The Suppression Effect in Ionization by Fast Electron Pairs (*).

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Summary. — Electron pairs of very high energies (about $10^{11}$ eV) were found by Perkins to have reduced ionizing power near their origin. The reason is that the angle between the two paths is very small so that over appreciable distances they stay close enough together for their electric fields very nearly to cancel except for atoms very close to the line of travel. The present paper gives a quantum treatment of this effect and the deviations from the semi-classical result are found negligible, in spite of the fact that the general conditions for the validity of classical mechanics are not satisfied. The phenomenon can be used to estimate the energy of the pair. The limitations of this method, both fundamental and practical, are discussed.

1. — Introduction.

The suggestion by King (1) that electron pairs of very high energy ($> 10^{11}$ eV), produced in cosmic ray showers, have a reduced ionizing power near their origin, due to the proximity of the two opposite charges and their resultant partial screening has been investigated by Perkins (2) and Wolter and Mięsowicz (3). Their results, while not intended to be primarily a test of any theory, are in accord with simple classical calculations. The effect has an additional interest in that it offers a method for obtaining a measure

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of the energy of the pair which is applicable in a region in which other methods
are difficult and laborious (*).

The object of this paper is to examine this effect from the theoretical
point of view. In Sect. 3 the rate of ionization of the pair is calculated quantum
mechanically, and the relation of this to the primary photon energy is examined
in detail. This raises questions about the nature of the measurement process
involved which are considered in Sect. 4 and 5. In Sect. 4, an evaluation is
made of the classical view of the effect, used by Yekutieli and Čudakov,
and the regions of its validity, and an explanation of the agreement of the
result is found. In Sect. 5 the effect of the interaction on the pair is studied
and the connection with the primary photon energy is considered. In Sect. 6
some numerical results are given as corrections to previous work.

2. - The formulation of the problem.

We wish ultimately to calculate the experimentally observed quantity,
which is the grain density along the track of the pair in emulsion. The concept
of particular physical interest from the measurement point of view is the rate
of ionization, while we shall calculate the rate of energy loss of the pair.
The proportionality of these three quantities is normally assumed on an em-
pirical basis (*) and we shall do that here, mentioning when necessary the
special features of the behaviour of each particular quantity.

The forces being purely electrodynamic, Born approximation is valid in
this energy region, as the expansion parameter

\[ \frac{e^2}{\hbar r} \sim \frac{1}{137} \ll 1. \]

We shall use lowest order perturbation theory in the calculation of all matrix
elements. We shall therefore neglect the interactions between the negatton
and positon of the pair and that between the pair and the nuclear screened
Coulomb field, as these produce no excitation of the atomic electrons in lowest
order. We shall treat the interaction of the atomic electron with the rest of
the atom exactly, using exact atomic wave functions. The perturbation is
the interaction between the pair and the atomic electron.

(*) The results of the measurement of the \( \pi^0 \)-lifetime by Orear (4) suggest that
a re-examination should be made of the experiment of Anand (5), in which the
suppression effect should be included.