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Production of Neutrons by the Capture of Cosmic-Ray Mesons at Sea Level*

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SEVERAL cases of nuclear disintegrations caused by the capture of mesons have been observed in photographic emulsions exposed to cosmic radiation at altitudes of approximately 3500 meters. One to five heavy, charged particles are emitted in this process. Mesons responsible for these events have been designated as σ- (or negative π-) mesons and are believed to have masses of approximately 300 electron masses. At the same altitude more than ten times as many mesons reach the end of their range in the emulsion without producing visible secondary tracks. The latter mesons are designated as ρ- (or positive and negative μ-) mesons and are supposed to be identical with the mesons of mass 200 which predominate at sea level.[1] No disintegrations caused by the capture of cosmic-ray mesons have been found at sea level in photographic emulsions. Several cases of negative mesons reaching the end of their range in the gas of a cloud chamber or in thin iron or lead foils inside the chamber have been observed at sea level. In no case were heavy particles observed starting at the end of the meson track.[2]

Experiments using G-M counters indicate that the capture of light cosmic-ray mesons is not accompanied by the emission of photons with energies above 30 Mev.[3]

In the investigation to be described, an attempt was made to obtain information concerning the capture of mesons at sea level by making a search for neutrons emitted during this process. This constitutes a new approach to the problem of meson-induced nuclear disintegrations through observing the emission of one or more neutrons which are not accompanied by charged heavy particles. By using materials of high atomic weight, fission induced by slow mesons could be detected in this way.[4]

Our apparatus consists of a fourfold coincidence counter telescope in which the incident mesons are deflected in magnetized iron plates. The arrangement distinguishes between positive and negative mesons but is not sufficiently selective to distinguish between particles of 200 and 300 electron masses. All mesons traversing the telescope impinge at a glancing angle upon a 1-cm lead stopping plate surrounded by a *V*-shaped bank of G-M counters allowing the entrance of the mesons on top. Below the *V* bank and interposed between two 8-cm-thick slabs of paraffin were located four BF_3 proportional counters containing boron of a 96 percent concentration of B^{10}.[5] Each time the telescope is tripped, a 20-microsecond oscillograph sweep is triggered and photographed. The *V* bank of G-M counters and the BF_3 counters produce separate and distinguishable pulses on the oscillograph trace, so that if either or both is tripped with the 20-microsecond interval, this information along with the corresponding time delays is recorded on the photograph.

Any fourfold coincidence followed by a neutron counter pulse and not accompanied by a *V*-bank pulse corresponds to stoppage of a meson in the lead plate with the resulting ejection of a neutron. Two types of processes besides neutrons produced in the capture of a meson could cause a "neutron" pulse to appear on the sweep; namely, cosmic-ray showers containing neutrons,[6] or showers containing a density of charged particles sufficient to trigger the BF_3 proportional counters. Both processes are recognizable since

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[1] C. M. G. Lattes, G. P. S. Occhialini, and C. F. Powell, Nature **160**, 453 (1947), and **160**, 458 (1947).

[2] T. H. Johnson and R. P. Shutt, Phys. Rev. **61**, 380 (1942); W. Y. Chang, Bull. Am. Phys. Soc. **23**, 42 (1948).

[3] O. P. Piccioni, Phys. Rev. **73**, 411 (1948); Bull. Am. Phys. Soc. **23**, 42 (1948).

[4] It was predicted by J. A. Wheeler (Bull. Am. Phys. Soc. **23**, 20 (1948)) that slow ordinary negative mesons could probably produce fission in uranium and with reasonable probability in heavier elements where the energy available exceeds with greater certainty the threshold for fission.

[5] The concentrated B^{10} was secured through the isotope branch of the Atomic Energy Commission at Oak Ridge, Tennessee.

[6] Vanna Tongiorgi, Phys. Rev. **73**, 923 (1948).

in either case at least one of the V-bank counters would be tripped simultaneously with the telescope. In the first case the neutron pulse would be delayed a few microseconds because of the slowing down of the neutron in the paraffin.

Out of 1167 negative mesons stopped in the lead plate, four were accompanied by neutron counter pulses having time delays of 1.6, 1.8, 5.6, and 8.2 microseconds after the telescope was traversed. No neutron pulses were observed during the stoppage of 688 positive mesons nor in the stoppage of 148 negative mesons where in the latter case the neutron counters were shielded by 1 mm of cadmium between paraffin and counters. In the course of the investigation 20 neutron counter pulses appeared which were accompanied by the discharge of at least one of the G-M counters of the V-bank. These neutron pulses were not delayed and their statistics were unaffected by the polarity of the magnetic telescope or the presence of cadmium surrounding the neutron counters.

The efficiency of the neutron counter arrangement for registering neutrons of several Mev created at the position of the stopping plate was determined by placing a Ra-Be neutron source of known intensity at this position. If, furthermore, account is taken of the fact that we register only those neutrons leaving the paraffin within 20 microseconds after the capture of the meson, while the mean transit time of the neutrons through the paraffin is of the order of 100 microseconds,[7] it follows that approximately two neutrons are produced per negative meson captured in lead. This number would be even higher if the neutrons are produced with energies exceeding ten Mev. Whether they are accompanied by heavy charged particles cannot be determined from our experiments. If one assumes that the appearance of neutrons indicates nuclear disruptions leading to the emission of several charged particles and say an average of four neutrons, approximately two meson captures would lead to one disintegration. Because of the poor statistics and other uncertainties, these numbers represent only the order of magnitude for this process. Since the number of heavy mesons at sea level is negligible, the produced neutrons are due to the capture of the light mesons. The appearance of neutrons might, on the other hand, indicate the fission of the lead nucleus as a result of the capture of light mesons rather than a disintegration resulting in the emission of several heavy particles. An attempt will be made to settle this question by using materials of different atomic weights for stopping the mesons.

[7] J. Rainwater and W. W. Havens, Jr., Phys. Rev. **70**, 136 (1946).