Charged-particle emission upon the absorption of π^- mesons in silicon

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The spectra of secondary particles accompanying the absorption of π^- mesons by ^{28}Si nuclei have been measured. This first experiment with a "live" target has apparently singled out the process of interest, without intranuclear rescattering, and furnished the spectrum of "direct" protons from the absorption event at the intranuclear *pp* pair.

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There is the hope that the absorption of pions by nuclei will become an effective tool for studying nuclear structure. Energy and momentum conservation strongly suppress the single-nucleon capture of pions, making absorption mechanisms involving several nucleons (at least two) stand out, so that intranuclear correlations can be studied.

The customary approach in pion-absorption experiments is to detect the emission of particles from nuclei. These measurements yield inclusive spectra of particles and the spectra of particles that are detected in coincidence. An important question which arises in the analysis of these spectra is just how directly the information on the particles emitted by the nuclei is related to the absorption mechanism.

Two-nucleon absorption is assumed to be the primary event in the description in Ref. 1 of the inclusive particle spectra accompanying the absorption of π^- mesons. The subsequent development of an intranuclear cascade results in a multiplication of particles and a modification of the spectra. In these calculations the initial absorption event is "forgotten" for the greater part of the spectrum, except for the high-momentum part. For example, the relative number of direct—not rescattered—protons in the inclusive spectra in absorption by ^{12}C nuclei is 5% according to the calculations in Ref. 1; the undistorted part corresponds to energies above 90 MeV. Figure 1a compares the calculations with experimental data from Ref. 1. A strong case can be made that the inclusive particle spectra carry too little information on the initial capture event.

Under these circumstances we would like to carry out measurements which would yield additional information in order to distinguish the direct reaction channels (channels which do not involve rescattering). In the present experiments we have used a "live" target, an Si (Au) semiconductor detector, to furnish this additional information. The measurements were carried out in the π^- meson channel of the synchrocy-

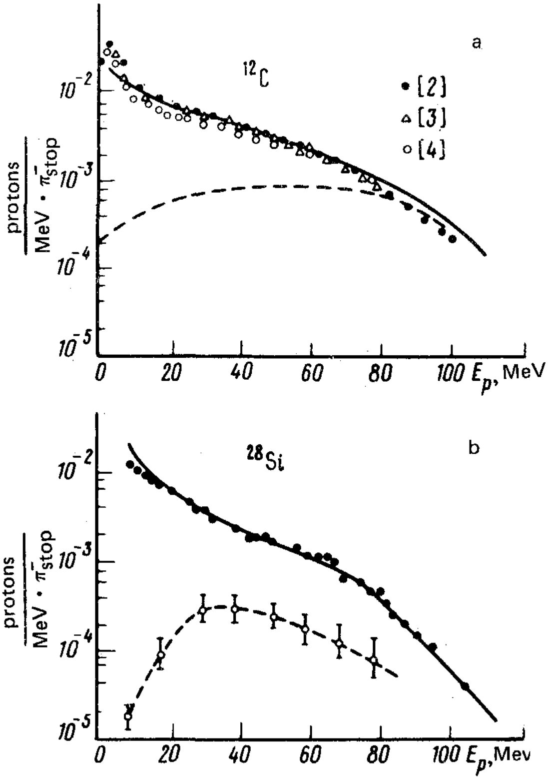

FIG. 1. a: Experimental and calculated spectra of protons emitted by ^{12}C nuclei during the absorption of π^- mesons. Dashed curve—calculated contribution of primary protons; solid curve—calculated with allowance for secondary processes.[1] b: Solid curve—Experimental proton spectrum accompanying the absorption of π^- mesons by ^{28}Si nuclei; dashed curve—experimental proton spectrum for events corresponding to the peak in the "live" target.

clotron of the Leningrad Institute of Nuclear Physics.[5] The spectrometer used in the measurements is described in Ref. 6. The pion beam is stopped in a target 3.2 cm in diameter and 0.1 g/cm^2 thick. The number of stopping events in the target is $\cong$2000 s^{-1}. The secondary particles are detected with telescopes of silicon detectors which can measure the particle energy within 0.5 MeV. Since we are using a detector as target, we can measure the energy evolved in the target and carry out a correlation analysis of the data. It also becomes possible to improve the absolute normalization of the particle yields, since in this case we are directly detecting the actual event in which the pion is stopped in the target, in contrast with earlier studies.

Figure 2 shows the spectra which we obtained for hydrogen and helium isotopes. These spectra have been corrected for the luminosity of the apparatus and for the loss of particles due to nuclear reactions. The solid curves are an approximation of the experimental data with allowance for energy loss in the target according to Ref. 4. The reconstructed spectra of the hydrogen isotopes and of ^{3}He are similar to each other.

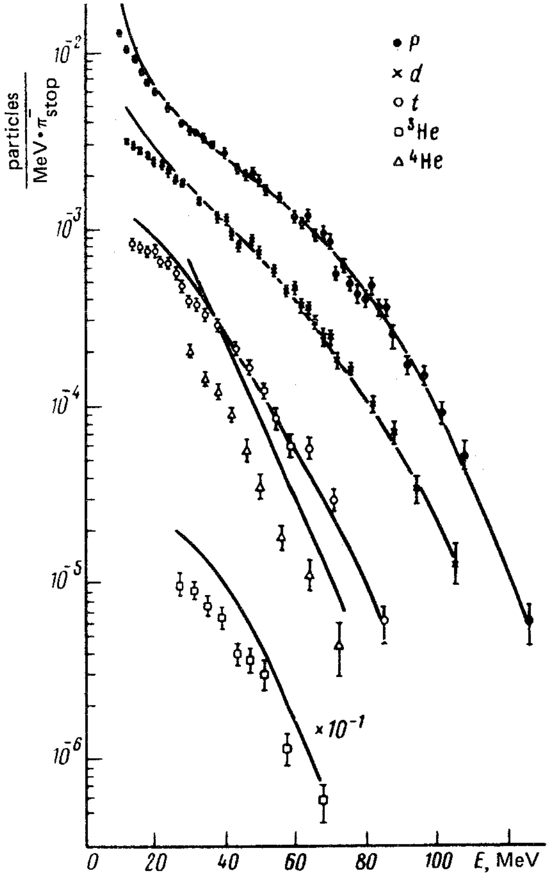

FIG. 2. Particle spectra accompanying the absorption of π^- mesons by ^{28}Si nuclei.

The ^{4}He spectrum, in contrast, has a qualitatively larger slope. This behavior of the spectra has been reported by workers studying other nuclei, and it is consistent in principle with the assumption that the deuterons, tritons, and ^{3}He nuclei are produced primarily through intranuclear pickup, whereas the α particles are due to knockout.[2,3] The particle yields Y (% per stopped π^-) for energies above the identification threshold corresponding to Fig. 2 are $Y_p = 27.7 \pm 1.2$ ($E > 8$ MeV), $Y_d = 9.5 \pm 0.5$ ($E > 10$ MeV), $Y_t = 2.2 \pm 0.1$ ($E > 12$ MeV), $Y_{^3\text{He}} = 0.33 \pm 0.02$ ($E > 24$ MeV), and $Y_{^4\text{He}} = 0.70 \pm 0.03$ ($E > 28$ MeV).

Since these are the first measurements in silicon, we cannot compare them directly with the results of other studies. We can compare our results with results for other nuclei. Table I compares the particle yields from ^{28}Si with the yields from ^{12}C and ^{40}Ca nuclei for two energy intervals. We see that the proton yields remain essentially constant, while the deuteron and triton yields decrease with increasing atomic number. The ^{3}He and ^{4}He yields for ^{28}Si and ^{12}C are almost identical, although the errors are

TABLE I.

		Y_p	Y_d	Y_t	$Y_{^3\mathrm{He}}$	$Y_{^4\mathrm{He}}$	$t/^3\mathrm{He}$
20 – 70 Mev	^{12}C	17.7 ± 2.7	9.8 ± 1,5	3.7 ± 0.6	—	—	—
	^{28}Si	13.8 ± 0,7	6,1 ± 0.3	1.6 ± 0,1	—	—	—
	^{40}Ca	15.2 ± 1.5	4,3 ± 0,4	1,52 ± 0,15	—	—	—
40 – 70 MeV	^{12}C	7.7 ± 1.2	3,1 ± 0.5	0.73 ± 0.15	0,10 ± 0.06	0,25 ± 0,06	7 ± 2
	^{28}Si	5.9 ± 0.3	1,7 ± 0,2	0,35 ± 0,05	0,10 ± 0.02	0,21 ± 0,02	3;5 ± 0.7
	^{40}Ca	5,7 ± 0,6	1,6 ± 0.2	0,45 ± 0,05	—	0,23 ± 0,02	—

large here, especially for ^{3}He. Table I also shows the ratio of the triton and ^{3}He yields. This ratio would be 4 according to the spin-isospin statistics in the hypothesis of pair absorption and the subsequent production of such particles through intranuclear pickup.[3] According to our measurements, this ratio is 3.5 ± 0.7.

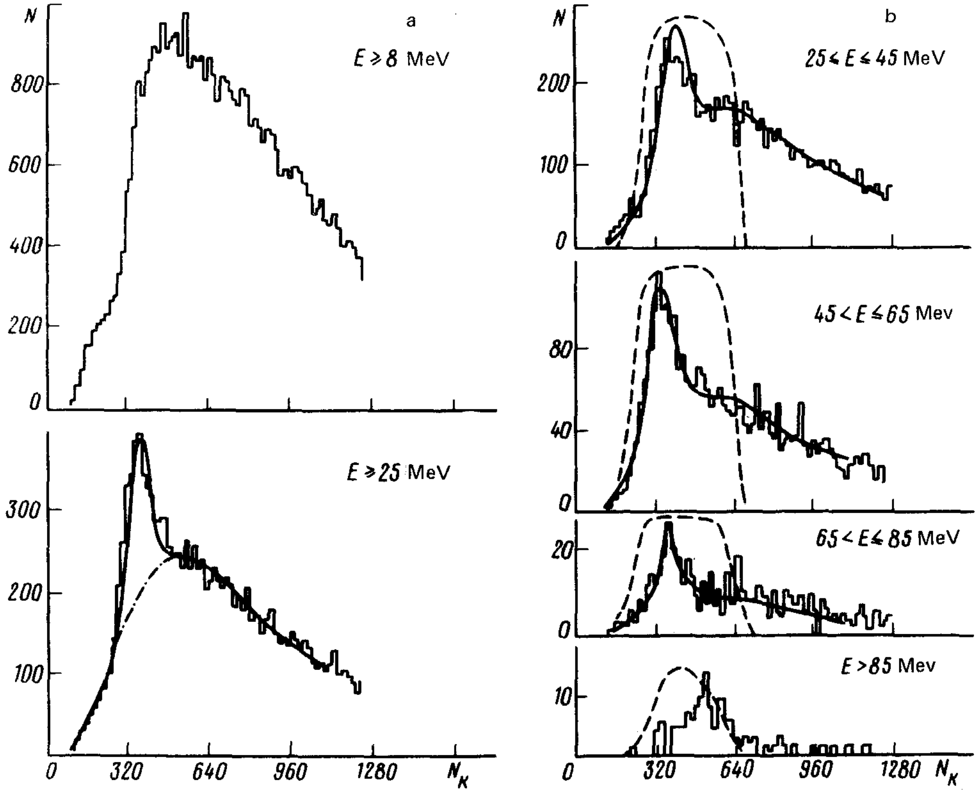

FIG. 3. Spectra of the energy evolution in the "live" target for various energy intervals of the detected protons. The channel width is 20 keV; channel 50 corresponds to a zero energy.

The primary distinction betwen this experiment and previous experiments is the use of a "live" target. Figure 3 shows spectra of the energy evolved in the target for events with detected protons. We see a peak at a low-energy evolution for protons with energies above 25 MeV (Fig. 3a). In Fig. 3b this peak can be traced in more detail. The dashed curves in Fig. 3b are the energy-evolution spectra calculated for the reaction $\pi^{-}\,{}^{28}\mathrm{Si}\text{-}pn\,{}^{26}\mathrm{Mg}$ [reaction (1)] according to the statistical model; these spectra have been normalized to the same peak height. We see that the observed peaks lie in a region which is kinematically allowed for reaction (1). The shift of the peaks toward the left boundary of the allowed region (at $E < 85$ MeV) and the widths of the peaks are consistent with the identification of reaction (1) as the mechanism for absorption at the *pp* pair.

It should be noted that for events with protons at energies above 85 MeV we observed a shift of the peak toward the right boundary of the allowed region. This shift apparently implies an increasing importance of the two-particle reaction channel for high-energy protons.

To find the proton spectrum for events belonging to the peak we determined the dependence of the peak contribution on the proton energy. The distributions were approximated by the sum of two curves: a normal distribution describing the peak and a polynomial describing the background. The solid curves in Fig. 3b illustrate this approximation. Figure 1b shows the inclusive proton spectrum and the spectrum of protons for the events singled out.

We see that the spectrum of protons belonging to the peak is sharply different from the inclusive spectrum. It has a maximum at 40 MeV. The average energy in the spectrum is $\cong 45$ MeV. This result is in qualitative agreement with the spirit of the calculations of Ref. 1, according to which this spectrum is the spectrum of direct protons from the event involving absorption by a *pp* pair—undistorted by secondary rescattering. According to our results, the relative number of such events for the proton energy interval 8–85 MeV is 2%, and that for the interval 25–85 MeV is 9.5%.

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