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# III-5-18. Scattering of Cosmic Ray Muons with Momenta between 300 and 1000 Mev/c in Lead Tin and Iron*

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A counter hodoscope experiment on the scattering of cosmic ray muons in lead, tin and iron is described. The momentum region 0.3 to 1 GeV/c was divided into three ranges. Only three lead distributions are shown in this paper. It was observed that the scattering is in agreement with Cooper and Rainwater's theory.

## 1. Introduction

A large number of various experiments indicate that the interaction of muons with matter is purely electromagnetic. This view is not supported by some experiments on the scattering of muons since more particles were reported to be scattered through large angles than would have been expected on the basis of pure Coulomb effects. The observed multiple scattering distributions are very similar to the predictions of Moliere's theory of multiple scattering by a point nucleus. This effect has become known as anomalous scattering. The situation prior to 1958 was reviewed by Fowler and Wolfendale[1]. Some of the recent experiments in agreement with the excess scattering at large angles[2,3,4], whereas other experiments on 1 Gev/c and 2 Gev/c muons have not shown this anomaly[5,6] but appears to be in agreement with theories of multiple Coulomb scattering from finite nuclei.

Previous workers have observed that the scattering changes from normal to anomalous in the region from about 300 to 1000 Mev/c and the experiment to be described is concerned with the scattering of cosmic ray muons in this potentially interesting region.

## 2. Experimental Details

A hodoscope system of Geiger counters, (A, B and C in Fig. 1), was used to determine the directions of the trajectories of muons before and after scattering. The scatterer was placed at system B while the momenta were determined from the residual range of the muons in the lead absorbers I and II, Fig. 1. Details of the experimental arrangement were discussed elsewhere[7,8].

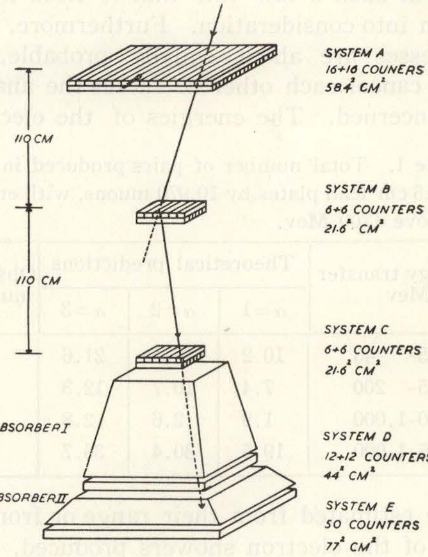


Fig. 1. The experimental arrangement.

It was shown[7] that the scattering function, $f(\phi)$, at an angle $\phi$ is given by

$$f(\phi)+1/4(a/L)^2[f''(\phi)+f'(\phi)/\phi]+\text{higher order noise terms}=\text{const.}\ N(\phi)/\sum \nu_k G_k$$

where $N(\phi)$ represents the total number of particles scattered through the angle $\phi$, while $\sum\nu_k G_k$ is the acceptance of the apparatus. $L$ is the distance between the systems A, B and B, C, whereas $a$ is the diameter of the counters. The experimental distribution as calculated from $N(\phi)/\sum\nu_k G_k$ was compared with theoretical distributions treated as dictated by the left hand side of the above equation including both first and second

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order noise terms and integrated over the momentum spectrum of the accepted particles. The theoretical distributions are not very sensitive to reasonable possible distortions of the accepted spectra. This is so because of the relatively narrow momentum ranges. The latter are shown in Fig. 2. The straggling was calculated from formulae given by Sternheimer[9]. The momenta referred to in these distributions represent the values in the middle of the scatterer.

If the efficiency of the anticoincidence system $E$ is not high, muons of momenta higher than the calculated values will be recorded. These muons will contribute heavily to the small angle region and will give rise to a distribution which decreases faster with increasing angle than would have been the case in an ideal experiment. Apart from this, particles will be scattered out of the beam in absorbers I and II. This may also distort the required angular distribution. Spurious events such as casual coincidences and knock-on electrons produced by muons can simulate scattered muons. High energy contamination amounts to about 2% of the accepted rate and spurious events constitute about 0.1% of the observed muons. The angular distributions were fully corrected for these small effects.

The effect of the zenithal variation of the muon intensity, and the proton contamination which was determined, was shown to have a negligible effect on the observed angular distributions.

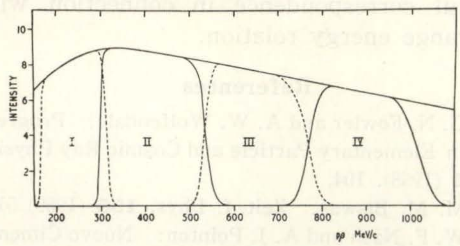


Fig. 2. Momentum spectrum of muons. The ranges are as follows: I: 165-312, II: 298-539, III. 533-773, IV: 773-1020 Mev/c. The experimental scattering distributions for ranges II, III and IV only are shown in this paper.

### 3. Discussion

Three experimental scattering distributions for lead are shown in Figs. 3, 4 and 5. The errors quoted are the Poisson fiducial limits[10]. It is seen that the results are in agreement with Cooper-Rainwater's theory[11] of multiple scattering by finite nuclei expressed in terms of the spatial angle[12].

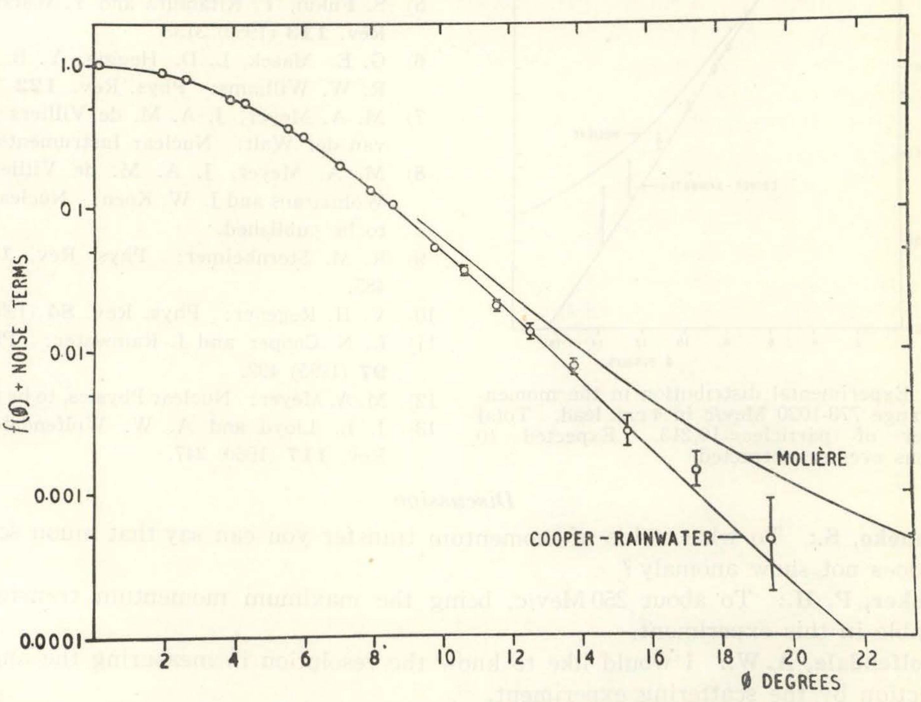


Fig. 3. Experimental distribution in the momentum range 298-539 Mev/c in 2 cm. lead. Total number of particles=10,000. Expected 10 spurious events subtracted.

Similar conclusions may be drawn from the iron and tin distributions. These results together with those of Fukui *et al*[5] ($1^{+0.15}_{-0.20}$ Gev/c) and Masek *et al.*[6] (2.00±0.03 Gev/c) therefore suggest that the scattering of muons is normal and that anomalous scattering does not exist in the momentum region 0.3 to 2 Gev/c. Although the data given by Fukui *et al* were re-examined by Lloyd and Wolfendale[13] and shown to be inconclusive, the present results, (Fig. 5), support Fukui's measurements.

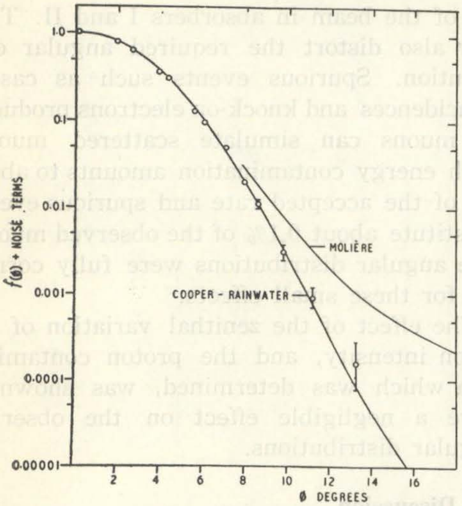


Fig. 4. Experimental distribution in the momentum range 533-773 Mev/c in 2 cm. lead. Total number of particles=10,000. Expected 10 spurious events subtracted.

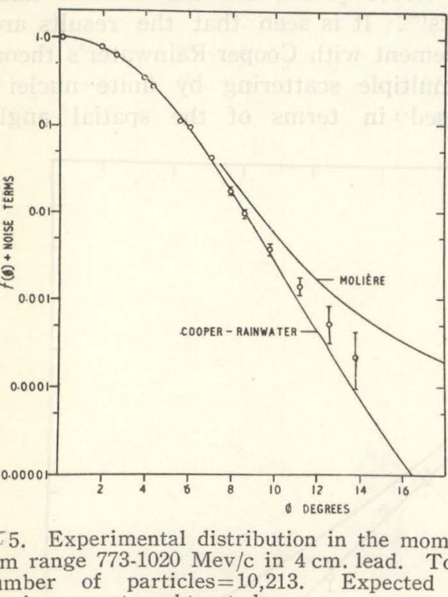


Fig. 5. Experimental distribution in the momentum range 773-1020 Mev/c in 4 cm. lead. Total number of particles=10,213. Expected 10 spurious events subtracted.

## 4. Acknowledgements

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### *Discussion*

**Kaneko, S.:** To what value of momentum transfer you can say that muon scattering does not show anomaly?

**Stoker, P. H.:** To about 250 Mev/c, being the maximum momentum transfer observable in this experiment.

**Wolfendale, A. W.:** I would like to know the resolution in measuring the angle of deflection by the scattering experiment.

**Stoker:** Perhaps 0.5°. The diameter of the G-M counter was 3.6 cm, but the distance was about 2 m.