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SPIN DYNAMICS IN RELATIVISTIC MATTER: Popular science abstract in English:

Spin is a fundamental quantity appearing in the modern problems of physics. It describes the intrinsic form of angular momentum carried by elementary particles as well as composite systems such as atoms and atomic nuclei. Recently, the role of spin degrees of freedom has become important in an area where it was not considered to play a major role, namely in high-energy nuclear collisions (commonly known as heavy-ion collisions). The reason for this was the first positive measurement of the spin polarization of particles produced in such collisions, which showed that the spins are aligned along the direction of the initial angular momentum of the colliding system — it seems that some part of the initial orbital angular momentum present in the early stage of the collision has been transferred to the spin part. Such a transfer is possible, since in quantum mechanics only the sum of the orbital and spin parts of the total angular momentum is conserved.

The main theoretical tool for describing the dynamics of nuclear collisions is relativistic hydrodynamics. Early perfect-fluid applications have recently been replaced by modern approaches that take into account dissipation and large deviations from thermodynamic equilibrium. The hydrodynamic modelling of heavy-ion collisions allowed for the determination of a viscosity of the produced matter that turns out to be the smallest one that can be found in Nature. The success of hydrodynamics and spin measurements suggest that matter produced in nuclear collisions is in fact a polarized fluid whose overall dynamics affects the spin degrees of freedom. Consequently, an obvious question arises about developing the formalism of relativistic hydrodynamics that takes into account spin polarization. The proposed NCN project focuses on this general issue. Interestingly, in 2016 the evidence was found for the spin-current generation in a vortical flow of liquid mercury. Thus, although the main motivation for the proposed project originates from the field of high-energy nuclear physics, the project's objectives will be certainly relevant for other fields, especially for spintronics and astrophysics.

The very idea of a spinning fluid is quite old and originates in the seminal paper by Weyssenhoff and Raabe. A more recent formulation of hydrodynamics with spin has been coauthored by the Principal Investigator of this proposal. The main idea of this approach is to use equilibrium functions for particles with spin. Nowadays, however, there are several new approaches aiming at the construction of relativistic hydrodynamics with spin. They all remain in a close relation to the underlying quantum physics. The most popular approach uses the quantum distribution functions (the so-called Wigner functions) for fermions with spin $1/2$ as the starting point, while the other frameworks use different physical arguments about gradient expansion and entropy production.

In spite of a very large current activity in the field of hydrodynamics with spin, we still lack a commonly accepted formalism that could be used for description of relativistic spin-polarized media. Moreover, several developments led us to problems that require further investigations, for example, the problem of non-local effects in the collisions of particles with spin. The aim of the proposed project is to construct a consistent formalism of hydrodynamics with spin that synthesizes from the physical point of view the most attractive ideas that have appeared so far in individual approaches of different groups. At the same time, the connected general problems will be studied in parallel. Wherever it is possible, the connections to other fields of physics will be explored. In particular, we plan to include the effects of magnetic fields, which will be very important in the astrophysical context, since magneto-hydrodynamics (without spin) is already a well-established tool in this area.

In the field of relativistic nuclear collisions, the inclusion of spin degrees of freedom represents now the frontline of scientific research. The polarization measurements offer a completely new perspective for studying properties of the produced matter. More and more data is collected for various colliding systems and for most of the polarization observables no theoretical explanation can be found. Taking into account such significant shortcomings of the current theories, it becomes very important to construct the spin dynamics models whose predictions can be directly confronted with the experimental data.