PROTON AND α-PARTICLES EMISSION FROM THE INTERACTION OF 22 MeV ENERGY PROTONS WITH ^{59}Co NUCLEUS*

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The energy spectra of protons and α-particles are obtained for a wide range of angles in reactions of 22 MeV energy protons and ^{59}Co nucleus. The experiment was performed at the isochronous cyclotron of the Institute of Nuclear Physics, Kazakhstan. The double-differential and integral cross sections of (p, xp) and $(p, x\alpha)$ reactions were measured. Experimental results were compared with the TALYS-1.9 nuclear model code calculations. In general, the calculated spectra were in good agreement with the measured ones.

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1. Introduction

New experimental data on double-differential cross sections of the formation of light-charged particles from the interaction of high-energy protons with nuclei, in addition to their significance for fundamental research, are a valuable source of information for various applied problems, in particular, in nuclear medicine and the nuclear industry in the design of ADS [1].

This paper presents new experimental data on the double-differential and integral cross sections of proton and α-particle production reactions measured on the ^{59}Co nucleus at the energy of the bombarding protons of 22 MeV. ^{59}Co was chosen as a structural element widely used in the design of nuclear installations [2]. Cobalt has only one stable isotope, which makes it a convenient test nucleus for verifying various nuclear models. There are

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a limited number of works on experimental double-differential and integral cross sections of reactions on the ^{59}Co nucleus induced by protons. In [3, 4], (p, xp) and $(p, x\alpha)$ cross sections were measured at energies of 14.0 MeV and 29.9 MeV. In [5], $(p, x\alpha)$ reaction cross sections were obtained at the energy of 72.3 MeV.

The theoretical analysis was carried out within the framework of the TALYS-1.9 calculation code, which is based on modern theoretical models of nuclear decay. With the help of this computer code, it is possible to calculate almost all channels of nuclear reactions in the energy range from 1 keV to 200 MeV and the associated observables.

The work is a continuation of research carried out at the Institute of Nuclear Physics, Kazakhstan to determine double-differential and integral reaction cross sections in a number of structural elements of nuclear power system [6–8].

2. Experiment

Experimental spectra of nuclear reactions (p, xp) and $(p, x\alpha)$ on the ^{59}Co nucleus were obtained on the isochronous cyclotron U-150M of the Institute of Nuclear Physics. The energy of the bombarding protons was 22 MeV. A self-supporting target with a ^{59}Co content of 97% and a thickness of 5.2 mg/cm^2 was used.

Based on the kinematic calculations of the energy range of the outgoing secondary particles, the working thicknesses of the detectors used were determined. To identify the reaction products (p, xp), a telescope consisting of a 100 micron thick silicon detector and a 2.5 cm thick total absorption detector (CsI(Tl) scintillator) was used. Cross sections of nuclear reactions were obtained in the angular range 30°–135°. The solid angle of the telescope was 4.62×10^{-5} sr. Measurements of the cross sections of nuclear reactions $(p, x\alpha)$ were performed in the angular range 30°–120°. The spectrometric telescope consisted of two silicon detectors with thicknesses of 50 microns and 1 mm. The solid angle of the telescope was 5.3×10^{-5} sr.

Systematic errors of the measured cross sections are mainly due to errors in determining the thickness of the target, calibration of the current integrator, and solid angle of the spectrometer did not exceed 10%. The statistical error depended on the type and energy of the detected particles and generally did not exceed 10%. A qualitative examination of the double-differential cross sections shows that a wide peak corresponding to elastic and inelastic scattering at low-lying levels is observed in the high-energy part of the proton spectrum. After integration by the angle of the double-differential cross sections, the integral cross sections of the reaction ^{59}Co (p, xp) and $(p, x\alpha)$ were obtained at the energy of the incoming protons of 22 MeV, shown in Figs. 1–2.

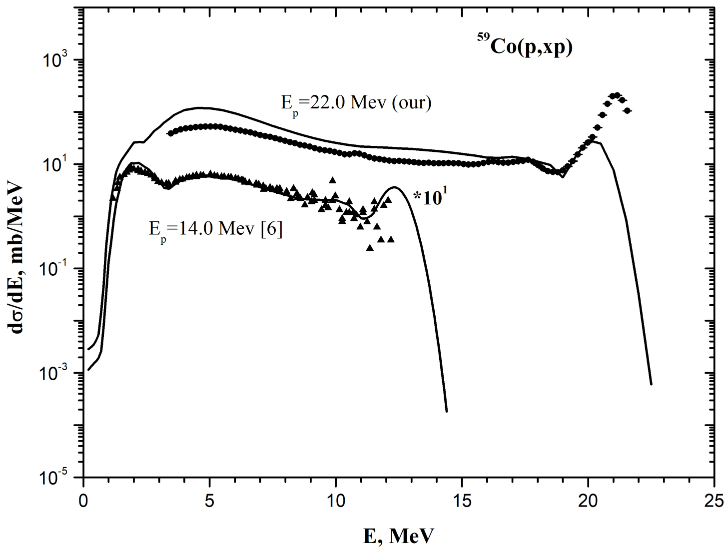

Fig. 1. Comparison of angle-integrated cross sections for the $^{59}\text{Co}(p, xp)$ reactions with theoretical calculations on TALYS code. Points — experiment, lines — theory.

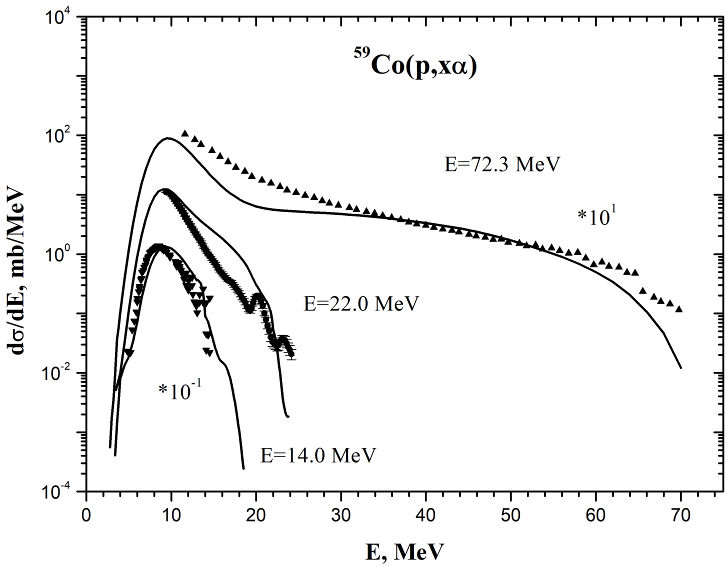

Fig. 2. Comparison of angle-integrated cross sections for the $^{59}\text{Co}(p, x\alpha)$ reactions with theoretical calculations on TALYS code. Points — experiment, lines — theory.

3. Analysis

Theoretical analysis of experimental cross sections of the (p, xp) and $(p, x\alpha)$ reactions on the ^{59}Co nucleus at proton energy of 22.0 MeV was performed using a modified version of the exciton model of pre-equilibrium nuclear decay [9–11]. Within this model, it is assumed that the nucleus has a set of equidistant single-particle states. The interaction, as a result of which the nucleus transitions from one state to another, is considered to be two-particle and weak enough, which makes it possible to apply perturbation theory when calculating transition probabilities. The energy of the system is conserved. In the two-component model, proton and neutron degrees of freedom are taken into account separately.

The state of the nucleus is characterized by four parameters p_π, h_π, p_ν, and h_ν, where p and h denote partial and hole, and π and ν proton and neutron degrees of freedom, respectively. It is assumed that the difference between the number of particles and holes during the transition to an equilibrium state remains constant.

Due to the assumption that the residual two-particle interactions are small, the first order of perturbation theory is used to find the probability of intra-nuclear transitions related to a unit of time.

For the theoretical analysis of the obtained experimental data, the TALYS-1.9 calculation code was used [12]. In addition to the calculations in the framework of the exciton model, calculations were performed in the framework of other mechanisms of nuclear reactions. For nuclear reactions involving complex ejectiles, direct-like reactions (stripping, pick-up, break-up, and knock-out mechanisms) were included in TALYS according to the Kalbach phenomenological parameterization. For the equilibrium cross-section calculation, the Hauser–Feshbach model with a width fluctuation correction was used.

Figures 1 and 2 show a comparison of theoretical and experimental data on the integral cross sections of the (p, xp) and $(p, x\alpha)$ reactions on the ^{59}Co at energies of 22.0 MeV. Additionally, a theoretical calculation is made for the available experimental data on the integral cross sections of the (p, xp) and $(p, x\alpha)$ reactions at energies of 14.0 MeV and $(p, x\alpha)$ at energies of 72.3 MeV. Satisfactory agreement of experimental and calculated values was obtained.

4. Conclusions

Experimental data on double-differential and integral cross sections of the (p, xp) and $(p, x\alpha)$ reactions from reactions initiated by protons with an energy of 22 MeV at the ^{59}Co nucleus were obtained for the first time. From the comparison of experimental and theoretically calculated integral spectra, it follows that the main contribution to the formation of the integral cross sections of the (p, xp) and $(p, x\alpha)$ reactions is due to the pre-equilibrium mechanism and decay of the composite core. The contribution of single-stage direct mechanisms is insignificant, except for the reaction (p, xp). The experimental results obtained replenish the database of nuclear data on reaction cross sections and can be used in the design of safe and waste-free hybrid nuclear power plants. The experimental results obtained make up for the missing cross sections of the studied reactions and can be used in the development of new approaches to the theory of nuclear reactions, as well as in the design of safe and waste-free hybrid nuclear power plants, in radiation materials science, in nuclear medicine.

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