IV. Production of Secondary Radiation

On the Theory of Explosion Showers in Cosmic Rays.*

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THE theory of Yukawa contains interaction terms between mesotrons and nuclear particles, which lead to cross sections for the scattering of mesotrons by nuclear particles that increase with increasing energy of the mesotrons. These interaction terms, therefore, permit an application of ordinary quantum mechanics only for small energies of the particles concerned, as, for example, in interaction of heavy particles in the nucleus.

For high energies of the particles one is restricted to the use of the wave equations in the sense of a correspondence principle. Such considerations lead to the result that the collision of particles of very high energy can often lead to the production of many mesotrons in one single act. This result can be illustrated by the theory of electronic radiation given by Bloch and Nordsieck. When a particle of very high energy collides with a proton, then a certain part of the mesotron proper field of the proton is shaken off in the collision. This part of the field would correspond to a small number of mesotrons, which increases only logarithmetically with the energy of the incident particle. In the propagation of the field, however, a strong scattering of mesotrons by mesotrons and a production of mesotron pairs by mesotrons takes place, and can be treated in a way similar to that used for the scattering of photons by photons in quantum electrodynamics. In this way the production of a large number of mesotrons is to be expected.

* Cf. W. Heisenberg, Zeits. f. Physik **113**, 61 (1939) for complete paper.

It can also be shown that the use of the classical equations together with the correspondence principle lead to results for the scattering of mesotrons by protons that are entirely different from those of the quantum-mechanical calculation. This is due to the fact that the proper field of the nuclear particle, which is neglected in the quantum theoretical formulas, provides an additional inertia for the motion of the nuclear particle, which decreases the scattering cross section considerably.

The most general result of such correspondence considerations consists in the conclusion that in the limit of extremely high energies of the incident particles the total cross sections for the production of other particles will tend to a finite value (if no long range forces of the Coulomb type are present). This result can also be expressed in the following way: since in the collision of any two particles other particles can always be produced, the forces between these two particles always have a finite range. So, in spite of the fact that in quantum electrodynamics, for example, the interaction of photons with electrons is assumed to have an infinitely small range (δ-type of force), the virtual possibility of pair production will lead to a finite range for the force between photon and electron. Therefore, the cross sections at very high energies also remain finite and do not decrease to zero. This fact may be important in the discussion of the question as to whether the measurement of position or of distance can be performed with arbitrary accuracy.