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From a scientific point of view, this project takes important for the further development of statistical physics issues related to:

1. observation of the so-called hybrid phase transitions, which were previously unknown, and
2. existence of systems, for which the principle of ensemble equivalence, which is one of the foundations of statistical physics, is not satisfied.

Water evaporation, melting snow, the loss of the magnetic properties of the heated piece of iron, superconductivity - all these phenomena are examples of phase transitions. The explanation of the causes and determining conditions for the occurrence of phase transitions, considered to be the most fascinating properties of matter, was one of the biggest challenges of the physics of the last century. At this time we managed to understand and explain a number of issues related to these phenomena and to develop universal methods to describe phase transitions in various systems.

In particular, it was shown that despite the great diversity of observed transitions, they can be divided into two types: discontinuous and continuous. The first of these occur suddenly. For example, the conversion of water to ice occurs abruptly. At the specified pressure and temperature above the melting point, water is fluid and mobile, and below this point it is rigid and motionless. There is nothing between one phase and the second – water does not become less fluid before it will turn to ice. At the melting (or freezing) point, the density of water changes abruptly. In the case of continuous phase transitions it is different. It is said, that they are noisy. In the vicinity of critical points at which the transitions occur, the systems are extremely susceptible to various disturbances. In such systems, even a small change in external parameters such as temperature, can cause huge changes. Approaching the critical points is evidenced by the huge fluctuations in various internal parameters of the systems, although the average values of these parameters remain continuous – unlike in the case of discontinuous transitions.

Hybrid phase transitions, which are the subject of research in this project, owe their name to creatures from Greek mythology – hybrids (usually depicted as a lion, with the head of a goat arising from its back, and a tail that might end with a snake's head), because just like the mythical hybrids they combine elements that do not fit together. These elements are the features of continuous and discontinuous phase transitions, which were thought that they could not exist in the same physical system. One of the aims of this project is to understand the mechanisms leading to the hybrid phase transitions.

In addition to hybrid phase transitions, the project will also examine the systems in which the principle of ensemble equivalence is broken. This principle of equivalence dates from the early twentieth century, from the works of Gibbs, who is considered an originator of statistical physics. It is one of the foundations of statistical physics and is deeply rooted in its theory and methods. Thanks to the concept of equivalence it is, for example, reasonable to regard energy and temperature as conjugate variables. With this idea, it is also meaningful the concept of "equation of state of thermodynamic system", an example of which is the ideal gas law (Clapeyron's equation), which describes the state of the ideal gas. The validity of this principle has been challenged in the early twenty-first century, when it was shown that in some physical systems with long-range interactions the use of methods based on two different ensembles does not lead to the same results. Is this undermines the credibility of statistical physics, whose methods have been developed in the twentieth century? Understanding the causes of ensemble nonequivalence in physical systems is another objective of this project.