Fermion production in early Universe[*]

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We study the production of fermions in the presence of electric and magnetic fields on de Sitter expanding universe, using perturbation theory. From our results we can extract important physical consequences such as, in the case of electric fields the particles are most probable emitted parallel on the direction of the field, while in the case of magnetic fields, the particles are emitted perpendicular on the direction of the magnetic field. Also our results show that, the processes of particle production are significant in the early Universe when the gravitational fields were very strong. Another important result is the Minkowski limit. It is well known that these QED processes are forbidden on Minkowski space because of the simultaneous laws of conservation for energy and momentum. Indeed, when we make the expansion factor zero, our results show that the probabilities became zero as well.

Our purpose is to study processes of pair production on de Sitter space-time in the presence of external electromagnetic fields, using perturbation theory.

The first idea that space expansion can generate particles belongs to Schrodinger. Since the paper of Schrodinger, this subject was approached by many authors, from different points of views, discussing many possibilities in which the phenomenon of particles production takes place. It is worth to mention the important results obtained by Parker, which studies the production of scalar particles and fermions on FRLW space-times, using the WKB method. The results of Parker predict that, the creation of particles takes place in the strong gravitational fields of early Universe. Even if we use a different method, our results also show that, the QED processes that imply particle production, are possible only in early Universe, when the gravitational fields were very strong. First we present the formalism that we intend to use, in order to study the production of fermions in de Sitter space-time. We are considering that the quantum fields are minimally coupled with de Sitter gravity. The general picture of quantum electrodynamics from Minkowski space-time can be applied to the de Sitter space as well, if we construct the theory of interaction (and the theory of free Maxwell field) in Coulomb gauge. By considering to work in Coulomb gauge and in the conformal chart, we can write down the solution of Maxwell equations as plane wave solutions, with well defined momentum, because the field equations are conformally invariant. Also the transition amplitude remains gauge invariant at a gauge transformation that imply only the spatial components of vector potential if we work in Coulomb gauge. Another important observation that needs to be mentioned here is the fact that, the quantum modes do not depend on the local chart in which one works and are supposed to be prepared by a global apparatus which consists from constructing sets of commuting operators, like in the usual quantum mechanics theory. With this prescription the vacuum state is uniquely defined and the *in* and *out* states are the exact solutions of the field equations.

The most important results delivered by this formalism are:

-the functions that define the probability are convergent and this can be seen when we plot the probability in terms of the ratio mass of the fermion/expansion factor. Also the graphical results show that, these processes are significant at large expansion, which means strong gravitational fields.

-the general form of the probability allows us to study the cases in which the probability is maximum or minimum with respect to the angle of emission between the momenta vectors of the produced particles. Because the probabilities are nonvanshing in two cases: when helicity is conserved or not, one can see which are the most probable cases in which the pair of fermions is annihilated into the vacuum or the particles became separate. For example, in the case of electric field, in the helicity conserving case the most probable transitions are those in which the pair of the created particles is emitted on the direction of the electric field, but the momenta vectors have the same orientation. While in the case in which helicity is not conserved it is very probable for the momenta vectors to have opposite orientations, because in this situation the probability is maximum, so the pair of particles can separate. On the contrary, in the situation in which the external field is the field produced by a magnetic dipole, the most probable transitions are those in which the pair of fermions is emitted perpendicular on the direction of the magnetic field. The pair of particles can separate, in the helicity conserving case, while in the helicity nonconserving case it is very probable for the fermion pair to annihilate into the vacuum.

-another important consequence that one needs to discuss about is the Minkowski limit of our results. These processes are forbidden on flat space because of the simultaneous conservation laws of energy and momentum. Indeed, our analytical results, show that the momentum conservation law is broken in these processes and the graphical results show that, when the expansion parameter is zero, the probabilities are vanishing recovering in this way the results from Minkowski QED.

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