

Generation and Propagation of Flexoelectricity-Induced Solitons in Nematic Liquid Crystals

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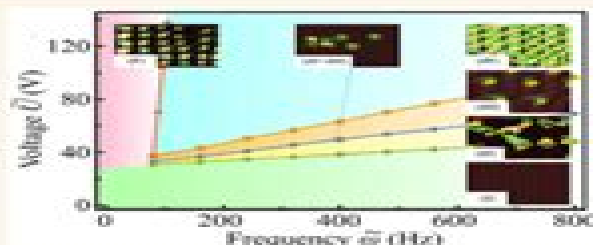
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ABSTRACT: Solitons in nematic liquid crystals facilitate the rapid transport and sensing in microfluidic systems. Little is known about the elementary conditions needed to create solitons in nematic materials. In this study, we apply a combination of theory, computational simulations, and experiments to examine the formation and propagation of solitary waves, or “solitons”, in nematic liquid crystals under the influence of an alternating current (AC) electric field. We find that these solitary waves exhibit “butterfly”-like or “bullet”-like structures that travel in the direction perpendicular to the applied electric field. Such structures propagate over long distances without losing their initial shape. The theoretical framework adopted here helps identify several key factors leading to the formation of solitons in the absence of electrostatic interactions. These factors include surface irregularities, flexoelectric polarization, unequal elastic constants, and negative anisotropic dielectric permittivity. The results of simulations are shown to be in good agreement with our own experimental observations, serving to establish the validity of the theoretical concepts and ideas advanced in this work.

KEYWORDS: soliton, nematic achiral liquid crystal, flexoelectricity, mechanism of generation, dynamic process



Solitons are wave packets that maintain their shape while propagating at a constant speed over long distances.

This preservation of shape is attributed to a nonlinear feedback mechanism that counteracts dispersion during their journey.^{1–3} Solitons have a widespread presence in nature, with manifestations observed in narrow water channels, proteins and DNA, optical fibers, magnets, and even in nuclear physics.^{4–6} Several recent reports have documented the emergence of solitons in liquid crystals (LCs) under an applied AC electric field.⁷ Potential applications of solitons include long-distance information carriers for optical signals or for particles and chemical species within nematic LCs.

In liquid crystals, three-dimensional solitons are typically observed near surface imperfections, dust particles, or electrode edges, traveling long distances aperiodically to the director field.^{8,9} Initial observations of such solitons were made by P. Cladis and colleagues¹⁰ decades ago. More recently, several research groups^{11–16} have explored solitons from an experimental perspective, while others have considered various underlying theoretical aspects.^{17–23}

Recent reports have discussed the motion of topological three-dimensional structures in AC fields, such as twist walls and skyrmions, by invoking the nonreciprocal evolution of the

director field.^{23–27} These findings illustrate how the “squirming” nonreciprocal evolution of the director, due to the intrinsic properties of nonpolar LCs, can generate the movement of localized solitonic structures. Chirality is believed to play a key role in the formation of these topological structures. Specifically, recent reports indicate that the presence of chirality allows for a broader range of folding modes, and topological solitons with Möbius structures can be manipulated by adjusting the induced AC field.²⁸ In our own work, in the process of generating solitons, we find that flexoelectricity plays a central role in the stabilization of solitons, which is reminiscent of the effects of chirality.

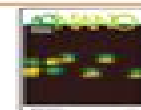
Experimental evidence suggests that solitons initially display quadrupolar symmetry at low frequencies, transforming into bullet-like structures with a curved director field at higher

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