Superconductivity is one of the most fascinating physical phenomena in which the material, cooled below the critical temperature (usually very low), the electricity flows without resistance. Thanks to this, superconductor may conduct electricity without loss. Another important feature of the superconductor is its diamagnetism, the ability to completely push the magnetic field out of the material. This is because in the superconductor, placed in the magnetic field, currents are induced which create a magnetic field that shields the inside of the material from the outer field. Consequently, the magnet placed above the superconductor can levitate. Despite over a century of history, superconductivity still surprises us. Unconventional superconductors are discovered, with properties other than those known previously, superconductivity appears in materials that we would not expect at all or with ever higher critical temperatures. In the materials we will be dealing with in our project, superconductivity is likely to arise due to the specific interaction between electrons and crystalline lattice vibrations - resulting in an attractive electron-electron interaction. Thanks to the fascinating physics and the wide practical applications (especially for the construction of extremely strong electromagnets), superconductivity is a growing field of fundamental research.

In our project entitled "The role of the resonant states, spin-orbit coupling and disorder in the superconductivity of selected materials", we intend to undertake theoretical investigations of superconductivity in aspects not yet investigated or discussed very rarely. Our aim will be the theoretical description and understanding of the properties of electron-phonon interactions and superconductivity in very interesting and unusual compounds, which we will briefly describe below:

1. Superconducting doped semiconductors in which resonant state is formed by the dopants. The purpose of our work will be to explain the mechanism of superconductivity in materials that are significantly different from typical superconductive metals. Existing theories describing this phenomenon must be verified because they are based on a number of assumptions that may not be fulfilled in these materials.

2. Superconductors containing heavy elements and noncentrosymmetric superconductors. In these systems we plan to carry out systematic studies of the role of relativistic spin-orbit interaction on material properties, anisotropic electron-phonon interaction, and properties of the superconducting phase, going beyond the BCS model, towards quantitative considerations based on accurate numerical calculations.

3. High entropy alloys - This new class of materials has an extremely complex chemical structure (from 5 to more than a dozen chemical elements), and at the same time forms very simple crystalline structures, the same as elemental metals such as iron or copper. Recently discovered superconductivity of these alloys also seems to go beyond the standard framework, and the unusual structure of these systems opens up many possibilities for optimizing the properties of the compound by modifying the composition or substitution of other elements.

Our research will be based on numerical calculations of the properties of real compounds of the given crystalline structure and composition. The electronic structure and phonon properties determined by the first principles calculations will be used for further quantitative analysis of thermodynamics of superconducting phase, based on the most accurate microscopic theories of superconductivity induced by the electron-phonon interaction. This will allow us to understand the properties of the studied materials, to predict the occurrence of superconductivity in new materials, and to create universal theoretical tools capable of serving the new team for advanced theoretical research over a number of consecutive years.