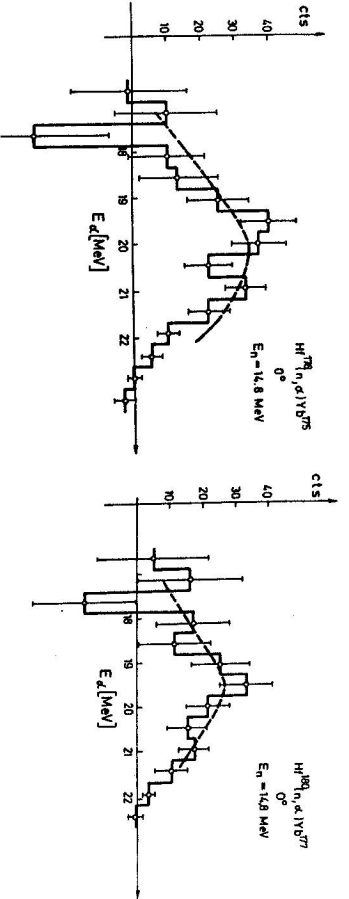The meaning of the symbols can be found in Ref. [7], for example.

Fig. 2. Comparison of the Hf^{178} (n, α) Yb^{175} spectrum with the calculation. The dashed line represents the preformed preequilibrium emission of the α-particles (Eq. 1).

Fig. 3. Comparison of the Hf^{180} (n, α) Yb^{177} spectrum with the calculation. The dashed line represents the preformed preequilibrium emission of the α-particles (Eq. 1).

This expression describes the emission of preformed α-particles in the framework of the preequilibrium model. The other approach which considers α-particles as formed from the excited nucleons of a composite nucleus and as removing four excitons from the system was not so successful in describing the measured spectra even when the term of Ribanský and Obložinský [8] ($\omega(\rho_p, 0, E-U)/g$) was taken into account, because the calculated maxima occurred at lower energies than the experimental ones. The same is also true of the spectra of Pr^{141} (n, α) La^{138} and Ho^{165} (n, α) Tb^{162} analyzed in Ref. [9] and Ta^{181} (n, α) was performed without the term $\omega(\rho_p, 0, E-U)$, but for the (n, α) reactions in the energy region considered this does not change the shape of the calculated spectra appreciably.

To conclude, we can say that the preformed α-particle preequilibrium model seems to give a good agreement with the experimental (n, α) data for a heavy system [11], although more theoretical effort is needed before a definite statement about the mechanism can be made.

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