Non-Equilibrium Field Theory and Transport Equations with Correlations ◊

R. Fauser [a] and H. H. Wolter
[a] GSI Darmstadt, Theorie, 64220 Darmstadt

In many fields of physics non-equilibrium processes are of great interest. They are usually described by transport theories, e.g. for the behaviour of plasmas, in models of the early universe, or in ultra relativistic and relativistic heavy ion collisions. In a series of papers [1–4] we have developed a many body theory in non-equilibrium for use in such transport phenomena. In particular, we are interested in relativistic heavy ion collisions and the role of correlations in the fragmentation processes.

We formulate the theory in the real time Green function formalism on a Schwinger-Keldysh time contour, which is appropriate for non-equilibrium processes. Such a formulation necessarily contains correlations which can be seen from the Wick theorem. The rearrangement of an operator product leads to contractions and normal ordered product. The expectation value of normal ordered products vanishes in the ground state or in thermal equilibrium, but not in a general non-equilibrium state because a vacuum for the creation and destruction operators cannot be defined. We therefore develop a formulation for a Wick theorem in non-equilibrium which expands the expectation value of an operator product in terms of 1-particle Green functions and correlation functions [2].

However, this form is not yet particularly useful when used in perturbation expansions considering the fact that usually summations of diagram classes are necessary. This is because in a given diagram a correlation function appears at most once. This problem can be circumvented by the use of cumulants, which are irreducible correlations in which all correlations of lower order have been subtracted off. We formulate a Wick theorem with correlations and show how summations can be performed [3].

As a concrete application of this formalism we develop a transport theory in non-equilibrium which includes correlations [4]. Usually this is achieved by performing a Wigner transformation and going to the semiclassical limit. However, a particular difficulty appears in a relativistic formulation with a four dimensional Wigner transform which involves the use of asymptotic states in the infinite past and future. In non-equilibrium, however, these states are not free and are therefore not known. Therefore we Wigner-transform only with respect to the space dimensions and develop an equal-time transport theory.

It is of particular interest how correlations enter such a formulation. We obtain a coupled set of transport equations for Green functions and correlation functions. In these the correlations enter as initial correlations, which are already present in the initial state, and as dynamical correlations, which evolve due to the interaction with the medium. We see that initial correlations are necessary for a consistent relativistic formulation with retardation effects. The dynamical correlations are seen to be equivalent to higher order contributions to the self energy in a Dyson formulation.

The formalism developed offers the possibility to investigate the role of correlations in the dynamical evolution of non-equilibrium processes. In particular, it should be useful, to investigate in a consistent framework the fragmentation processes in heavy ion collisions.

References

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◊supported by GSI, grant LMWolT

The Relativistic Landau-Vlasov Method in Heavy Ion Collisions ◊

C. Fuchs [a] and H. H. Wolter
[a] Institut für Theoretische Physik, Universität Tübingen

We formulate a method to solve the relativistic kinetic equation for heavy ion collisions using covariant testparticles of gaussian shape in coordinate and momentum space. These gaussians are a generalisation of covariant δ-functions and provide a solution of the relativistic Vlasov equation in a harmonic approximation if their centers obey classical equations of motion. The gaussian in momentum space is discussed in relation to the spectral function and to the problem of off-shell dynamics. We show that this representation of the phase space distribution is well adapted to control numerical fluctuations, and thus to give a reliable starting point to study physical fluctuations and fragmentation.

Published in: Nucl. Phys. **A589** (1995) 732

◊supported by BMFT, grant 06LM363