

Surface effects on the relaxation dynamics of hexatic-*B* liquid-crystal films

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Based in a linearized hydrodynamic model, we study the relaxation dynamics of hexatic-*B* liquid-crystal films in two distinct cases. First, we investigate the hexatic order relaxing through a purely diffusive process for which the particles velocity field is assumed to be negligible. In this case, the asymptotic relaxation of deformations in the hexatic order presents a pronounced dependence on the boundary conditions. We found that a surface tilted order is enough to drive the slowest relaxation mode from an acoustic to an optic character. Second, we study the viscous case which is characterized by the coupling between the particles velocity field and the bond orientational order. In this case, underdamped modes with oscillatory-exponential relaxation are obtained on a narrow range of wave vectors. Further, the viscous relaxation of surface and inner layers deformations display distinct scaling behaviors under a surface tilted order.

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I. INTRODUCTION

Free-standing liquid-crystal films have been extensively studied as an ideal setup to investigate the crossover from three-dimensional (3D) to two-dimensional (2D) behavior. Birgeneau and Litster proposed that some liquid crystalline phases with a short-range positional order would present long-range bond orientational order originally predicted by theories of dislocation-mediated melting in two-dimensional solids [1–3]. Several experimental studies have demonstrated the existence of the so-called hexatic-*B* liquid-crystal phase in a great variety of compounds, being the unique system where hexatic order has been observed at high temperatures [4–6]. In this context, the hexatic-*B* phase is described as a set of stacked hexatic layers with short-range in-plane positional order, but with long-range bond orientational order.

The great variety of phenomena associated with the interplay between surface effects and bulk ordering has increased the interest in the study of static and dynamical properties of free-standing liquid-crystal films. In smectic-*A* films, the surface tension reduces the fluctuations in the smectic order close to the surface, providing a quasi-long-range order characterized by the logarithmic divergence of fluctuations in the limit of large film thicknesses. As a result, surface ordering plays an important role in phenomena such wetting transition [7,8], layer-by-layer thinning [9,10], and the existence of smectic films at high temperatures [11,12]. Also, several works have demonstrated that the dynamical properties of free-standing smectic-*A* films are strongly dependent on the boundary conditions [13–19]. In particular, experiments using coherent soft-x-ray [13,17] and hard-x-ray [16,18] dynamic scattering have shown that the relaxation time stays finite for small wave vectors of the in-plane fluctuations, due to the surface contribution to the free energy. As a consequence, the algebraic decay of the dynamic density-density correlation function is expected to be governed by a time-dependent exponent in an overdamped regime [13]. On the other hand, recent studies using x-ray photon correlation spectroscopy and neutron spin echo methods have observed distinct relaxation regimes which depend on the wavelength of in-plane fluctuations for films in an underdamped regime

[18]. In this case, the intensity-intensity correlation function presents a combination of damped and oscillatory behaviors which results from inertial terms [16,18]. Also, one nanosecond correlation spectroscopy probed under- and overdamped undulatory modes [19].

Contrasting with smectic-*A* films, fluctuations in the hexatic order present a logarithmic divergence without a predominant surface term. However, surface ordering has been demonstrated to be responsible for certain unusual phenomena close to the hexatic-*B*–smectic-*A* phase transition, such as specific heat anomalies [20–22] and a nonmonotonic thickness dependence of the transition temperature [23]. For temperatures at which the hexatic order is well stabilized, the mean angle fluctuation was shown to obey a universal scaling behavior with the relevance of surface ordering being determined by a characteristic length scale [24]. With concern to the dynamical properties, the existence of a local hexatic order in smectic-*A* films was observed to induce a sound propagation anisotropy in the vicinity of smectic-*A*–hexatic-*B* transition [25,26]. The anisotropy is related to the coupling between the local hexatic order and the smectic layer spacing gradient [26,27]. Moreover, the temperature dependence of transport coefficients in two-dimensional hexatic films has been predicted close to the melting transition by including dynamical effects of disclinations and dislocations [28]. Furthermore, the bond orientational field and hydrodynamic velocity distributions were theoretically determined around a moving dislocation which allowed to relate the disclination velocity field to the bond orientational order variations far from disclinations [29]. Light-scattering studies of bond orientational order in tilted hexatic liquid-crystal thick films have shown two main relaxation modes [30–32]. An acoustic mode, whose relaxation time diverges in the limit of very small wave vectors, corresponds to fluctuations in the orientation of the in-plane director component. An optic mode was also found associated with the bond orientational fluctuations. Such mode is characterized by a finite relaxation time in the limit of small wave vectors. The emergence of an optic mode was directly related to the coupling between the bond orientation and the tilt angle. This coupling is commonly represented in the elastic free energy as a conjugate field on the bond orientational order.

In the present work, we examine the effects of surface ordering operators on the relaxation dynamic of hexatic- B liquid-crystal films within a linearized hydrodynamic model. We consider two distinct cases. First, we assume that the velocity field is negligible with the bond orientational field relaxing through a purely diffusive process. In a second moment, we consider a non-null velocity field taking into account rotational and shear viscosities. In both cases, we compute the relaxation times and their dependence on the boundary conditions is analyzed. Also, we study the temporal evolution of a surface Gaussian deformation as well as its transmission to the inner layers. In the diffusive case, we observe that a surface tilted orientational order promotes an exponential asymptotic relaxation of orientational deformations. In the viscous case, we observe that the surface layer presents the same slow relaxation for different surface couplings. However, the asymptotic temporal relaxation of the orientational distortions in inner layers depends on the surface ordering field.

II. MODEL

The long-range bond orientational order in hexatic layers is characterized by a local order parameter $\psi_6(\mathbf{r}) = \psi_0 e^{6i\theta(\mathbf{r})}$, where $\theta(\mathbf{r})$ is the angle between bonds and some reference axis [2]. Here, we will consider a film with N layers well within the hexatic phase. In this regime, amplitude fluctuations and topological defects may be disregarded. The in-plane deformations on the hexatic order are then governed by harmonic orientational fluctuations that can be represented by the hydrodynamic Hamiltonian

$$H = \int_{a_0}^L d^2r \left[\frac{dK_a}{2} \sum_{i=1}^N |\nabla \theta_i(\mathbf{r})|^2 + \frac{J}{2d} \sum_{i=1}^{N-1} [\theta_{i+1}(\mathbf{r}) - \theta_i(\mathbf{r})]^2 \right], \quad (1)$$

where L is the transversal length of film, a_0 is the in-plane molecular distance which is taken as a lower cutoff and d is the layer spacing. K_a is the effective Frank constant associated to the energy cost for distortions in the bond orientational order in the layer plane. J is the interlayer coupling constant associated with relative distortions between adjacent layers. Due to the suppression of smectic fluctuations on the boundary layers by the surface tension, the elastic constants related to hexatic order distortions are stronger at the surface than at bulk layers [33–35]. This surface ordering in hexatic films is represented by an enhancement of operators that act just on the surface layers, such as

$$\begin{aligned} \Delta H_S = \int_{a_0}^L d^2r \left[\frac{d\Delta K_S^1}{2} |\nabla \theta_1(\mathbf{r})|^2 + \frac{d\Delta K_S^N}{2} |\nabla \theta_1(\mathbf{r})|^2 \right. \\ \left. + \frac{\Delta J_S^1}{2d} [\theta_2(\mathbf{r}) - \theta_1(\mathbf{r})]^2 + \frac{\Delta J_S^N}{2d} [\theta_N(\mathbf{r}) - \theta_{N-1}(\mathbf{r})]^2 \right]. \end{aligned} \quad (2)$$

The film inhomogeneity can be distinct in each surface depending on interactions at interfaces gas/film and/or substrate/film. In the following, we will just consider sym-

metric boundary conditions with $\Delta K_S^1 = \Delta K_S^N = \Delta K_S$ and $\Delta J_S^1 = \Delta J_S^N = \Delta J_S$. Also, we may include a surface field conjugate to the bond orientational order due to the possible existence of a tilted order at the surfaces [24]

$$\Delta H_f = \frac{h}{2} \int_{a_0}^L d^2r [\theta_1^2(\mathbf{r}) + \theta_N^2(\mathbf{r})]. \quad (3)$$

The total Hamiltonian is given by $H_T = H + \Delta H_S + \Delta H_f$. In order to study dynamical properties, we considered the linearized motion equations for deformations in the hexatic order of the i th layer [28]

$$\frac{\partial \vec{v}_i}{\partial t} = -\frac{K_i}{2\rho_0} (\hat{z} \times \nabla) \nabla^2 \theta_i + \eta \nabla^2 \vec{v}_i, \quad (4)$$

$$\nu \frac{\partial \theta_i}{\partial t} = \frac{\nu}{2} (\nabla \times \vec{v}_i)_z - \frac{1}{d} \frac{\delta H_T}{\delta \theta_i}, \quad (5)$$

where ρ is the average mass density of the system and η and ν are the shear bulk viscosity and angular viscosity, respectively [36]. The velocity field \vec{v}_i denotes the motion of particles into the i th layer. The first term in the right side of Eq. (5) represents the bond orientational order response to the existence of local vortices in the velocity field. It has a similar term in Eq. (4) which represents the response of the velocity field to inhomogeneities in the bond orientational order. In the smectic- A phase, it is well known that four of five viscosities diverge in the limit of low frequency resulting from the nonlinear coupling between velocity field and thermally excited undulatory modes [37]. A similar result was derived for the angular viscosity in 2D hexatic liquid crystals from renormalization group theory [38]. In this case, the angular viscosity is expected to have a logarithmic divergence for long wavelengths. However, the range of wavelengths and frequencies where dynamical properties are dominated by the singular contribution seems not to be experimentally accessible [38]. Therefore, we will assume ν to be constant without affecting our main results in most of the experimental range of wave vectors and frequencies.

III. DIFFUSIVE RELAXATION

In this section, we will assume that the velocity field is negligible. In this regime, the motion equations results in a set of N coupled equations for the bond orientational distortion displacement. Using the Fourier decomposition of the orientational deformation written in the form

$$\theta_i(r) = \int_{2\pi/L}^{2\pi/a_0} \frac{d^2q}{(2\pi)^2} \theta_i(q) e^{i\mathbf{r}\cdot\mathbf{q}}, \quad (6)$$

and introducing the following dimensionless variables $(J/\nu d^2)t \mapsto t$ and $(d\sqrt{K_a}/J)q \mapsto Q$, the hydrodynamic equations for each Fourier component can be written in a compact form given by

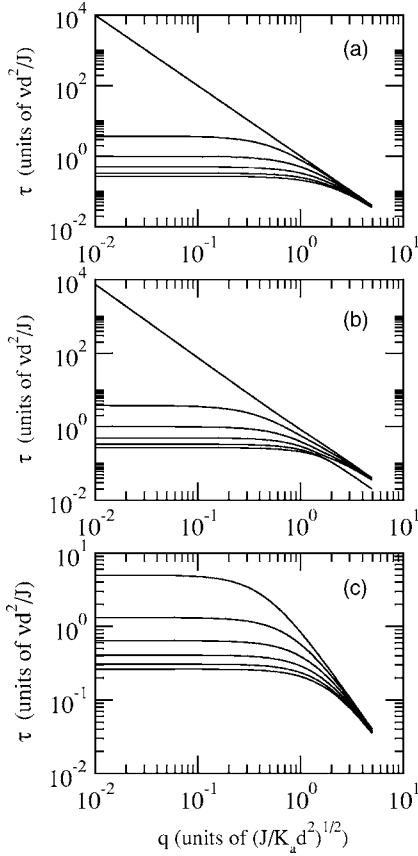


FIG. 1. Dimensionless relaxation time as a function of the wave vector for distinct boundary conditions. (a) Homogeneous film: a single mode exhibits a diverging relaxation time in the limit of small wave vectors. (b) $K_s/K_a=2$: in the limit of large wave vectors the surface modes display a shorter relaxation time. (c) $dh/J=1$: the surface ordering field keeps all relaxation times finite even in the small wave-vectors regime.

$$\frac{\partial \tilde{\theta}(Q, t)}{\partial t} = -M(Q) \tilde{\theta}(Q, t). \quad (7)$$

Here $\tilde{\theta}(Q, t)$ is a $N \times 1$ matrix with components $\theta_i(Q, t)$ and $M(Q)$ is the interaction matrix defined by

$$M_{1,1} = M_{N,N} = \frac{K_s}{K_a} Q^2 + \frac{J_s + dh}{J}, \quad (8)$$

$$M_{i,i} = Q^2 + (J_s + J)/J, \quad i = 2, N-1, \quad (9)$$

$$M_{i,i} = Q^2 + 2, \quad i = 3, \dots, N-2, \quad (10)$$

$$M_{i,i+1} = M_{i+1,i} = -1, \quad i = 2, N-3, \quad (11)$$

$$M_{1,2} = M_{2,1} = M_{N,N-1} = M_{N-1,N} = -J_s/J, \quad (12)$$

where $K_s = K_a + \Delta K_s$ and $J_s = J + \Delta J_s$ are the surface elastic constants. Computing the eigenvalues $\lambda^m(Q)$ and associated eigenvectors $\phi^m(Q)$ of the interaction matrix, it is straightforward to show that the formal solution of Eq. (7) is given by

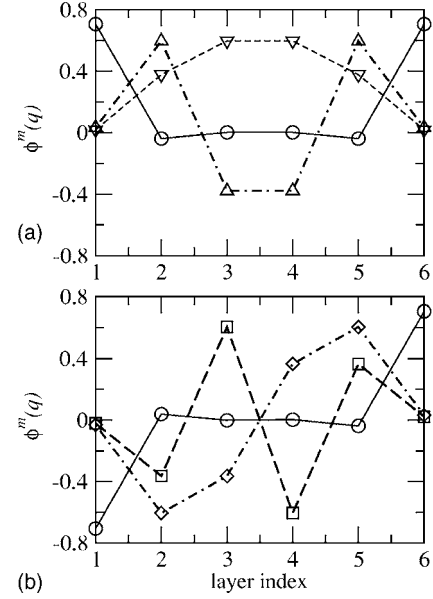


FIG. 2. (a) Symmetric and (b) antisymmetric normal modes of a six-layers film with $K_s=2K_a$ in the regime of large wave vectors. Notice that only two modes (one symmetric and one antisymmetric) have significant amplitudes located at the surface layers. Therefore, these modes present a faster relaxation as depicted in Fig. 1(b) due to their enhanced rigidity.

$$\tilde{\theta}(Q, t) = \sum_{m=1}^N \theta^m(Q, t) \phi^m(Q). \quad (13)$$

The time evolution of each component on the above normal modes decomposition depicts a purely exponential relaxation on the form

$$\theta^m(Q, t) = \theta^m(Q, 0) \exp\left[-\frac{t}{\tau^m(Q)}\right]. \quad (14)$$

The relaxation time $\tau^m(Q)$ associated to the m th normal component is just the inverse of the mode eigenvalue [$\tau^m(Q) = 1/\lambda^m(Q)$]. In Fig. 1, we report the computed relaxation times as a function of the in-plane wave vector q for a film with six layers under distinct boundary conditions. For a homogeneous film, we observe that the longest relaxation time diverges with $\tau \propto q^{-2}$ while the other ones stay finite as shown Fig. 1(a). The divergence of the relaxation time of the slowest mode for $q \rightarrow 0$ is typical of the acoustic mode observed in light-scattering experiments [30–32]. All relaxation times decay as $1/q^2$ for long wave vectors.

In Fig. 1(b), we consider a film with more rigid surfaces represented by $K_s=2K_a$. In the regime of small wave vectors, all relaxation times present a wave-vector dependence similar to that observed for a homogeneous film. In the large wave-vectors regime, two modes present a faster relaxation dynamic. In order to better understand this feature, we plotted the eigenmodes in this case and observed that these two faster modes are mainly restricted to the surface layers while the other modes have a very small surface component (see Fig. 2). The shorter relaxation time of the surface modes is due to the strong rigidity of the surfaces. In spite of this, all

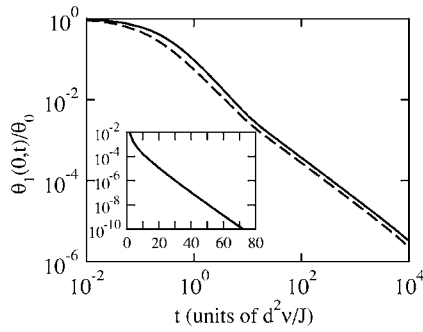


FIG. 3. Normalized deformation amplitude in the surface layer as a function of t for different boundary conditions. For a homogeneous film with $K_s=K_a$ (solid line) as well for a film with rigid surfaces with $K_s=2K_a$ (dashed line), we can notice that the asymptotic deformation amplitude presents a power-law decay as $\theta_1(0,t) \propto t^{-1}$. In the inset, we can observe that the deformation amplitude has an exponential decay for films with a surface tilted bond orientational order.

relaxation times still decay with q^{-2} . For the case of a stronger surface coupling ($J_s > J$) (not shown) there is no significantly change in the relaxation times.

In Fig. 1(c) we consider the presence of a surface tilted order represented by the conjugate field h . In this case, we obtain that all relaxation times stay finite as $q \rightarrow 0$. Hence, a tilted surface order induces a faster relaxation of the bond orientational distortion in this regime. The slowest relaxation mode has an optic character with a wave-vector independent relaxation time in the small wave-vector regime. Such optic mode has indeed been observed experimentally in smectic- C and smectic- I films [30–32]. However, the experimental systems investigated have bulk tilt alignment while here we consider only surface tilt. Therefore, the present result indicates that a surface tilt is enough to promote the emergence of the optic mode. For large q the conjugate field becomes irrelevant and one obtains the same behavior as that observed for nontilted surfaces.

From the above results, we study the relaxation dynamics of a surface deformation in the bond orientational order. We consider an initial distortion located at one of the film surfaces while the other layers are kept undistorted. Such initial deformation can be represented as

$$\tilde{\theta}(R, t=0) = \begin{pmatrix} \theta_1(R, t=0) \\ 0 \\ \vdots \\ 0 \end{pmatrix}. \quad (15)$$

We will take the initial distortion of the surface layer as Gaussian

$$\theta_1(R, t=0) = \theta_0 e^{-(R/R_0)^2}, \quad (16)$$

where $R=(r/d)(K_a/J)^{-1/2}$ is a dimensionless distance from a reference point with maximum distortion. As a representative case, we will assume in the following $R_0=(10a_0/d) \times (K_a/J)^{-1/2}$. In Fig. 3 we plot $\theta_1(r=0, t)$ as a function of t for different boundary conditions. For a uniform film, we

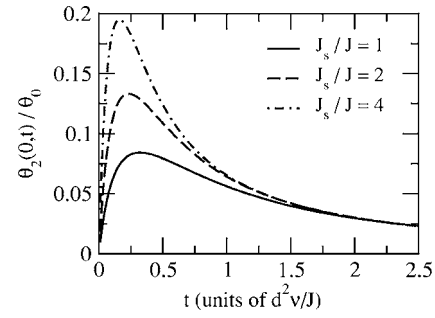


FIG. 4. Normalized deformation amplitude in the second layer as a function of t for different values of J_s/J . We can observe that the deformation amplitude increases and the typical time response decreases as J_s/J becomes larger.

observe that $\theta_1(0, t)$ decays asymptotically as t^{-1} resulting from the divergence of the longest relaxation time as $q \rightarrow 0$. A similar temporal dependence is observed for films with rigid surfaces but $\theta_1(0, t)$ presents slightly lower values than in the uniform case. On the other hand, for films with a surface tilted orientational order we observe that the deformation amplitude decays exponentially with t due to the fact that all relaxation times stay finite for $q \rightarrow 0$. An enhancement in the surface couplings does not induce any significant modification in the temporal dependence of $\theta_1(0, t)$. However, the surface coupling is expected to play an important role in the transmission of surface deformations to inner layers. In Fig. 4 we plot $\theta_2(r=0, t)$ as a function of t for different ratios of J_s/J . We notice that the maximum deformation on the second layer increases as J_s/J becomes large while the response time decreases.

IV. VISCOUS RELAXATION

In this section, we assume that the velocity field is non-null. In this case, we have a system of $2N$ coupled motion equations given by Eq. (4) and Eq. (5) which govern the temporal evolution of the velocity and bond orientational fields in each layer. Differentiating Eq. (5) with respect to t and making some mathematical manipulations, the set of coupled equations can be written in a compact form as

$$\frac{\partial^2 \tilde{\theta}}{\partial t^2} = - \left[(M + c_1 c_2 Q^2 I) \frac{\partial \tilde{\theta}}{\partial t} + \left(c_1 c_2 Q^2 M + \frac{c_1 c_2^2 Q^4}{4} I \right) \tilde{\theta} \right]. \quad (17)$$

In the above equation, I is the identity matrix and M is the interaction matrix defined by Eqs. (8)–(12). t and Q are the same normalized quantities introduced in the diffusive case while $c_1 = \eta^2 / K_a \rho$ and $c_2 = \nu / \eta$ are usual dimensionless experimental parameters. For typical liquid crystal compounds both c_1 and c_2 are greater than a unit [29,36]. As in the diffusive case, the formal solution of Eq. (17) can be expressed in terms of the eigenvectors of the interaction matrix. In this case, the coefficients of the expansion in Eq. (13) are given by

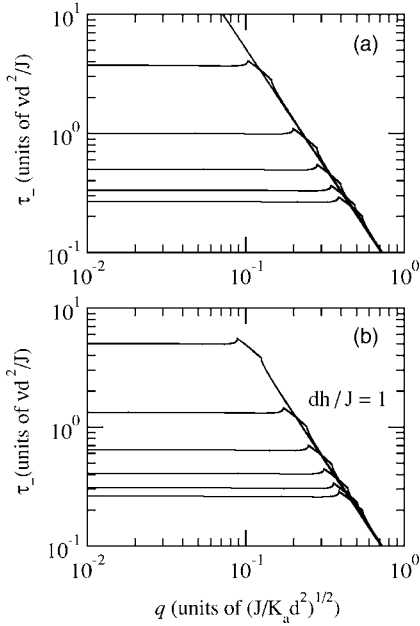


FIG. 5. Dimensionless short relaxation times as a function of the wave vector for distinct boundary conditions. (a) Homogeneous film, (b) $dh/J=1$. In both cases, we can note that τ_- presents a behavior similar to that reported for the diffusive case. The intermediate range of wave vectors bounded by singularities delimits the oscillatory exponential decay regime for each mode.

$$\theta^m(Q, t) = A_m(Q)e^{-\alpha_+^m t} + B_m(Q)e^{-\alpha_-^m t}, \quad (18)$$

where $A_m(Q)$ and $B_m(Q)$ are determined by the decomposition of the initial distortion. The inverse of the relaxation times are given by

$$\alpha_{\pm}^m = \frac{1}{2}(\lambda_m + c_1 c_2 Q^2 \mp \sqrt{\Delta_m}), \quad (19)$$

with

$$\Delta_m = (\lambda_m + c_1 c_2 Q^2)^2 - (4c_1 c_2 Q^2 \lambda_m + c_1^2 c_2^2 Q^4). \quad (20)$$

From Eq. (19), we can identify two distinct relaxation processes for the bond orientational modes in the viscous case. For $\Delta_m > 0$, the m th mode relaxes through a purely exponential process with the relaxation times being defined as $\tau_{\pm}^m = 1/\alpha_{\pm}^m$. On the other hand, $\Delta_m < 0$ implies that the associated mode relaxes through an oscillatory exponential process. In this case, the relaxation time is given by $\tau^m = 2/(\lambda_m + c_1 c_2 Q^2)$ while the oscillation frequency is expressed as $\omega_m = \sqrt{|\Delta_m|}/2$. In Figs. 5 and 6 we plot the relaxation times for a six layers film in the hexatic- B phase under different boundary conditions. We took $c_1=10$ and $c_2=2$ as represented values of the relevant viscosity effects. In Fig. 5 we observe that the shorter relaxation time τ_- presents a wave-vector dependence similar to that observed in the diffusive case for both boundary conditions. However, an intermediate range of wave vectors emerge for which an oscillatory-exponential relaxation takes place. In contrast to the diffusive case, we notice that the longer relaxation time τ_+ of all modes diverge with q^{-2} as $q \rightarrow 0$ even for films

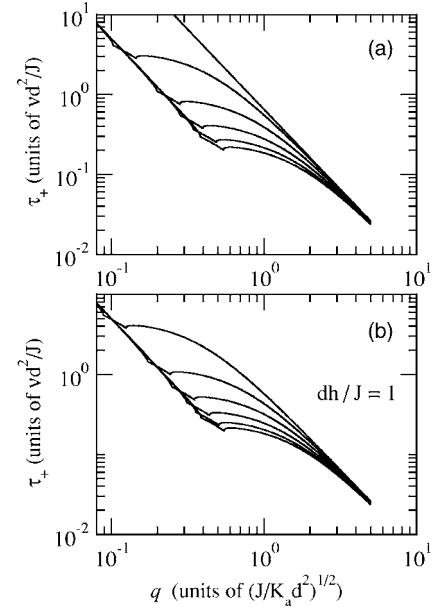


FIG. 6. Dimensionless long relaxation time as a function of the wave vectors for a six layer film under distinct boundary conditions: (a) Homogeneous film and (b) $dh/J=1$. Here we can observe the divergence of τ_+ in the limit $Q \rightarrow 0$ for all modes even under a surface ordering field.

under a surface ordering field as shown in Fig. 6. In this case, the bond orientational distortions are expected to present a slow relaxation dynamic even in films with a surface tilted order.

In Fig. 7 we plot the oscillation frequency of each mode as a function of the wave vector. For homogeneous films, the

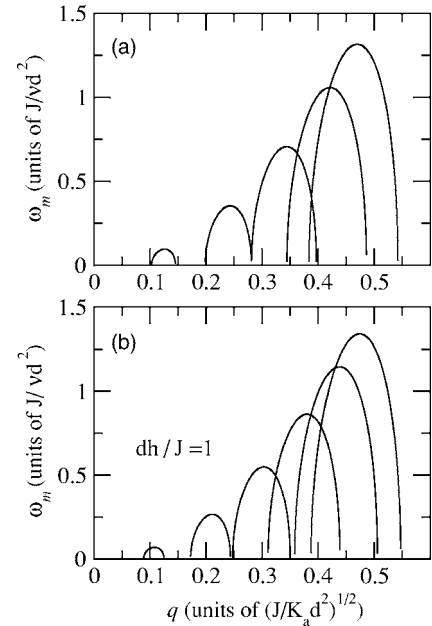


FIG. 7. Dimensionless oscillation frequencies versus wave vectors for a six layer film on the same boundary conditions of Fig. 5. (a) Homogeneous film for which a single mode relaxes exponentially. (b) $dh/J=1$ for which all modes present an oscillatory-exponential relaxation.

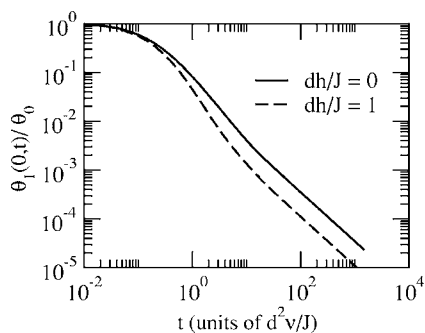


FIG. 8. Normalized deformation amplitude in the first layer as a function of t for films under distinct boundary conditions. The asymptotic deformation amplitude presents a power-law decay as $\theta_1(0,t) \propto t^{-1}$ even under a surface ordering field.

relaxation modes oscillate in distinct ranges of wave vectors as shown in Fig. 7(a) while the slowest relaxation mode depicts a purely exponential relaxation dynamics. In Fig. 7(b), we observe that all modes relax through an oscillatory-exponential process for film with a surface tilted order. Also, we obtain a more pronounced wave-vector overlap among the oscillating modes.

Due to the divergence of the relaxation times as $q \rightarrow 0$, bond orientational order shall present a power-law relaxation dynamics even in the presence of surface tilted order. In Fig. 8 we compute the amplitude of a surface deformation as a function of time. We observe that $\theta_1(0,t)$ presents the same asymptotic decay for homogeneous and surface tilted films. This result is supported by the divergence of the longer relaxation times in the limit of short wave vectors irrespective to the boundary conditions imposed to the surface layers. The asymptotic scaling $\theta_1(0,t) \propto t^{-1}$ is the same one observed in the diffusive case.

Although a surface tilted order does not modify the relaxation dynamics of the surface layer, inner layers present a faster decay in the presence of this surface ordering field. In Fig. 9, we plot $\theta_2(r=0,t)$ as a function of t under distinct boundary conditions. For films with a surface tilted order, we found that asymptotically $\theta_2(r=0,t) \propto t^{-2}$. The sensitivity on the boundary conditions of the asymptotic time evolution of hexatic distortions in the inner layers results from the distinct wave-vector dependence of the eigenmodes spectral decomposition coefficients. A closely related sensitivity to initial conditions was previously observed to occur in one-dimensional harmonic and diluted Anderson chains [39,40].

V. SUMMARY AND CONCLUSIONS

In conclusion, we studied the relaxation dynamics of hexatic- B liquid crystal films using a linearized hydrodynamical model. Two distinct cases were investigated for

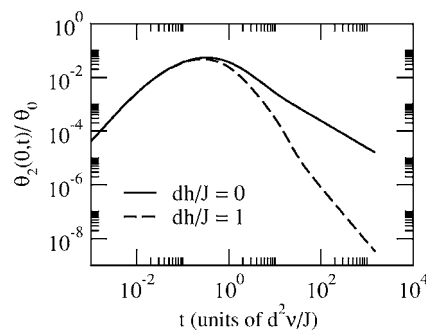


FIG. 9. Normalized deformation amplitude in the second layer as a function of t for films under distinct surface ordering. We can observe that the asymptotic behavior $\theta_2(t) \propto t^{-1}$ in homogeneous films (solid line) is replaced by $\theta_2(t) \propto t^{-2}$ in films with a surface tilted order (dashed line).

films under different boundary conditions. In the diffusive case, we observed that surface effects modify the behavior of the longest relaxation time in the regime of small wave vectors. In particular, a surface tilted order induces the longest relaxation time to stay finite in the limit of small wave vectors. As a result, surface deformations in the hexatic order presents an exponential relaxation dynamics in contrast to the power-law relaxation dynamics observed in homogeneous films. Also, it was shown that the surface coupling plays an important role in the transmission of surface deformations into the inner layers. It is important to recall that an optic mode with a finite relaxation time in the regime of small wave vectors has been previously observed in bulk tilted smectic liquid-crystal films [30–32]. Here we have shown that a surface tilt is enough to induce the emergence of such mode in the diffusive case. In the viscous case, it was shown that the longer relaxation time always diverges in the regime of small wave vectors. In this case, surface effects do not modify qualitatively the relaxation dynamics of surface deformations in the hexatic order. However, the temporal evolution of inner layers deformations was observed to depend on the boundary conditions. In fact, it was observed that the asymptotic behavior $\theta_2(t) \propto t^{-1}$ in homogeneous films is replaced by $\theta_2(t) \propto t^{-2}$ in films with a surface tilted order. Moreover, it was observed an oscillatory-exponential relaxation in a finite range of wave vectors. This result shall be contrasted with that exhibited by smectic- A films for which underdamped oscillations may be observed down to very low wave vectors [18]. For typical liquid crystals, we expect $\omega \approx 0.1$ GHz and $\tau_+ \approx 100$ ns which may be measured by the recently developed technique of photon correlation spectroscopy in the nanosecond scale [19].

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