III-5-17. Direct Electron Pair Production in 0.15 cm Lead Plates by High Energy Cosmic Ray Muons

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Introduction

Direct pair production by charged particles has been investigated for electron and muon primaries in nuclear emulsions and in metal plates contained in Wilson cloud chambers by several investigators[1)2)3)]. These results were compared with Bhabha's theory[4)], with Bhabha's theory as modified by Block *et al*[5)] or with Racah's theory[6)], and more recently with the theory computed by Murota *et al*[7)], using the Feynmann-Dyson method. The modified Bhabha theory gives cross sections for direct pair production less than predicted by the original Bhabha theory, and is in close agreement with Racah's prediction of total cross section[5)]. The Murota theory gives a higher cross section than the modified Bhabha theory for a given primary energy in some regions of transferred energy[1)].

The cross section for direct pair production by high energy muons in lead plates obtained by Roe and Ozaki[1)] and Gaebler *et al*[2)], is about one half that predicted by Murota *et al* (taking the indefinite constant $\alpha=2$). Gaebler *et al* also found that the number of direct pairs decreases less rapidly with increasing energy transfer than the prediction of Murota *et al.*

In order to evaluate the general formula for the transition probability per unit time by integration, Murota et al imposed certain energy limits. Thus they arrived, as Bhabha, at simple formulas for the differential and total cross section which are only applicable in some prescribed energy intervals.

It is assumed by Murota *et al* that the energies of the participating particles are large compared to their respective rest mass energies. We made only one further assumption[11)], namely that the energy transferred to the pair is much less than the primary energy. Under these conditions, eq. (23) of Murota[7)] for the second order differential cross section, became:

$$d^2\sigma=\frac{2}{3\pi}(Z\alpha')^2r_e^2\left[\log\left(\frac{\alpha R(1-v^2)}{\gamma(1+x)^{1/2}}\right)-1\right]\times\left[\{(2+v^2)+(3+v^2)x\}\log\left(1+\frac{1}{x}\right)-(3+v^2)+\frac{1-v^2}{1+x}\right]\frac{d\varepsilon}{\varepsilon}dv \qquad (1)$$

where

σ=cross section,

Z=atomic number,

$\alpha'=\frac{1}{137}$=fine structure constant,

r_e=classical electron radius

$\gamma=\frac{\mu c^2}{E}$, $\gamma_0=\frac{2mc^2}{\varepsilon}$

$R=\frac{\gamma}{\gamma_0}=\frac{\varepsilon}{E}\frac{\mu}{2m}$

ε_+=energy of positron,

ε_-=energy of negaton,

$v=\frac{\varepsilon_+-\varepsilon_-}{\varepsilon_++\varepsilon_-}=\frac{\varepsilon_+-\varepsilon_-}{\varepsilon}$

$x=R^2(1-v^2)$

This formula was integrated by a computor over all values of v for given values of ε, α and R, and compared with our experimental results obtained with a multiplate cloud chamber exposed to cosmic ray muons with energy above 1700 Mev. Formula (1) for the pair production cross section, led to a cross section which was 2 to 3 times smaller than that given by the formula of Murota *et al.*

Experimental Arrangement

The four upper lead plates in the cloud chamber were 0.15 cms thick, the next four were 0.33 cms, while the bottom plate was 1.33 cms. This thick bottom plate facilitates energy estimations, since it allows an electron shower to develop. The experimental set-up is described in more detail elsewhere[8)].

Results

10,970 traversals of muons with energy above 1700 Mev. were selected for analysis according to criteria set for the appearance of the muon primaries on both the direct and mirror photographs. The knock-on electrons and electron pairs produced were selected according to whether respectively one or more than one secondary electron were produced by a muon in a lead plate. Because of the thin lead plates used, any by considering only high energy transfers, double knockon production or the absorption of one of the pair electrons in a plate occurs at such a low rate that it need not be taken into consideration. Furthermore, these processes are about equally probable, and thus cancel each other as far as the analysis is concerned. The energies of the electrons

Table I. Total number of pairs produced in four 0.15 cm lead plates by 10,970 muons, with energy above 1700 Mev.

Energy transfer Mev	Theoretical predictions			Observed number
	$\alpha=1$	$\alpha=2$	$\alpha=3$	
15- 45	10.2	17.1	21.6	9
45- 200	7.4	10.7	12.3	11
200-1,000	1.9	2.6	2.8	5
15-1,000	19.5	30.4	36.7	25

were estimated from their range or from the size of the electron showers produced, using Wilson's Monte Carlo calculations[9].

The results are shown in the table and in the figure. The solid line histograms represent the theoretical distribution (1) integrated over v, for the indefinite constant $\alpha=1$, 2 and 3, evaluated for the cosmic ray muon spectrum above 1700 Mev as found by the Durham magnetic spectrograph[10].

Discussion of the results and Conclusion

There is an overall agreement of the experimental results with the theory. The experimental spectrum seems to be flattened with respect to the theoretical spectrum. Thus too many high energy events were recorded and too few low energy events. This flattening of the experimental spectrum may be due to fluctuation effects in the energy determination for the secondary electrons from absorption or shower production. The

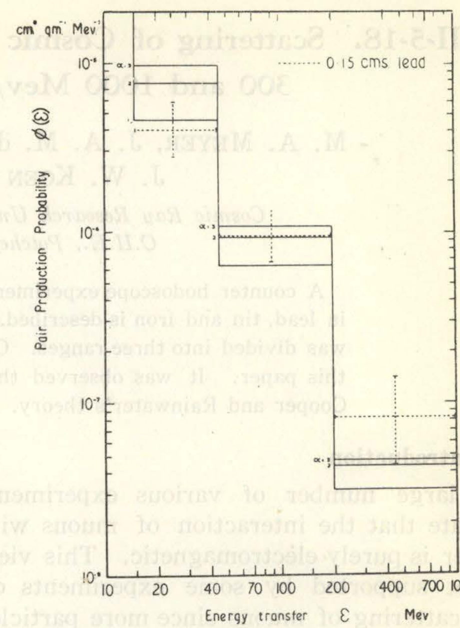

Fig. 1. Solid line histograms represent the evaluations from the theoretical formula (1) for $\alpha=1$, 2, and 3 for the cosmic ray muon energies above 1700 Mev. The experimental points are shown.

total number of pairs observed in the energy region from 15-1000 Mev seems to favour a value between 1 and 2 for the indefinite constant α of the theory. A full report on these results are in preparation for publication.

References

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