by extensive air showers with the number of particles $> 3 \times 10^3$. Nuclear-active particles of $\geq 1.5 \times 10^{13}$ ev are accompanied by such showers in $83 \mp 4\%$ of the cases. This shows that the particles are accompanied by extensive air showers almost independently of their energy.

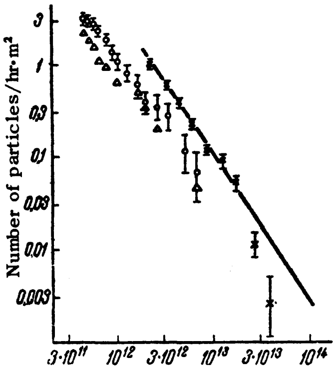

FIG. 2. Integral energy spectrum of nuclear-active particles; o and △ – data of reference 2. The energy of detected particles and the detection efficiency was estimated for the data of reference 1 according to reference 2, and a correction for the difference of observation levels was applied. ×) results of the present experiments.

The integral energy spectrum of nuclear-active particles observed at 3860 m above sea level is shown in Fig. 2. The energy of the particles detected in the experiment was determined according to the relation given above. The detection efficiency was found by comparing the number of ionization bursts under layers of graphite of different thickness. It can be seen from the figure that, in the energy region 10^{12} to 10^{13} ev, the energy spectrum is given by the formula $F(>E) \sim 1/E^{1.53\pm0.07}$, which is in agreement with the energy spectrum of the primary cosmic radiation in the corresponding energy range.[1]

It is interesting to note that considerably fewer particles with energy $\geq 3 \times 10^{13}$ ev were found than it could be expected if the similarity between the spectra of nuclear-active particles and of the primary cosmic radiation were extended to that region. The probability that the discrepancy between the observed and expected number of nuclear-active particles with energy $\geq 3 \times 10^{13}$ ev can be explained by statistical fluctuations is less than 3%. This result indicates clearly that the character of nuclear interactions changes at $\sim 3 \times 10^{14}$ ev.[3] According to this assumption, primaries of $> 3 \times 10^{14}$ ev lose their energy on the production of secondary particles in the first interaction and are absorbed in the atmosphere sooner than particles of lower energies.

In conclusion, the authors express their gratitude to Prof. N. A. Dobrotin and G. T. Zatsepin for helpful discussion of the results.

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ELASTIC SCATTERING OF 5 TO 22 Mev POSITIVE PIONS BY CARBON

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THE cross sections for the elastic scattering of pions by light nuclei at energies above 30 Mev have been obtained experimentally. It was difficult to investigate the scattering of slower pions by the method previously used, although such data are required to give a complete picture of interactions between pions and nuclei. Low-energy pion scattering is naturally studied in light nuclei, where the Coulomb forces are relatively small. We have investigated the elastic scattering of 5- to 22-Mev pions in carbon, using a 750 cm^3 propane bubble chamber.[1] The chamber was irradiated by a positive pion beam from the synchrocyclotron of the Joint Institute for Nuclear Research. The investigated energy interval corresponds to residual pion ranges in propane from 0.125 to 2 g/cm^2. Pions were identified from $\pi \rightarrow \mu \rightarrow e$ decay after stopping in the working material of the chamber. We used 5675 photographs of tracks of pions stopped in the chamber in the analysis. We did not study star production by 5- to 22-Mev pions. It must be noted that the observed scattering of 5- to 22-

Mev pions is elastic. There is very little inelastic scattering of positive pions at such energies. For example, inelastic scattering on emulsion nuclei is practically zero at 30 Mev.[2–4] We also have indications that inelastic scattering diminishes with decreasing energy in carbon.[5,6]

We measured the angular projections of singly-scattered pions on the plane of the photographic film. Out of the 5675 pions, 75 were scattered in the given energy interval at an angle with a projection greater than 15°. After taking Coulomb scattering into account we found that 31 particles underwent nuclear scattering. In order to determine the nuclear scattering cross section in carbon we took into account: (1) Pion scattering (Coulomb and nuclear) by hydrogen contained in the propane; (2) possible imitation of $\pi \rightarrow \mu - e$ decay by muons (10 to 20% muon admixture in the beam); (3) transmission of the chamber (unequal probability that the chamber would register scattering at a given angle for different energies); (4) imitation of single scattering by multiple scattering, and also superposition of multiple scattering on single scattering. Special attention was devoted to determining the boundaries of the angular and energy intervals, and account was taken of the statistical transfer of particles to adjacent intervals due to inaccurate determination of angles and energies (the accuracy of measurement was 2° for angles and 10% for energies). Coulomb scattering in carbon and hydrogen was calculated by the Rutherford formula, which was projected on the plane:

$$\frac{d\sigma(\varphi)}{d\varphi} = 0.8139 \frac{32 Z^2}{\pi (p\beta c_{\text{Mev}})^2} \frac{\sin\varphi + (\pi - \varphi)\cos\varphi}{\sin^3\varphi} 10^{-26} \frac{\text{cm}^2}{\text{rad}},$$

where φ is the projection of the angle of pion scattering.

The table gives the cross sections for elastic nuclear scattering of pions which were obtained in the present work as well as data taken from other authors. It can be seen that at 8 to 22 Mev the cross section does not differ within the limits of error from the result obtained at 33 Mev. At 5 to 8 Mev a considerable growth of the scattering cross section is observed. It is significant that at these energies the pion wavelength already exceeds the radius of the carbon nucleus. For a 6-Mev pion $\lambda\!\!\!^{-} = 4.78 \times 10^{-13}$ cm whereas the radius of the carbon nucleus is $R = 3.2 \times 10^{-13}$ cm. We know that in the limiting case, when the particle wavelength $\lambda\!\!\!^{-} \gg R$, the elastic cross section for a sufficiently high potential $+V$ approaches 4 times the geometric cross section. (At low energies the potential is positive since repulsion occurs, as follows, for example, from work on mesic atoms.[13]) The observed increase of the cross section can evidently be attributed to this effect. However, at 5 Mev the pion wavelength is still comparable with nuclear dimensions and in our case we must consider both S and P waves, especially since the angular distribution of particles undergoing nuclear scattering is directed forward. The energy dependence of the cross section and the angular distributions will be analyzed at a later date.

Elastic scattering of pions by carbon

Energy interval, Mev	Sign of pion	Angular interval, degrees	Elastic scattering cross section, 10^{-27} cm (nucl.)	Author
5–8	+	>15	402±152	Our data
8–15	+	>15	78±45	
15–22	+	>15	56.0±32	
5–22	+	>15	97±27	
33	+	>10	96±30	[7]
46	+	> 0	182±46	[7]
35–60	+	>20	78±23	[8]
52–72	+	>20	89±10	[9]
68	+	> 0	112±20	[7]
90	—	>15	240±30	[10]
125	—	>20	179±18	[11]
230	—	>10	200±32	[12]

We may note in conclusion that for the purpose of verifying the correctness of pion energy determination from the residual range we determined the energies of decay muons in 120 instances. The muon range in propane was 3.15 ± 0.02 mm for a propane density of 4.00 ± 0.05 g/cm^2 (at 67°C and pressure between 5 and 6 atmos), which corresponds to the muon energy $E = 4.10 \pm 0.04$ Mev.

We take this opportunity to thank Prof. A. I. Alikhanian for his interest and Prof. V. P. Dzhelepov for making the synchrocyclotron of the Joint Institute for Nuclear Research available.

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STATISTICAL INTERPRETATION OF EXPERIMENTAL DATA ON MULTIPLE PRODUCTION OF PARTICLES AT 1 TO 20 Bev

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THIS communication presents a comparison of experimental data on multiple particle production in nucleon-nucleon and pion-nucleon collisions at a few Bev with Fermi's statistical theory.[1] In the calculations two forms of this statistical theory were employed (for details see the review paper, Ref. 2), — with and without account being taken of resonant nucleon-pion interactions through the introduction of isobaric states.[3] The radius of the effective volume is taken to be $\hbar/\mu c = 1.4 \times 10^{-13}$ cm. The methods developed in Ref. 4 were used to calculate the statistical weights.

The table gives the experimental[5,6] and theoretical distributions of p-p collisions at different energies according to the number of generated pions (W_n is the percentage of cases with the production of n pions).

Maenchen et al.[7] investigated interactions between negative pions and protons at 4.5 to 5 Bev and detected 61 2-prong events, 43 4-prong events and 2 6-prong events. The "isobaric" version of the statistical theory gives 64, 39, and 3 as the corresponding numbers, while the "nonisobaric" version gives 70, 35 and 1.

The momentum spectra in the center-of-mass system which are given in Ref. 7 are also in good agreement with the isobaric version (Figs. 1 and 2).

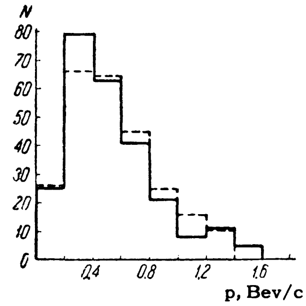

FIG. 1. Experimental[7] (solid line) and theoretical (dashed line) momentum spectra of secondary charged pions in the c. m. system from π^-–p collisions at 4.5 to 5 Bev.

$\bar{p}_{exp} = 0.54$ Bev/c; $\bar{p}_{theor} = 0.55$ Bev/c; $N_{tot} = 253$

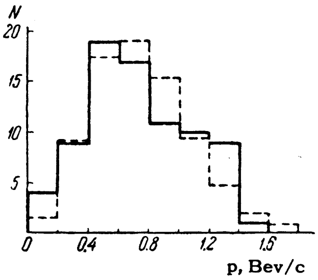

FIG. 2. Experimental[7] (solid line) and theoretical (dashed line) momentum spectra of secondary protons in the c. m. system from π^- – p collisions at 4.5 to 5 Bev.

$\bar{p}_{exp} = 0.74$ Bev/c; $\bar{p}_{theor} = 0.75$ Bev/c; $N_{tot} = 80$

We also calculated the distributions according to the number of secondary particles and the momentum spectra for nucleon-nucleon collisions at an average energy of 20 Bev, for comparison with experimental results[8] on nuclear interactions between cosmic-ray protons and Be, which in most cases can be regarded as nucleon-nucleon interactions. Unfortunately the experimental material does not permit a sufficiently reliable comparison of the experimental and theoretical secondary-particle distributions. However the momentum spectra for the experimentally observed multiplicities agree within statistical errors.

Our calculations confirm an earlier conclusion[2] (from an analysis of data on p-p, n-p and π-p collisions at energies different from those used here) that the Fermi theory including isobaric states gives a satisfactory description of multi-

Energy (lab. system), Bev	$W_1 : W_2 : W_3 : W_4$		
	Experimental	Theoretical (with isobaric states)	Theoretical (without isobaric states)
0.8 [5]	100 : 0 : 0 : 0	100 : 0 : 0 : 0	100 : 0 : 0 : 0
1.5 [5]	80 : 20 : 0 : 0	69 : 30 : 1 : 0	94 : 6 : 0 : 0
2.75 [5]	36 : 48 : 16 : 0	31 : 49 : 17 : 3	78 : 20 : 2 : 0
3.0 [6]	$(42^{+27}_{-25}) : (45^{+25}_{-29}) : (12^{+8}_{-5}) : (1^{+4}_{-0})$	25 : 46 : 25 : 4	68 : 31 : 1 : 0