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Abstract

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ENERGY DISTRIBUTION OF α-PARTICLES IN THE PHOTODISINTEGRATION OF ARGON

The study of the energy and angular distributions of α-particles produced in photonuclear reactions is of interest both for establishing the correct mechanism of these reactions and for studying the individual properties of nuclei. The principal difficulty in studying photonuclear reactions with the emission of α-particles is the small cross section of these reactions. Data on the energy distributions of photo-α-particles from various elements ([1–4]), obtained almost entirely by the photographic-plate method, have insignificant statistical accuracy and require a large expenditure of labor and time. It is obvious that increasing the existing statistical accuracy would make the experimental results more reliable. The method used in the present work, employing an ionization chamber with grids, makes it possible to obtain energy spectra of α-particles within 30–40 hours, with a total statistical sample of up to 20,000, at least for a number of elements.

A block diagram of the apparatus is shown in Fig. 1. A beam of γ-quanta with $E_{\gamma\,\max} = 70$ MeV from the synchrotron of the Physico-Technical Institute of the Academy of Sciences of the USSR, stretched in time to 1500 μsec, was limited by a lead collimator $C.K.$ with an aperture of 2×20 mm, and then, through a cleaning magnetic channel SN, passed through a volume of gas bounded by the double high-voltage electrode 1. Charged particles arising as a result of photodisintegration of the gas (argon) were recorded by an ionization chamber operating with electron collection. This geometry of the experiment made it possible to reduce considerably the background ionization arising when the γ-beam passed through the chamber volume.

The operating principle of the multigrid ionization chamber is described in detail in ([5]). The grounded shielding grid 3 made it possible to obtain on the collecting electrode 4 an electric pulse proportional to the energy of the registered particle. A negative pulse

$$V_{\ominus} = -\frac{Ne}{c}\left(1 - \frac{R^*}{d}\cos\varphi\right)$$

Fig. 1. Block diagram of the setup

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Fig. 2. Energy spectra of α-particles arising in photodisintegration of argon: a –at a pressure in the chamber of 1 atm., b –3 atm.

Figure 2: Fig. 2. Energy spectra of α-particles arising in photodisintegration of argon: a –at a pressure in the chamber of 1 atm., b –3 atm.

([6]) from grid 2 was used to distinguish α-particles against the background of lighter charged particles. Here R^* is a quantity differing only slightly from the particle range; φ is the angle between the normal to electrode 1 and the direction of emission of the particle; $d = 35$ mm is the distance between the high-voltage electrode 1 and grid 2. In the case when $R^* \cos\varphi \geq d$, the negative pulse is absent. Thus, particles whose ranges do not fit within the volume between 1 and 2 do not produce a negative pulse on grid 2. The maximum possible particle range for the geometry used and at a pressure $P = 1$ atm is 9 cm, which corresponds to energies of protons 2.3 MeV, deuterons 3.05 MeV, H^3 3.54 MeV, He^3 8.1 MeV, and He^4 9.08 MeV. By recording pulses from the collecting electrode in coincidence with negative pulses from the grid in the region 3.5-9 MeV, one can obtain energy spectra of charged particles in which protons, deuterons, and tritons will be completely excluded. Separation of the spectra of He^3 nuclei and α-particles by this method is not possible. Below, everywhere it is assumed that the yield of He^3 in all cases is much smaller than the yield of α-particles, and all measured spectra are identified with the spectra of α-particles.

By varying the pressure of the filling gas, different portions of the energy spectrum can be recorded. It should be noted that in the present case what is measured is not the energy of the charged particle, but the sum of the energies of the particle and the recoil nucleus.

Fig. 1. Block diagram of the setup

Pulses from the collecting electrode 4 and grid 4 were amplified by preamplifiers 5 and amplifiers 6. The selector 7 blocked the outputs of the amplifiers and removed the blocking only for the time during which γ-radiation passed through the chamber, in order to avoid electrical pickups caused by the synchrotron apparatus. The coincidence circuit 8 selected, from all pulses of the energy channel, only those accompanied by negative pulses from the grid. An electron-beam tube 11 with two pairs of deflecting plates was used as the recording device. Circuit 10 served to form the pulses arriving at the plates of the tube, while the sweep circuit 9 triggered the electron beam.

Fig. 2. Energy spectra of α-particles arising in photodisintegration of argon:

Fig. 3. Comparison of the experimental energy distribution of α-particles with that calculated according to the statistical theory for the reaction $A^{40}(\gamma\alpha)S^{36}$. 1—experimental spectrum, 2—calculated spectrum

Figure 3: Fig. 3. Comparison of the experimental energy distribution of α-particles with that calculated according to the statistical theory for the reaction $A^{40}(\gamma\alpha)S^{36}$. 1—experimental spectrum, 2—calculated spectrum

a —at a pressure in the chamber of 1 atm., b —3 atm.

The proper operation of the entire setup was checked from the energy spectrum of the α-particles of natural uranium, whose lines simultaneously served as reference points for the energy calibration. The half-width of the lines of the α-spectra did not exceed 150 keV. This makes it possible to assert that the characteristic features of the spectrum of photo-α-particles were obtained correctly.

The energy spectra of α-particles arising in the photodisintegration of argon were obtained at argon pressures in the chamber of 1, 1.3, 2, and 3 atm. The positions of the maxima in these spectra lay, respectively, at 4.6, 4.87, 4.4, and 4.3 MeV, while the half-widths of the spectra were, respectively, 2.62, 2.76, 3.20, and 3.65 MeV. The small difference between the spectra at different pressures indicates a weak influence of protons, deuterons, and tritons on the spectra being recorded. Figure 2 gives the energy spectra of α-particles at the two extreme pressures, 1 and 3 atm, and for each case indicates the detection levels and the maximum possible values of the energies of the registered protons, deuterons, and tritons.

Fig. 3. Comparison of the experimental energy distribution of α-particles with that calculated according to the statistical theory for the reaction $A^{40}(\gamma\alpha)S^{36}$. 1—experimental spectrum, 2—calculated spectrum

The detection efficiency of all charged particles for which $R^* > d$ decreases with increasing R^*. Therefore, in practice the detection efficiency of light particles at the indicated maximum energies is extremely small. A decrease in the detection efficiency for particles of high energy also distorts the α-particle spectra. This leads to the need to record the energy spectra of α-particles at different pressures. Comparison of the energy spectra of α-particles obtained at pressures of 1 and 3 atm shows an increase in the number of registered particles both to the right and to the left of the maximum for pressure $P = 3$ atm. The increase in the number of registered particles on the left is explained by an increase in the detection efficiency of light particles. The difference in the region of higher energies is due to a decrease in the detection efficiency of the corresponding α-particles at $P = 1$ atm.

The spectra described make it possible to construct the true energy spectrum of α-particles arising in the photodisintegration of argon, shown in Fig. 3.

The obtained energy spectrum of α-particles, which has a maximum at 4.8 MeV and a half-width of 3.3 MeV, is compared with the spectrum calculated according to the statistical theory for the reaction $A^{40}(\gamma\alpha)S^{36}$. The calculation was carried out using the formula

$$I(\varepsilon)\,d\varepsilon = \varepsilon\sigma_{\alpha}(\varepsilon)e^{-\varepsilon/T}\int_{B_{\alpha}+\varepsilon}^{70}\sigma_{\gamma n}(E)N(E)\,dE\,d\varepsilon,$$

where $\sigma_{\alpha}(\varepsilon)$ was taken from work (7), $\sigma_{\gamma n}$ from work (8), and $B_{\alpha} = 6.76$ MeV is the threshold of the reaction $A^{40}(\gamma\alpha)S^{36}$. The value T was taken equal to 1 MeV, similarly to how this was done for the reaction $A^{40}(\gamma p)Cl^{39}$ in work (9). From a comparison of the experimental and calculated spectra it is seen that the maximum of the experimental distribution is shifted by approximately 2 MeV toward lower energies. The chosen value of T must be reduced by approximately a factor of two in order to bring the two spectra into agreement. However, in that case the calculated spectrum, although it coincides in its maximum with the experimental one, differs from it in the high-energy region. The value $T = 0.5$ MeV is small in comparison with the temperatures obtained from other photonuclear reactions for nuclei in the region of A values close to 40. Thus, it does not appear possible to achieve agreement between the experimental and calculated spectra by a reasonable variation of the temperature values.

The observed discrepancy between the experimental and calculated spectra can most probably be explained in two ways. It is possible that, in addition to the reaction $\mathrm{A}^{40}(\gamma\alpha)\mathrm{S}^{36}$, a considerable contribution to the measured spectrum was made by the reaction $\mathrm{A}^{40}(\alpha\gamma n)\mathrm{S}^{35}$, and this led to a shift of the maximum toward lower energies. A second possible explanation is that the true values of the penetrability of the Coulomb barrier are somewhat larger than those used in Ref. ([7]). This will also lead to a shift of the calculated spectrum of α-particles toward lower energies.

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Note: Figure translations are in progress. See original paper for figures.