neutrons by Pb^{206}. Since the ground state of the even-even nucleus Pb^{206} is " + 0 " and the thermal neutron has no orbital momentum, Pb^{207} is formed in a + ½ state. Under these conditions, γ-transitions to the $p_{1/2}$ ground state and the 870 kev $p_{3/2}$ state must be of the electric dipole type (the spin changes by one and the parity changes), and since the energies involved in these transitions, 6.73 mev and 5.86 mev, differ little from each other, they should have almost the same intensity.

In actuality only a γ-transition to the ground state is observed in the capture of a thermal neutron by Pb^{207}.[14,15]. The absence of a γ-transition to the $p_{3/2}$ level can be explained by the fact that the radiative capture of thermal neutrons takes place without the formation of a compound nucleus, as a result of which the excitation of $p_{3/2}$ hole-levels is improbable.

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Possibility of Formation of Penetrating Radiation (μ-Mesons) in the Collision of High Energy Protons with Nuclei

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It is well known that the interaction of slow μ-mesons with nuclei is extremely small[1]. The process of capturing slow μ^--mesons is assumed to be written in the form[2]

$$\mu^- + p \rightarrow \nu + n. \quad (1)$$

Information about the interaction of fast μ-mesons is less certain. In the work in references 3 and 4 it was discovered that for energies exceeding 100 mev, μ-mesons underwent an anomalously greater scattering. The cross section for the anomalous scattering was considerably greater than $10^{-28}cm^2$/nucleon, and is in marked disagreement with the existing theory of scattering of these particles in the Coulomb field of a nucleus with a finite radius. Some authors have assumed that the presence of an anomalous scattering indicates the possibility of a non-coulombic interaction for fast μ-mesons and nuclei.**

The starting point of the present work was the assumption that the anomalously large scattering cross section for μ-mesons was due to a specific nuclear interaction. Such a strong interaction cannot be caused by an extremely small probability process of emission by nucleons of μ and ν particles, i.e., processes which are responsible for reaction (1). Generally speaking, the mechanism of scattering of fast μ-mesons by nucleons cannot appear in processes of absorption of slow μ^--mesons, since the probability of capturing slow μ^--mesons by nuclei is extremely small ($\sim 10^6 sec^{-1}$ for $Z\sim 10$). It is not difficult to see that a strong interaction may be caused by only virtual processes of emission by nuclei of two particles (μ,χ) where the mass of the particle χ may not be less than the μ-meson mass.

It is natural to come to the conclusion that the scattering of μ-mesons depends on the interaction between the nucleon field and the field of a pair of μ-mesons corresponding to the virtual process:

$$(N) \rightarrow (N) + (\mu, \mu) \quad (N\text{—Nucleon}). \quad (2)$$

The possibility of a sufficiently strong pair interaction has already been implied many times[6].

In particular, Wentzel[7], proposed a structural theory of π-mesons based on a pair interaction of μ-mesons (μ^+,μ^- or $\mu^{\pm},\mu^{\circ}$)

In the present work it was assumed that the virtual process (2) took place. Moreover, it was assumed that the coupling constant has a value sufficient to explain the "anomalous scattering" and it was considered that, in addition to charged mesons, there also exist hypothetical neutral μ°-mesons. Under these assumptions, the cross section for μ°-meson formation by collisions of protons with nuclei, when the relative energy considerably exceeds the threshold for formation of a pair of μ-mesons, must be 1-10 % of the cross section for formation of π-mesons. An experiment is described below in which an attempt was made to detect μ°- mesons.

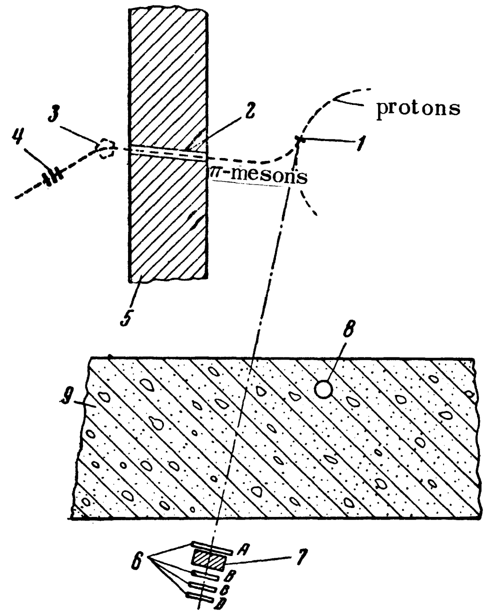
The fundamental property of the hypothetical μ°-meson followed from the "anomalous scattering" of μ-mesons as was done above. It is natural to suppose that the cross section $\sigma(\mu^{\circ}\to\mu^{\pm})$ for the process of exchange scattering of μ-mesons by nucleons

$$\mu^0 + N \to \mu^{\pm} + N, \tag{3}$$

is, as an order of magnitude, the same as the cross section for the usual scattering of charged mesons by nucleons ($\gtrsim 10^{-28}$ cm^2/nucleon if the original assumptions are correct). In connection with this we carried out an experiment to detect μ°-mesons as the products of conversion according to reaction (3).

It is characteristic that the value of the cross section $\sigma(\mu^{\circ}\to\mu^{\pm})$ ($\approx 10^{-28}$cm^2/nucleon) turns out, on the one hand, to be sufficiently small, so that it gives rise to the large penetrability of μ^o -mesons (the mean free path equals several meters of iron) and on the other hand it is sufficiently large so that the μ°-mesons can be detected as a product of this conversion. The large penetrability of this hypothetical radiation permits setting up an experiment for detecting it through the shield of the accelerator, where the background of neutrons is very small. One can expect that at a distance of 40m from the irradiated target of the synchrocyclotron the flux of μ°-mesons $\Phi(\mu^{\circ})$ is approximately 1 cm^{-2} sec^{-1} if, of course, it is understood that the assumptions are correct. The estimate of the flux of $\mu^{\pm}$-mesons, emerging from a thick converter, set at a distance of 40m from the target of the synchrocyclotron, gives $\Phi(\mu^{\pm}) \sim 0.5$ cm^{-2}min^{-1}.

"The detector of μ°-mesons was a telescope, consisting of a triple bank of proportional counters, connected in coincidence (resolving time 9.3 μ-sec). The effective area of each of the banks is 256 cm^2. An additional bank of proportional counters of effective area 576 cm^2 was placed in front of the converter (a copper block 16 cm thick or a steel block 20 cm thick. It worked in an anti-coincidence system and served to decrease the background of charged particles. The distance between the outside group of counters connected in coincidence was 80cm.



Experimental Arrangement. *1*-target; *2*-collimator; *3*-deflecting magnet; *4*-telescope of scintillator detectors, used as a monitor; *5*-iron shield; *6*-telescope of proportional counters, serving as a "detector of penetrating radiation"; *7*-converter; *8*-counter, filled with BF_3; *9*-concrete shield.

The fundamental part of the measurement was made at a time when the synchrocyclotron was used for other experimental work, in which it generated a beam of π-mesons. The carbon target of the synchrocyclotron (2.5 mm thick) was bombarded with protons of energy 670 mev. Charged π-mesons (see Figure) deflected by the fringing field of the accelerator, proceeded through the collimator, were focused by the auxiliary magnet and then were detected by the telescope of scintillating counters. The readings of this telescope in our experiment gave us the possibility of controlling the intensity of the circulating beam of protons. "The detector of μ°-mesons" was situated behind a set of three concrete walls, which in the figure is represented schematically in the form of a single block 8m thick. The distance from the target, exposed to protons, to the detector was 38m. The telescope was aligned tangentially to the equilibrium orbit of the circulating proton beam.

The experimental data are given below

	With accelerator off	With accelerator switched on to full intensity
Triple coincidence counts in 10 min	1.11 ± 0.26	1.36 ± 0.31
counts of the first group of counters in 1 min	1582 ± 4	1821 ± 6

As is readily seen, the increase in the counts due to the accelerator is very small. Apparently, it is produced by the diffuse secondary particles originating from the background of neutrons in the shield. The background of chance coincidences is negligibly small. It is determined by the method of out-of-alignment coincidences. The efficiency of the charged particle telescope was determined in a separate experiment. In the limiting case, when it is assumed that the increase in triple coincidences is due entirely to the emission of μ°-mesons from the target, we may on the basis of the given data obtain an upper limit for the flux of $\mu^{\pm}$-mesons originating in the converter. In this way we find that $\Phi(\mu^{\pm}) \ll 3 \times 10^{-3}\text{cm}^{-2}\text{min}^{-1}$. This value is two orders of magnitude smaller than that which was expected in the original assumption. In another experiment where the protons bombarded a beryllium target, we found an analogous result. The conversion of the μ°-mesons in this case took place in a steel block 20cm thick, and with a monitor using a counter filled with BF_3.

To estimate the maximum fraction of μ° -mesons from the recorded effect (see above) we conducted a supplementary experiment. "The detector of μ°-mesons" was turned relative to its initial direction by an angle of 60°. In this way the detection of charged products of the conversion of μ°-particles never took place because the anomalous scattering, according to the experimental data, took place chiefly at small angles. It was found that, within the limits of error of the experimental data obtained with the rotated detector, the results agreed with the data given above. This allowed one to come to the conclusion, that the principle part of the counts detected in this experiment consisted of the background. Nevertheless in the estimate of the upper limit of the cross section for formation of a pair $\mu^{\pm},\mu^{\circ}$ mesons we assumed that the effect was completely due to μ°-mesons.

The upper limit for the value $\sigma^{\mu\mu^{\circ}}_{NN}$ (the cross section for the emission of a pair from the collision of two nucleons at a relative energy of 680 mev) was estimated by the use of the assumptions-a) the angular distribution of μ-mesons originating in nucleon-nucleon collisions is isotropic in the center of mass system, b)the mean energy of μ°-mesons in the laboratory system ≈130mev, c) the cross section for exchange scattering $\sigma(\mu^{\circ} \to \mu^{\pm}) \sim 10^{-28}\text{cm}^2/$ nucleon. It was found that $\sigma^{\mu\mu^{\circ}}_{NN} \ll 7 \times 10^{-31}\text{cm}^2/$ nucleon, i. e, four orders of magnitude smaller than the value of the cross section for the formation of π-mesons.

The result obtained allows one to reach the following conclusions: 1) "The anomalous scattering"** of μ-mesons cannot be explained by an interaction between the nucleon field and the pair field (μ,μ°). 2) The "structural" theory of π-mesons proposed by Wentzel apparently does not conform to reality. 3) The contribution to the pair interaction (μ,μ°) to the nuclear force is insignificant ($\lesssim 10^{-3}$ of the contribution of the π-mesons).

At the time of completion of the present work there was published the work in reference 8 in which an attempt was made to detect pair formation of charged μ-mesons by photons of energy 345 mev on nuclei of Al and Be. The authors came to the conclusion that the relative strength of the interaction (μ^{+},μ^{-}) was similar to our conclusions on the interaction $(\mu^{\pm},\mu^{\circ})$.

This report is based on the results of the work completed in 1954 and previously reported in reports of the Institute for Nuclear Problems, Acad. Sci. USSR.

** It has recently been the custom to consider that anomalous scattering was explained rather as a deficiency of the existing theory of coulomb interaction than as a specific nuclear interaction of μ--mesons.

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Formation of Neutral π-mesons in $(n-p)$ Collisions at Effective Neutron Energies of 590 mev

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THe kinematic calculation of the processes of formation of π^0-mesons in collisions of neutrons with free protons:

$$n + p \rightarrow \pi^0 + d, \quad (1)$$

$$n + p \rightarrow \pi^0 + n + p, \quad (2)$$

which are accompanied by the decay of these mesons into two γ-quanta shows that the probability of emission of the γ-quanta at 90° (in the laboratory system) from the beam of neutrons, depends very slightly on the angular distribution of π^0-mesons in the center of mass system of the colliding nucleons as well as on the velocity of the center of mass. This fact makes it possible in principle to determine the sum of the total cross sections for forming π^0-mesons in reactions (1) and (2) by measuring the number of γ-quanta coming out of the target at an angle of 90°.

The arrangement of the apparatus, used in the experiment, is shown in Fig. 1. Neutrons of high energy were generated by bombarding the internal beryllium target of the synchrocyclotron with protons of energy 680 mev. The intensity of the beam of neutrons of energy above 400 mev in the region of the apparatus was ~ 1-2 $\times 10^4$ neutrons/cm^{2}sec. The energy distribution of neutrons in the beam was investigated in a special experiment by Fliagin[1] and is shown in Fig. 2.

Gamma-quanta from the decay of π^0-mesons, generated in the target, were detected in the telescope of two scintillators and one Cerenkov counter labeled in the Figure by the numbers 1, 2 and 3, respectively. The conversion of the

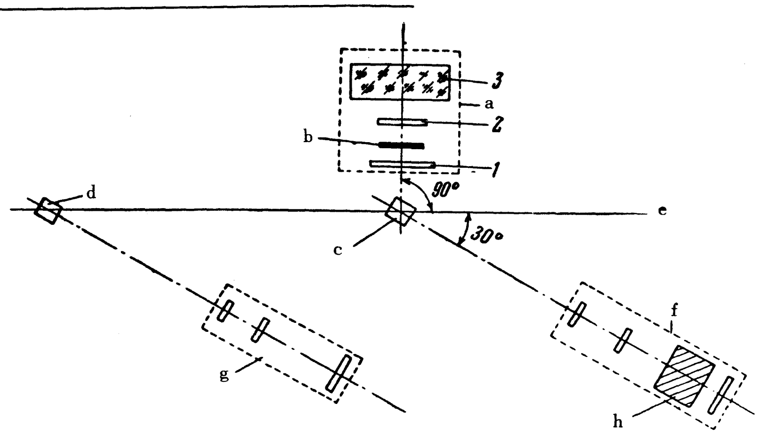

FIG. 1. Scematic Arrangement of the Apparatus
a - telescope-detector of γ-quanta, b - converter, c - target, d - scatterer, e - neutron beam, f - telescope-detector of protons, g - telescope-monitor, h - Tungsten filter