

### **Polar order built into soft-matter phases with 3D structure (PolSoftMatt)**

The idea of a liquid with ordered dipole moments and thus ferroelectric properties was put forward by M. Born over a hundred years ago. Although the idea seemed simple, its implementation was unexpectedly difficult, because the dipole interactions are too weak and thermal fluctuations too strong to obtain a long-range ordering of dipole moments in liquids. So far, the concept of polar fluids has been realized, but only partially, in liquid crystalline phases, but it should be noted that in these phases the polar order is a side effect of steric interactions. The polar order in liquid crystalline phases is obtained, for example, by a reduction of the symmetry of the phase resulting from the molecular chirality or by a strongly inhibited rotation forced by the shape of the molecule, e.g. bending of the molecular core. However, in 2019, reports appeared that a ferroelectric nematic phase had been discovered, which reopened the discussion on whether ferroelectric liquids exist. So far, the number of materials claimed to exhibit a ferroelectric nematic phase is limited only to one group of molecules. It is still possible that also in this class of materials the polar order is a secondary effect and results from the specific shape of molecules.

The Born's question, whether polar liquids exist, is interesting and worth answering solely from the basic science point of view. It is also intriguing to find out whether and how molecular chirality can modify the structure of polar liquid phases; for example, is the effect similar to the one in nonpolar nematic phases, in which strong chirality induces helical photonic structures in one- (cholesterics) or three-dimensions (blue phases). However, the project also has applicative significance - the ferroelectricity of liquid phases, especially those with three-dimensional arrangement of molecules, will enable easy and effective control of phase properties, e.g. photonic, with an electric field.

The aims of this project are: to enlarge the library of materials forming the ferroelectric nematic phase, to determine general principles of designing ferroelectric nematics, to obtain materials that form more complex polar structures with three-dimensional arrangement of molecules, e.g. 'blue phases' or gyroid phases, and to obtain new functional materials. The proposed research plan covers the synthesis of new materials, including chiral ones, capable of forming polar phases, resolving the structure of the created phases with the use of microscopic techniques (optical, electron and atomic force microscopy) and X-ray diffraction (also resonant diffraction - a specific method that enables the study of a phase structure without the positional order of molecules). Experimental research will be combined with theoretical work that will allow to predict the stability and properties of polar phases, for example, under strong interaction with surfaces, i.e. under the conditions used in optical displays. The structure of new phases as well as their response to external fields will also be modelled, because this is a key condition for the correct interpretation of the experimental results as well as for the prediction of material properties that will enhance desired applications of new phases.