INELASTIC SCATTERING OF 14 MeV NEUTRONS ON Mg^{24}

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The cross section for excitation of the first excited level of the Mg^{24} nucleus by scattering of 14-MeV neutrons is measured by comparison with the cross section for the $Mg^{24}(n,p)Na^{24}$ reaction.

A quantitative determination of the probability of excitation of individual levels of nuclei in inelastic scattering of fast neutrons entails many experimental difficulties. The problem can be simplified if the cross section for the elastic scattering can be compared experimentally with the known cross section of some process on the same nucleus. We have measured the excitation cross section of the first level of Mg^{24} in inelastic scattering of neutrons with energy 14 MeV, by comparison with the cross section of the (n, p) reaction on the same nucleus.

Figure 1 shows the level scheme of Mg^{24}, obtained on the basis of the data of [1,2]. When a sample of natural magnesium is bombarded with neutrons, the reaction $Mg^{24}(n,p)Na^{24}$ causes a certain amount of radioactive Na^{24} to accumulate in the sample. The Na^{24} nuclei experience β decay which goes almost completely to the 4^+ level of Mg^{24}. The γ-cascade excites the first 2^+ level of Mg^{24}, with energy 1.37 MeV. Since the effective cross section of the (n, p) reaction is known with good accuracy, we can determine the cross section for the excitation of the 2^+ level in inelastic scattering of neutrons by Mg^{24}, by measuring the spectrum of the γ radiation in the inelastic scattering of 14-MeV neutrons by magnesium, activating the sample under the same conditions, and measuring the spectrum of the activated magnesium sample. Such a method obviates the need for determining the absolute values of the spectrometer efficiency, the neutron and γ-ray fluxes, and the self-absorption in the sample.

In the $Mg^{24}(n,p)Na^{24}$ reaction, the Na^{24} is produced in two states: in the ground state (60%) and in a metastable state 1^+ with energy 0.47 MeV (40%) [2]. The lifetime of the 0.47-MeV metastable level is given in [3] as 0.02 sec. In a small fraction of the cases, the β decay can go from the metastable level directly to the ground level of Mg^{24}, but the probability of such a transition is

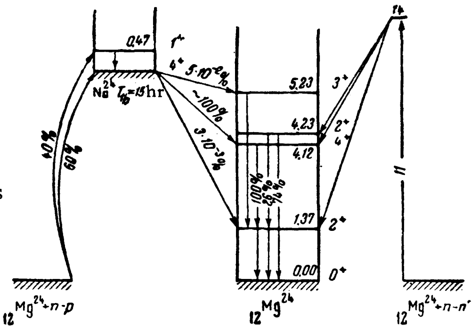

FIG. 1. Level scheme of Mg^{24} (the level energies are in MeV).

low. Starting from the value of log (ft) for the given case, we can estimate the fraction of the β decay in the decay of the 0.47-MeV level of Na^{24}. Its value is of the order of 1%. Since we have used subsequently the values of the (n, p) reaction cross section, obtained using radiochemical methods, the corresponding values of these cross sections characterize, in view of the smallness of the lifetime of the metastable state, the probability of production of Na^{24} only in the ground state. This in itself excludes the need for a correction to take account of the β-decay in the ground state of Mg^{24}. Therefore, to determine the cross section of inelastic scattering we can assume that each $Na^{24} \xrightarrow{\beta} Mg^{24}$ decay event is accompanied by excitation of the first state 2^+ of Mg^{24}.

If the magnesium sample is activated under the same conditions as in the study of the inelastic neutron scattering on the same sample, and if the γ spectra for inelastic scattering and β decay in the activated sample are measured by one and the same spectrometer, then the relative probabilities of the registration of the γ quanta in both cases can be easily related. Then the cross σ_{np} of the (n, p) reaction and the cross section $\sigma_{nn'}$ for the inelastic scattering of the neutrons by Mg^{24} with excitation of the first excited level will be related by the equation

$$\sigma_{nn'} = \sigma_{np} \frac{N_2 t_m}{N_1 t_a'} (1 - e^{-\lambda t_a}) e^{-\lambda t_d} \frac{n_1}{n_2} f,$$

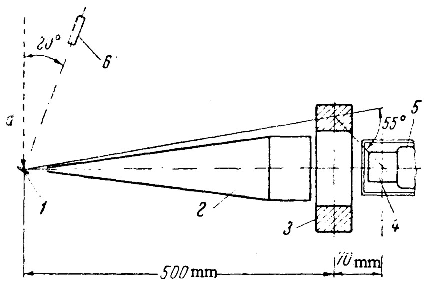

FIG. 2. Geometry of the experiment: 1 – neutron source; 2 – lead shield; 3 – scatterer; 4 – scintillator of γ spectrometer; 5 – photomultiplier; 6 – proportional counter for α particles.

where N_1 is the registered number of pulses from the scintillation detector at the peak of the total absorption of the 1.37-MeV γ line from the activated sample; N_2 is the number of pulses in the same region of the spectrum in measurements of the γ spectrum for inelastic scattering of the neutrons under the same geometry (the accumulation of the radioactive substance during the measurement time can be neglected); t_m is the time of measurement of the γ spectrum during β decay (t_m is small compared with the half life, which is 15 hours); t_a is the sample activation time; t_d is the delay time following the activation to permit the decay of the short-lived isotopes; λ is the decay constant; n_1 is the total count of the neutron flux monitor during the time of measurement of the γ spectrum in inelastic scattering; n_2 is the total count of the same monitor during the activation time of the sample; f is a correction factor for the anisotropic distribution of the γ radiation in the inelastic scattering.

The γ-radiation spectrum from the $Mg^{24}(n, n'\gamma) Mg^{24}$ reaction was measured in the annular geometry shown in Fig. 2. The sample was made from a natural mixture of magnesium isotopes. The γ spectrometer used was a single-crystal scintillation spectrometer consisting of an NaI(Tl) crystal measuring 40 × 40 mm and an FÉU-29 photomultiplier. The spectra were analyzed with a BMA-50 50-channel pulse-height analyzer[4]. The activation of the sample and the subsequent measurement of the γ spectrum in β decay were carried out in a perfectly identical annular geometry. In order to prevent activation of the spectrometer crystal and, consequently, in order to decrease the background in the succeeding measurements, the crystal was replaced during the activation time by an analogous luminescent counter. The spectra of the inelastic neutron scattering γ rays and the γ rays accompanying the $Na^{24} \xrightarrow{\beta} Mg^{24}$ β^-decay are shown in Figs. 3 and 4. The 14-MeV neutrons were generated in the reaction $T^3(d,n)He^4$ by bombarding a thick zirconium-tritium target with 120-keV deuterons. The neutron yield was monitored by counting the α particles from the indicated reaction. The neutron flux was measured additionally by a counter with thin plastic (0.5 mm thick). The values of the cross section of the (n, p) reaction on Mg^{24} were measured in [5-7], where the activation method was used. The following results, which agree well with one another, were obtained: $\sigma_{np} = 191$ mb[5], $\sigma_{np} = 129$ mb[6], and $\sigma_{np} = 203$ mb[7].

Verbinski et al[8] measured the (n, p) cross section by measuring the number of protons generated in the reaction. The reaction cross section $\sigma_{np} = 32$ mb obtained in that investigation is approximately one-seventh the activation cross section. Apparently, only the part of the cross section corresponding to emission of high-energy protons is measured when the (n, p) cross section is determined by counting the protons. Therefore, to calculate the cross section for the inelastic scattering of the neutrons by Mg^{24}, we used the average of the values obtained for the (n, p) cross section in [5-7], amounting to 204 ± 14 mb.

To correct for the anisotropy of the angular distribution of the γ rays in the inelastic scattering, we measured the angular distribution of the γ radiation for the given angle resolution. The angular distribution obtained is shown in Fig. 5. The corresponding correction for the cross section σ_{nn} is 2% of the total cross section. The cross section measured in this way for the inelastic scattering of 14-MeV neutrons by Mg^{24}, which leads to the excitation of the 1.37-MeV first excited level, is 590 ± 95 mb. Deuchars and Dandy [9] measured the cross section for the excitation of the same level by the method of absolute measurements of the γ spectrum from inelastic scattering of 14 MeV neutrons by magnesium; the value 550 ± 100 mb which they obtained is in good agreement with our result. It must be noted, however, that these values for the probability of excitation of the first-excited level contain both the probability of the direct transition from the ground state, and the probability of excitation as a result of a γ cascade from higher levels, which are also excited during the inelastic scattering of the neutrons.

The observation of the cascade γ quanta is quite difficult in the case of Mg^{24}, owing to the low efficiency of the spectrometer with the inorganic scintillator to γ radiation with energy near 2 MeV. This causes the γ lines due to the transitions from the levels 4^+ (level energy 4.12 MeV) and 2^+ (en-

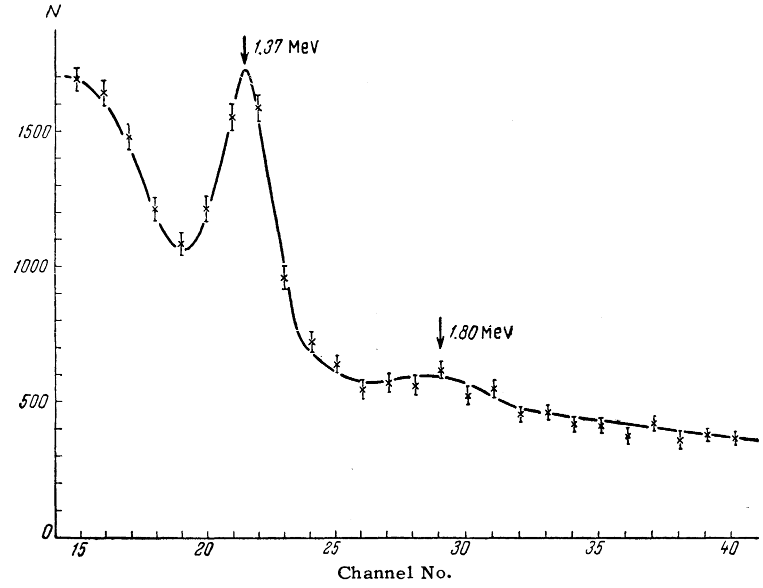

FIG. 3. Apparatus spectrum of γ quanta generated in inelastic scattering of 14-MeV neutrons by magnesium.

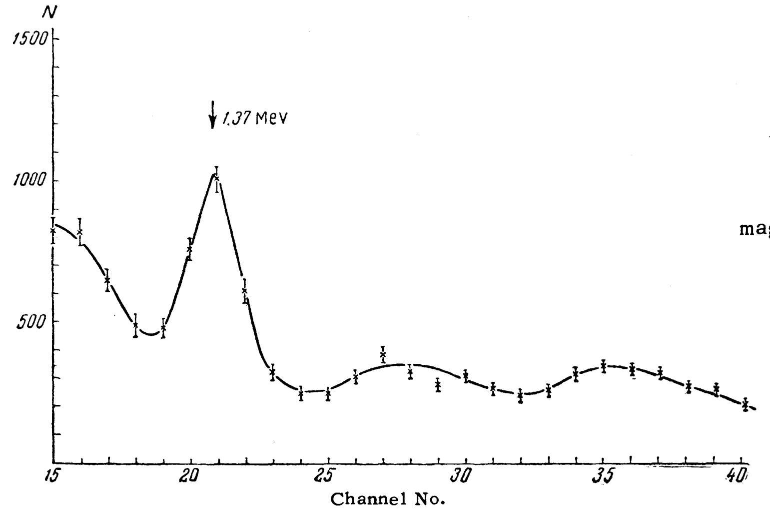

FIG. 4. Apparatus spectrum of γ quanta from a sample of magnesium activated with 14-MeV neutrons.

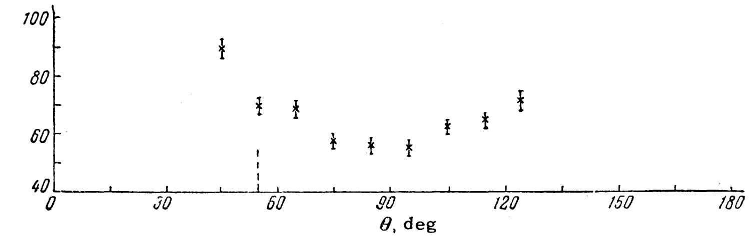

FIG. 5. Angular distribution of 1.37-MeV γ quanta generated by inelastic scattering of neutrons by magnesium.

ergy 4.23 MeV) to the 1.37 MeV level to be poorly registered by the spectrometer. They are weakly separated, as one 2.76-MeV line, over the level of the γ background for inelastic scattering, although they are clearly seen in the γ spectrum of the activated sample. Since the total background in the registration of γ spectra generated by inelastic scattering of 14-MeV neutrons is quite high, the absence of this clearly pronounced line, which has low registration probability, does not necessarily mean the absence of the corresponding γ transitions. The total cross section of all the inelastic processes on Mg^{24} was investigated in several places [10-12] using spherical geometry, and amounts to approximately 970 ± 20 mb. This value includes, obviously, the cross sections for the following energetically feasible reactions: (n, n′), (n, p), (n, np), and (n, α). The 14-MeV neutron capture cross section, as is well known, is quite small, and its contribution can be neglected. The reaction (n, 2n) has a threshold of 17 MeV, while the cross sections of the (n, α) and (n, np) reactions have not been measured. Taking into account the obtained value of the cross section $\sigma_{nn'}$

and summing it with σ_{np}, we can indicate an upper limit for the sum of the cross sections of the (n, α) and (n, np) reactions, $\sigma_{n\alpha} + \sigma_{n,np} \leq 0.1$ b. The method used in this work for measuring the cross sections of inelastic scattering of fast neutrons by comparison with the cross section of the (n, p) reaction may be useful also for the investigation of the cross sections on other nuclei. It is probably possible to measure in this way the cross sections for the excitation of the levels of Si^{28}, Ti^{48}, Cr^{52}, Fe^{56}, Al^{27}, S^{32}, Ni^{58}, etc.

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