What are glass-forming materials?

All materials or molecular liquids able to form a glassy state are termed commonly as 'glass-formers'. When a liquid is cooled down below the freezing temperature two scenarios are possible. In the first and probably the most typical case, the liquid starts to crystallize and forms a crystal of a regular, well-defined array of atoms/molecules. On the other hand, if the process is carried out in a suitable manner (e.g. using a 'relatively' fast cooling rate) it is possible to avoid crystallization and passage of the tested substance into the metastable supercooled liquid state. Then, on further cooling, it will eventually solidify (vitrify) and form a glass, which is a solid state without the long-range order characteristic for crystalline materials. Broadly speaking, materials able to form a glassy state are a fundamental part of technological developments and widespread in nature. The unique features of such materials and potentially unlimited application range can be tuned by understanding a subtle balance between vitrification and crystallization phenomena which compete with each other while determining the final outcome. This, however, remains one of the central issues within the condensed-matter physics, just like the puzzling nature of the glass transition phenomenon.

Our motivation and research objectives

When an electric field is applied, molecules carrying a permanent dipole moment tend to align towards the field direction. In the limit of low fields ($\leq$ 1 kV/cm), the structure and dynamics are not affected persistently by the field itself. In other words, interactions of the dipoles with electric field reveal the properties of the material in the same thermodynamic state as it would have in the absence of the external field. However, under sufficiently high electric fields, thermodynamic potentials become more sensitive and polar systems will be forced to adjust to a new equilibrium state, same as when changing the temperature or pressure. As a consequence, changes in dynamics and structural properties of glass-forming materials might occur. In such case, we enter into nonlinear dielectric phenomena of significant cognitive and applicational meaning. Interestingly, studies carried out in the presence of high electric fields might provide essential information needed to understand the glass transition puzzle. In turn, validating if the electric field can be potentially used as a highly selective tool that facilitates separation of different polymorphic forms of the same compound while hindering the growth of unwanted ones might have significant meaning in pharmaceutical science or chemical engineering. Finding small organic glass-formers to change crystallization patterns in response to the applied electric field can also be potentially useful in photonic applications or modern technology (organic memory devices, molecular switches or sensors). It is worth to note that such experiments are extremely challenging and carried out only by a few research groups in the world.

This project will cover the following research activities:

(T1) Dynamics of glass-forming liquids in the presence of external electric field.

Here, the most interesting aspects that will be explored are:

(a) the relationship between entropy reduction and changes in the structural dynamics induced in the presence of a high electric field,

(b) the influence of high electric fields on the secondary relaxation dynamics and physical aging of glasses,

(c) measurements of the third and fifth harmonic susceptibilities to access dynamic heterogeneity and probe its growing length scale as approaching the glass transition.

(T2) High field crystallization: supercooled liquids and plastic crystals.

Here, we aim to study the effect of strong electric field on the nucleation and crystal growth rates, possibility to obtain selectively certain polymorphic forms, as well as verifying whether field induced changes in the crystallization behavior are fully reversible when static orienting electric field is turned off (and if does so, what is the time scale of such recovery).

(T3) High field versus (and) high-pressure effects.

This task will involve testing whether the changes in configurational entropy invoked in the presence of high electric fields have something in common with that generated when variations of thermodynamic variables such as temperature and pressure are used. To put in other words, whether for polar molecular glass-formers the external electric field can be labeled as another, equivalent (?!) control variable, like T or p. As a final point, we also plan to perform very challenging high electric field studies under high-pressure conditions with the aim to see the effect of variation in density/molecular packing on electric field-induced changes in the molecular dynamics and crystallization of glass-forming materials.

Many of the issues outlined above have a pioneering character. Therefore, we are convinced that obtained results, will reach far beyond the current state of the art. It is worth to note that such experiments are still very rare within the scientific community.