Normal and anomalous diffusion models for the electrical impedance of liquid crystalline materials

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The impedance spectroscopy technique involves applying an oscillating electric field at different frequencies to a sample [1]. The impedance response of the sample provides information about various physical parameters, such as ionic motion, adsorption-desorption coefficients, viscosity, molecular polarization, conductivity, and growth dynamics [2]. The Poisson-Nernst-Planck (PNP) diffusing model, particularly its extension PNPA (anomalous), formulated using fractional calculus, has been shown to be a robust approach to interpreting impedance data in soft matter. Unlike the Warburg diffusion model, PNPA simultaneously satisfies the fractional diffusion equation and Poisson's equation, offering more reliable results.

The focus of the tutorial is thus on using impedance spectroscopy connected to the PNPA model to study ionic diffusion in soft matter, in general, and in cholesteric and modulated liquid crystal materials, in particular [3]. The model uses fractional derivatives to measure diffusivity rather than examining conductivity directly at low frequencies. Fractional calculus has been shown to be a valuable conceptual and formal tool to handle an entire class of problems [4,5]. For this reason, in this tutorial, we review the main fractional tools to formulate a diffusive model in terms of time-fractional derivatives and apply it to investigate the impedance spectroscopy of nematics, cholesterics, and other modulated phases of liquid crystals (like the twist-bend ones) in the framework of the PNPA model and anomalous diffusion behavior [6], aiming to characterize the physical parameters and diffusivity from the conductivity at low-frequency regimes [7].

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