Study of the channels of the reaction of the splitting of ^{58}Ni by 1-GeV protons

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(Submitted 25 May 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **28**, No. 1, 45–49 (5 July 1978)

We measured the spectra of prompt γ quanta, both single and in coincidence with low-energy protons and α particles, produced from ^{58}Ni by protons of 1 GeV energy. It is shown that the residual nuclei, identified by the observed transitions, are produced mainly in reactions with proton emission.

PACS numbers: 25.40.Rb

In experiments with registration of prompt γ emission of nuclei under the influence of high-energy particles, it was shown that in the γ-quantum spectra the majority of the intense γ transitions belong to the residual nuclei, the formation of which corresponds to emission of one or several α particles from the target nucleus.[1–14] In a

 0021-3640/78/2801-0042$00.60

number of studies this result was interpreted as an indication of a high probability of nuclear decay channels with emission of α particles. One cannot exclude, however, the possibility that these nuclei are produced in reactions with nucleon emission. To determine the mechanism whereby the residual nuclei are produced, correlated measurements of the prompt γ quanta and of the charged particles are necessary. We report here the results of such measurements.

The experiment was performed with a proton beam of energy 1 GeV and intensity 5×10^7 protons/sec from the cyclotron of the Leningrad Institute of Nuclear Physics. The target with ^{58}Ni, containing 96.8% of the main isotope, had a thickness 9.3 mg/cm^2. A Ge(Li) detector of 50 cm^3 volume was placed 10 cm away from the target at an angle 90° relative to the proton-beam direction. To identify the charged particles we used an ionization chamber (ΔE detector) and a mosaic of six Si(Au) detectors with sensitive-layer thickness 300 μm each (E detectors). The ΔE—E system had an effec-

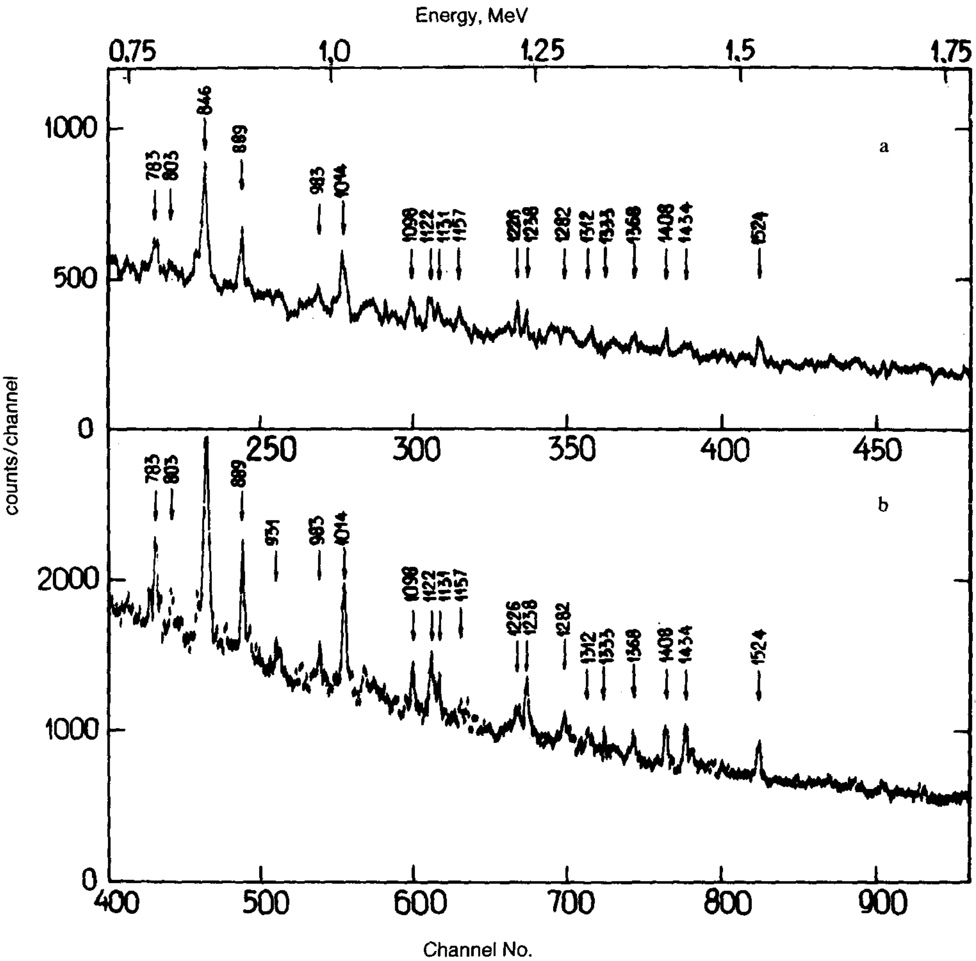

FIG. 1. Spectra of prompt γ quanta, measured for coincidence with α particles (a) and with protons (b).

tive solid angle 0.5 sr and made it possible to register simultaneously charged particles at angles 60, 90, and 120 degrees relative to the proton-beam direction. We registered protons of energy 2–15 MeV and α partcles of energy 5–25 MeV. The main experimental difficulties were connected with the production of the background conditions necessary for the operation of the Ge(Li) detector. This could be attained to a considerable degree because of the good temporal structure of the synchrocyclotron beam: the beam duration was 10 msec at a frequency 40 pulses/sec. The energy resolution during the entire measurement time was 5 keV for 1-MeV γ quanta.

The spectra of the prompt γ quanta, measured in coincidence with protons and α particles, are shown in Fig. 1. The other nuclei are identified by the energies of the observed γ transitions. The cross sections for the production of residual nuclei, determined from the intensity of the corresponding γ transitions, are listed in Table I. The

TABLE I. Cross sections for production of residual nuclei from ^{58}Ni, obtained from the spectrum of single γ quanta (σ_γ) and from the spectrum of γ quanta measured for coincidence with protons ($\sigma_{p\gamma}$) and α particles ($\sigma_{\alpha\gamma}$).

Residual nucleus	E_γ, keV	σ_γ, mb	$\sigma_{p\gamma}$, mb	$\sigma_{\alpha\gamma}$, mb	$\bar{N}_p$	$\bar{N}_\alpha$
^{54}Fe	1408	17 ± 3	34 ± 11	3 ± 2	2 ± 0.7	0.2 ± 0.1
	1131	9 ± 3	23 ± 11	3 ± 1.5	—	—
^{52}Cr	1434	9 ± 3	21 ± 13	≤2	2.3 ± 1.6	0.2
	1333	10 ± 3	10 ± 7	≤2	—	—
^{50}Cr	783	11 ± 3	55 ± 10	6 ± 2	5 ± 2	0.5 ± 0.2
	1098	10 ± 3	38 ± 10	5 ± 2	—	—
	1282	9 ± 3	40 ± 11	5 ± 2	—	—
^{48}Ti	983	4 ± 2	26 ± 8	3 ± 1.5	6.5 ±2	0.8 ± 0.3
	1312	5 ± 2	22 ± 9	4 ± 2	—	—
^{46}Ti	889	14 ± 4	69 ± 11	10 ± 2	4.9 ±1.8	0.7 ± 1.7
	1122	16 ± 4	60 ± 10	7 ± 2	—	—
^{44}Ca	1157	≤2	14 ± 7	4 ± 2	≥7	≥2
^{42}Ca	1524	5 ± 3	50 ± 10	9 ± 2	10 ± 2.5	1.8 ± 0.4
	1226	6 ± 3	43 ± 8	7 ± 2	—	—

cross sections were obtained assuming an isotropic angular distribution of the γ quanta and charged particles. The absolute values of the cross sections were obtained from the relative measurements of the counting rates of the p-γ and α-γ coincidences and from the counting rate of the single α particles. In the calculation of the cross sections we measured the differential cross section of production of α particles from ^{58}Ni, which was measured by us earlier and found to be $(d\sigma/d\Omega)_\theta = 120° = (25 \pm 3)$ mb/sr.[15]

In addition to the γ transitions indicated in Table I, the γ-quantum spectra reveal also γ transitions of Al and Ge, due to the interaction of the particles emitted from the target with the material of the detecting system. Special measurements have shown that about 50% of all the registered coincidences are due to such secondary reactions. Table I gives also the intensities of the γ transitions from the spectrum of the single γ quanta, measured in coincidence with the protons incident on the target. The measurements were made on a proton beam with intensity 5×10^4 protons/sec. The ^{58}Ni target was 10 g/cm^2 thick.

The data obtained from the spectrum of the single γ quanta agree with the results of analogous experiments[7,8,14] and show that the most intense γ transitions belong to those residual nuclei whose production corresponds to emission from ^{58}Ni of one or several α particles. However, as follows from the results of the correlated measurements, in this reactions there is a large probability of emission of low-energy protons besides the α particles. For example, the production cross sections σ_γ and σ_{p_γ} in ^{46}Ti differ by an approximate factor of five, which corresponds to formation, on the average, of five protons in this reaction. The data on the multiplicities of the protons ($\bar{N}_p$) and α particles ($\bar{N}_\alpha$) are given in Table I. The number of emitted protons is 5–10 times larger than that of the α particles. The combined charge of the produced particles agree within the limits of errors with the difference between the atomic number of ^{58}Ni and those of the corresponding residual nuclei. This indicates that the number of produced fast protons and α particles, with the exception of the leading particle, is probably small. We note also that the relative fraction of decays with α-particle emission is larger for those residual nuclei whose production corresponds to a larger loss of nucleons by the target nucleus.

As seen from Table I, reactions with proton emission are also characterized by large cross sections for the production of individual residual nuclei. It is possible, as noted in[14], that the effect is connected with the predominant formation of even-even nuclei situated in the β-stability band.

The angular distributions of the protons and α particles in reactions with production of identified residual nuclei turned out to be isotropic, within the limits of measurement errors, in the angle range from 60 to 120° relative to the direction of the proton beam.

The energy distributions of the α particles for the reaction channels with formation of ^{54}Fe, ^{50}Cr, ^{46}Ti, and ^{42}Ca were obtained by a difference method. Although the number of events in these distributions is small, they are similar and are characterized by a maximum in the region of the nominal Coulomb barrier at an α-particle energy 9–10 MeV. Spectra of this form agree with the well-known Maxwellian spectrum of single particles,[15] which is usually interpreted within the framework of the evaporation model.

The results, however admit also of another interpretation, which was proposed by us in[16]. At the present time it is known that when high-energy particles interact with hadrons giant multipole resonances are excited. It was shown recently that a giant quadrupole resonance decays predominantly with emission of α particles.[17,18] The energy distributions of such α particles have a maximum in the region of the Coulomb barrier and a form close to a Maxwellian distribution. Within this mechanism it is possible to explain also, the observed α-particle spectra.

We are grateful to A.A. Vorob'ev for interest in the work and for numerous fruitful discussions.

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