On the “Spontaneous pair creation” in strong electric fields of QED

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ABSTRACT

One of the spectacular phenomena of QED is the existence of strong electric fields, which can be achieved experimentally. So far, only relatively weak fields have been created in the laboratory. In high-energy collisions of quarks and leptons, one can create strong fields on a very short time scale. In this paper, we will discuss the implications of a strong electric field for the QED of spontaneous pair creation. We will show that in strong fields, the probability of pair creation is dramatically increased, and the pair creation becomes a resonance.

QED in external fields

Approximation of QED

• As usual, we use the ladder approximation which is the principal approximation for calculations.
• However, for values of the external electric field, we have to include higher-order corrections.

Implementation of the Smatrix in Fock space

• For example, in the case of the Dirac equation, the Hamiltonian operator is given by

Consequences of the approach

• The Hamiltonian of the Dirac equation is given by

Pockspace & the field operator

• The Hamiltonian operator is given by

Spontaneous pair creation

On the “Spontaneous pair creation”

• This means that the number of particles created in state \( \nu \) is given by

Time evolution

• The problem is reduced to the equation of motion for the order parameter \( \phi \), which is given by

Spontaneous pair creation – proof ideas

• The idea of spontaneous pair creation is that the order parameter \( \phi \) is given by

Resonances (continuation)

• The main question is to understand the mechanism of the resonance.
• We will consider the two limiting cases of the resonance.

Experiments

• First, we consider the case of spontaneous pair creation in strong electric fields.
• We will show that in this case, the probability of pair creation is dramatically increased.

The goals

• The main goal of the experiments is to study the effect of the electric field on pair creation.
• The experiments are performed in strong electric fields, and the results are compared to the theoretical predictions.

References


Classical Dirac Equation

Consider a field in time-dependent electromagnetic field \( E(t) \). \( E(t) \)

The Dirac equation is given by

\[ \frac{\gamma^\mu \partial_\mu - i e A_\mu }{2m} \psi = i \frac{\hbar}{2m} \gamma^5 \partial_\mu \psi \]

where \( \gamma^\mu \) are the Dirac matrices.

The spectrum of the Dirac equation is given by

\[ \pm \frac{\hbar c}{2} \sqrt{m^2 + (E(t) \cdot \gamma^\mu \partial_\mu )^2} \]

where \( m \) is the mass of the particle.

Consequence: The spectrum is split into two parts.

\[ \pm \frac{\hbar c}{2} \sqrt{m^2 + (E(t) \cdot \gamma^\mu \partial_\mu )^2} \]

where \( m \) is the mass of the particle.

Spontaneous pair creation

On the “Spontaneous pair creation”

• The pair creation comes entirely from the time variation of the external fields and is therefore not related to a vacuum state.

Towards applications

• The primary goal of a potential change is to understand the effect of the electric field on pair creation.

Future

• The goal of future experiments is to study the effect of the electric field on pair creation.

The goals

• The main goal of the experiments is to study the effect of the electric field on pair creation.
• The experiments are performed in strong electric fields, and the results are compared to the theoretical predictions.

References