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III-5-15. Neutron Production by Cosmic Ray Muons

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Introduction

The production of evaporation neutrons by fast muons was first reported by Sard (1950) and since then the subject has been extensively studied, mainly by Sard and his colleagues. The neutrons arise from two distinct processes. In the first, the muon strikes an electron which produces an electron-photon cascade and neutrons are generated in ensuing (γ, n) reactions. In the other process there is a direct interaction between the charge of the muon and the nucleons of the material; the mechanism is often interpreted in terms of the interaction of virtual photons accompanying the muon, their number being calculated from the Williams-Weizsäcker approximation. Studies of the muon interactions are therefore useful in that they effectively give information on the interactions of high energy photons.

In the present work, which uses muons from the cosmic radiation, studies are confined to negative particles in order to eliminate possible ambiguities arising from proton interactions. Attention is focussed particularly on the variation of the total cross-section with muon momentum.

Experimental Arrangement

The arrangement is shown in Fig. 1. The spectrograph, in the form modified for the present experiment, comprises three detecting arrays, two above and one below a large electromagnet. Each detecting array consists of a tray of geiger counters and eight layers of neon flash tubes. The maximum detectable momentum is 150 Gev/c when the magnet is operated at maximum current.

The neutron detector is a standard *IGY* pile containing lead and paraffin wax. The

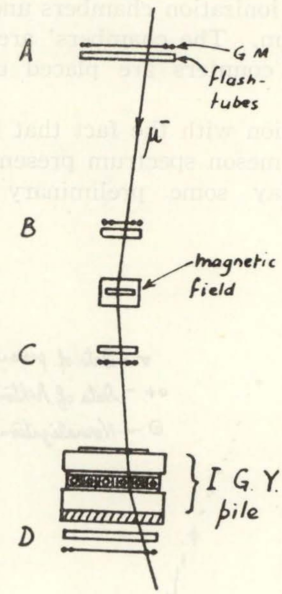

Fig. 1.

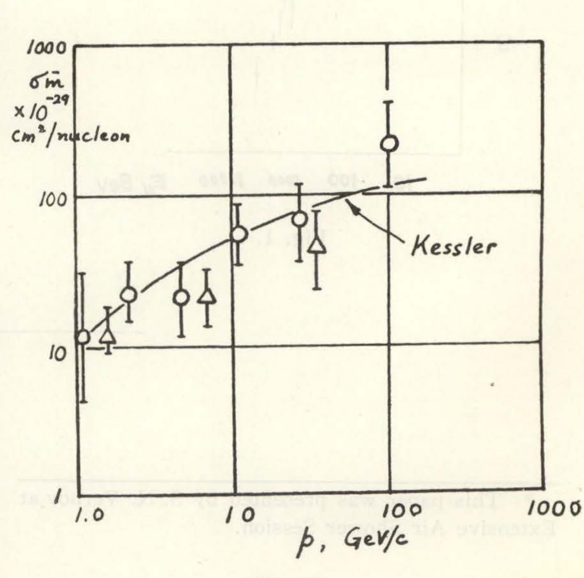

Fig. 2.

mean thickness of lead in the pile is 13.2 cm. Beneath the pile there is a further 11 cm of lead and the final detecting layer of the original spectrograph. This layer is valuable in giving information on the charged particles emerging from the interactions.

The sequence of events was as follows: 20 μ sec after a particle passed through the spectrograph a gate was opened for 230 μ sec (or 680 μ sec in the second experiment) and if a neutron occurred during this period shutters were opened and the flash-tubes photographed. The number of detected neutrons was also recorded.

Results

Events were selected in which a single negative particle traversed the arrays A, B and C and the predicted position of the track in D, assuming no interaction or scattering in the pile, was calculated. The events were then allocated according to the information given by array D. The events of interest here are those where either a single track is seen in D close to the the predicted position or a shower. A correction is necessary for chance coincidences between a muon and a neutron in the pile. The correction is applied only to those events where the separation of observed and predicted positions in D can be accounted for my multiple scattering.

The product of cross-section and average multiplicity has been found for bands of momentum with the result shown in Fig. 2. Also shown is the expected variation, for both direct interaction and the knock-on effect, calculated using the Williams-Weizsäcker approximation as modified by Kessler and Kessler (1957). It has been assumed that the product of photo-nuclear cross-section and average multiplicity is as given by de Pagter and Sard (1960).

Conclusion

Fig. 2 shows that there is good agreement between theory and experiment for the production of neutrons by negative muons in the momentum range 1-100 Gev/c.

References

P. Kessler and D. Kessler: Compt. Rend. **244** (1957) 1896.

R. D. Sard: Phys. Rev. **80** (1950) 134.

J. de Pagter and R. D. Sard: Phys. Rev. **118** (1960) 1353.

Discussion

Kitamura, T.: If you put a suitable cut off in the Heitler expression, how is the results?

Wolfendale, A. W.: The expected cross-section is a little higher but not inconsistent with the experimental results.

Ozaki, S.: What is the values of $\sigma_{h\nu-\pi}$, you used?

Wolfendale: We assume that the experimental values found with real photons can be used. For example, following de Pagter and Sard, we take

$$\bar{m}=2\times10^{-27}E_{\gamma}\ \mathrm{cm^2/atom}.$$