Edge dislocation in a vertical smectic-*A* film: Line tension versus temperature and film thickness near the nematic phase

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The line tension of a dislocation is measured in a vertical smectic-*A* film as a function of temperature and film thickness. There are two contributions to the line tension: a bulk contribution that corresponds to the energy of the dislocation in an infinite medium and a surface correction that accounts for interactions with the two free surfaces. Both terms are measured in pure 8CB (octylcyanobiphenyl) as a function of temperature when the bulk nematic-smectic-*A* transition temperature T_c is approached.

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I. INTRODUCTION

A smectic-*A* phase consists of rodlike molecules arranged in fluid layers with perpendicular orientation [1]. In free-standing films, layers are perfectly parallel to the free surfaces [2]. If the number of layers is different in two parts of the film, a step is formed in between [3], which corresponds to an edge dislocation localized in the middle of the film [4]. Such a dislocation costs energy to the system. The energy per unit length, or line tension, is the one-dimensional analog of surface tension. We know two different methods to measure the line tension of a dislocation in a free-standing film of a smectic-*A* liquid crystal.

The first one is to determine the critical radius R_c of a dislocation loop in a horizontal film as described by Géminard *et al.* [5]. It can be shown that in thick films where interactions between the free surfaces are negligible, R_c is simply given by

$$R_c = \frac{E}{b\Delta P}, \tag{1}$$

where E is the line tension, b the Burgers vector, and $\Delta P = P_{\text{air}} - P_{\text{smectic}}$ the hydrostatic pressure drop between the air and the smectic that is imposed by the meniscus [6]. Indeed, a meniscus forms between the film and its support and acts as a reservoir imposing the pressure in the system. This method requires the nucleation of different-sized loops, which can be achieved by placing a heating wire underneath the film [5]. For each of the loops we then observe whether it is growing ($R > R_c$) or collapsing ($R < R_c$). It is then possible to approach R_c by successive steps. This method only works for very thick films in which the line tension of the dislocation is independent of the film thickness. Indeed, the film thickness irreversibly decreases by one layer (or more) after the nucleation of a loop which initial radius is larger than R_c. Another complication is the requirement to measure the pressure inside the meniscus from its radius of curvature at regular time intervals. We recall that the Laplace law applies in smectic meniscus and that the pressure difference is given by

$$\Delta P = \frac{\gamma}{\mathcal{R}} \tag{2}$$

where $\mathcal{R}$ is the radius of curvature of the meniscus in its circular part [5,6].

The second method is inspired by the sessile drop method for measuring the surface tension of a liquid. It consists of nucleating a dislocation loop in a vertical film and of measuring its shape anisotropy when it is in contact with the top edge of the frame on which the film is stretched [7]. In the static approximation, the shape of the loop depends on the gravity constant g via the differential equation:

$$E\kappa = b(\Delta P_0 + \rho g z), \tag{3}$$

where κ is the local curvature of the dislocation, ρ the liquid-crystal density, and z the vertical coordinate. ΔP_0 is a constant equal to the pressure difference at $z=0$ in thick films and which includes a term coming from the interaction between the free surfaces in thin ones (disjoining pressure). This equation can be solved numerically [7]. Fitting the experimental shape to the theoretical one given by Eq. (3) (see Fig. 1) allows us to obtain E and ΔP_0. This method, which applies whatever the film thickness, proved to be very useful in measuring the line tension of the dislocation as a function of both the film thickness and the Burgers vector at room temperature [7].

In this paper we focus on the measurement of the line tension of elementary dislocations when a second order smectic-*A*-to-nematic phase transition is approached. The line tension contains two contributions: a bulk one and a surface one. The former is difficult to estimate because it depends on the core radius and on the associated core energy, whereas the latter can be exactly calculated [4]. One of our purposes is to find which of these two contributions become dominant at the nematic-smectic-*A* phase transition.

The plan of the paper is as follows. In Sec. II we recall theoretical background of the subject. In Sec. III we describe our experimental setup and we explain the difficulties we have encountered measuring the line tension as a function of temperature. In Sec. IV we propose a method to deduce the line tension from our measurements and we show its evolu-

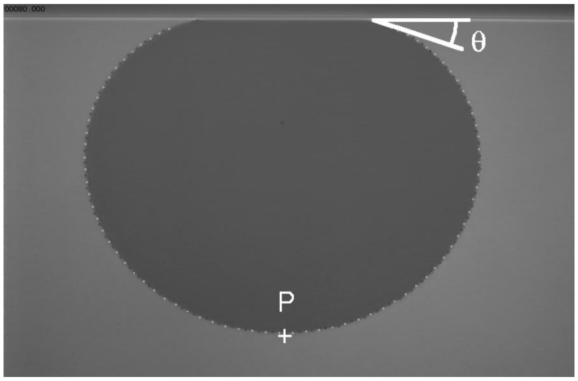

FIG. 1. Dislocation loop in a vertical film (8CB, $T=33\,°\mathrm{C}$, $N=12$). The Burgers vector equals $b=60$ Å (two layers), which explains the high contrast of the line. The dotted line is the best fit to the equilibrium shape calculated from Eq. (3) with $E/b=1.43$ dyn/cm. The meniscus is visible on top of the photograph. The horizontal loop diameter is equal to 466 μm.

tion as a function of the film thickness and temperature. In Sec. V we show that the contact angle of the dislocation with the edge of the meniscus also depends on the film thickness and temperature. In addition, we suggest the existence of a wetting transition at a temperature T_N that is higher than T_c. At this temperature, the film spontaneously thins from N to $N-1$ layers. Conclusions and perspectives are given in Sec. VI.

II. THEORETICAL BACKGROUND

According to Ref. [4], the line tension of a dislocation in a free-standing film reads

$$E=E_\infty+\delta E_s, \tag{4}$$

where E_∞ is the line tension in an infinite medium and δE_s a surface correction. The bulk term was first calculated by Williams and Kléman [8,9] and reads

$$E_\infty=\sqrt{KB}\frac{b^2}{4\pi r_c}+E_c \tag{5}$$

where K is the bending modulus, B the compressibility modulus, r_c a core radius, and E_c the core energy. The surface term was calculated more recently by Lejcek and Oswald [4,9]. It reads

$$\delta E_s=\frac{B\lambda b^2}{4\sqrt{\pi\lambda d(N+1/2)}}\mathrm{Li}_{1/2}(A)$$

with

$$A=\frac{\gamma-\sqrt{KB}}{\gamma+\sqrt{KB}}, \tag{6}$$

where $\lambda=\sqrt{K/B}$ is the penetration length, d the layer thickness, N the number of layers in the film, and γ the smectic-A-air surface tension. The special function $\mathrm{Li}_{1/2}(A)$ is defined by

$$\mathrm{Li}_{1/2}(A)=\sum_{p=1}^{\infty}A^p\frac{1}{\sqrt{p}}.$$

At a second-order nematic-smectic-A phase transition, B goes to zero but K and γ remain finite. Thus, in this limit, $A\approx 1-2\sqrt{KB}/\gamma$ and the surface term becomes [10]

$$\delta E_s=\frac{B^{1/2}\gamma^{1/2}b^2}{4\sqrt{\pi d(N+1/2)}},$$

when

$$B\to 0. \tag{7}$$

The critical behavior of the bulk contribution E_∞ when the transition is approached is more difficult to predict because r_c and E_c are unknown. Assuming the core energy has the form

$$E_c\approx 2\gamma_c r_c, \tag{8}$$

where γ_c is some cutoff energy that goes to zero at the transition, and minimizing E_∞ with respect to r_c, one obtains

$$r_c=\left(\frac{B\lambda}{8\pi\gamma_c}\right)^{1/2}b \tag{9}$$

and

$$E_\infty=\left(\frac{2B\lambda\gamma_c}{\pi}\right)^{1/2}b=\left(\frac{2}{\pi}\right)^{1/2}B^{1/4}K^{1/4}\gamma_c^{1/2}b. \tag{10}$$

This model predicts that E_∞ is proportional to b, in agreement with previous experimental observations [7]. On the other hand, we cannot conclude from this model which of the two terms E_∞ or δE_s goes faster to zero at the transition because it depends on the critical behavior of the phenomenological cutoff energy γ_c. This is one of the major points that will be addressed in this paper.

We also emphasize that the previous model assumes that the compressibility modulus B (and so the smectic-order parameter) is constant out of the core of the dislocation and equals the bulk elastic modulus within the whole thickness of the film. This assumption is valid in thick films, but fails in very thin ones (typically less than 20 layers). This effect increases when the transition temperature is approached as discussed in more details in Sec. VI.

III. EXPERIMENTAL PROCEDURE

To measure the line tension of the dislocations as a function of temperature our previous setup [7] was equipped with an oven (Fig. 2). The oven consists of two copper blocks with two vertical grooves placed face to face. The grooves from a channel in which the frame supporting the film can move up or down. The frame opening is 4 mm wide, 4 mm high, and 0.5 mm thick. The temperature is regulated within $\pm 0.02\,°\mathrm{C}$, but special care has been taken to homogenize the temperature inside the oven. Heaters and differential thermocouples have been introduced at carefully chosen places in order to reduce the temperature gradients inside the oven and across the film as much as possible. It is crucial to eliminate

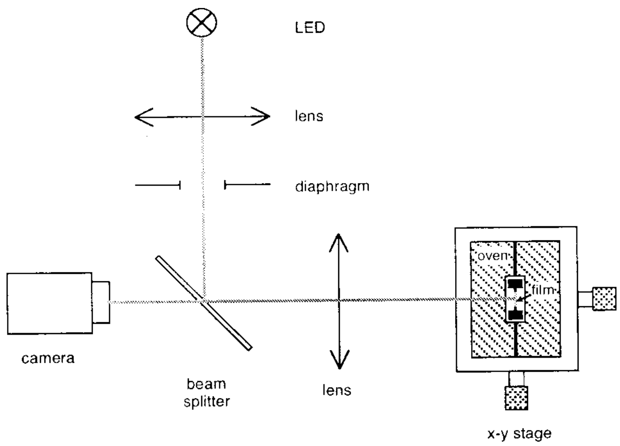

FIG. 2. Experimental setup.

convective rolls that spontaneously develop in the films. Such rolls were detected by observing the slow motion of very small dust particles (smoke particles) that were intentionally introduced in the liquid crystal. We found that temperature gradients must be less than 0.01 °C/cm in order to prevent convection. Convective rolls can also develop in the vicinity of the heating wire that is used to nucleate the dislocation loop [5,7]. The wire does indeed have a temperature slightly different from the rest of the oven. In Fig. 3, it is colder. In this case, we observe that the loop strongly bends to the bottom when the wire is approached to the film. This deformation increases when the distance between the film and the tip of the wire decreases and it does not change direction when the wire is above or below the dislocation. By contrast, the deformation changes direction (the loop bends up) when the wire is hotter than the oven. This effect is probably due to two convective rolls in the air of opposite signs that drag the matter inside the film and deform the loop (Fig. 3). These effects can be eliminated by properly heating the wire and its support (in order to compensate the thermal leak) and by moving the wire away from the film immediately after the loop has been nucleated. The film is observed through an objective lens which closes the oven to avoid air flows. The oven and the frame supporting the film are mounted on an X,Y,Z stage that permits one to focus and to choose the observation field. Pictures are recorded and then digitized on a computer equipped with a frame grabber card. A FORTRAN routine detects the experimental shape of the loop which is then fitted to the theoretical static profile given by solving Eq. (3) numerically. The film thickness is determined by observing the film reflectivity and the loop contrast with three light-emitting diodes of different wavelengths (red: $\lambda = 645$ nm; green: $\lambda = 524$ nm; and blue: $\lambda = 470$ nm) during the thinning process. Note that we can decrease the number of layers one by one by nucleating loops with the heating wire and the heat-impulse method [5]. This way, it is possible to deduce *a posteriori* the film thickness by noting the successive maxima and minima of reflectivity for each wavelength.

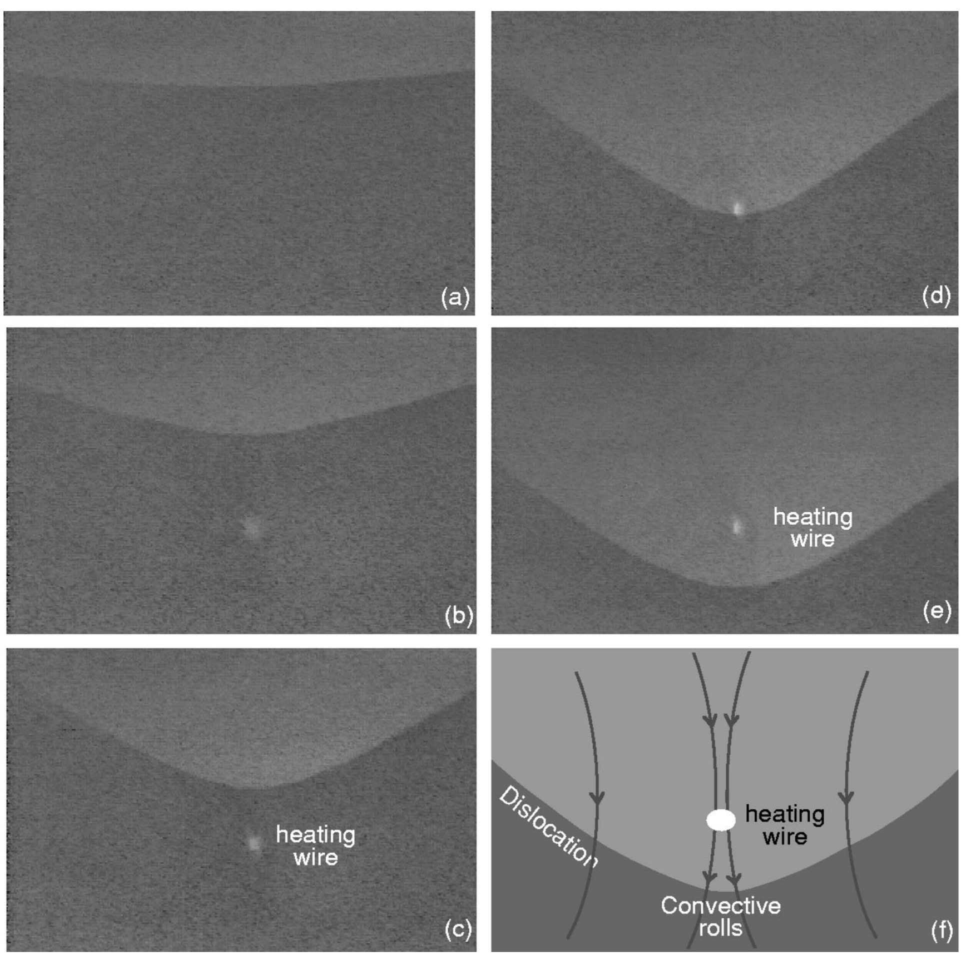

FIG. 3. Bottom part of a dislocation loop and its deformation when the tip of the heating wire (a little bit colder than the oven) is approached. From (a) to (c) the distance between the film and the wire decreases. In (a) the tip is out of focus of the microscope and the loop is not distorted. In (b) and (c) the heating wire is typically 100 and 40 μm behind the film (bright spots on the pictures). The dislocation bends down very strongly. In (d) and (e) the frame together with the loop are moved to the bottom while the heating wire is fixed. The loop deformation is unchanged. In (f), we propose an explanation for the loop distortion when the wire is colder than the oven in terms of convective rolls induced by the heating wire.

All our experiments were performed in 8 CB (4n-octyl-cyanobiphenyl from Merck Corp.). This compound exhibits a quasi-second-order nematic-smectic-*A* phase transition at $T_c \approx 33.4\,^\circ\mathrm{C}$ [11(a)–11(c)].

IV. LINE TENSION MEASUREMENTS

We performed systematic measurements of the line tension of elementary dislocation ($b=d$) as a function of temperature and film thickness.

These measurements prove challenging for several reasons. We have already stressed the problem of temperature gradients that occur when the temperature is raised. This problem was solved by improving the thermal homogeneity of the oven. A more serious problem that was too quickly eluded in Ref. [7] concerns the dynamics of the dislocation loop. Indeed, loops constantly grow even after meeting the top side of the frame. This motion is unavoidable because the pressure in the meniscus is smaller than the atmospheric pressure. As a consequence, loops are never at equilibrium and Eq. (3) cannot be strictly applied. Nevertheless, it can be used as a first approximation if the growth time of the loops $\tau_{\mathrm{growth}} \approx a/V$ is long in comparison with their typical relaxation time $\tau_{\mathrm{relax}} \approx \eta N\, da/E$ when they are deformed [12]:

$$\tau_{\mathrm{growth}} \approx \frac{a}{V} \gg \tau_{\mathrm{relax}} \approx \frac{\eta N d a}{E}. \tag{11}$$

In the above expression, a is the loop size, V the dislocation velocity, Nd the film thickness, and η the in-layer shear viscosity. Having in mind that $V=\mu \Delta P$, where μ is the dislocation mobility, Eq. (11) becomes

$$\Delta P \ll \frac{E}{\mu \eta N d}. \tag{12}$$

Note that the loop size does not enter into this equation.

In thick films of 8CB, $N=100$ while $d=30\,\text{Å}$, $\eta \approx 5$ Poise [13], $E \approx 7\times 10^{-7}$ dyn [5], and $\mu \approx 5\times 10^{-7}\ \mathrm{cm^2\,sg^{-1}}$ [14] at room temperature. Equation (12) then gives $\Delta P \ll 9000\ \mathrm{dyn/cm^2}$. In typical experiments $\Delta P \approx 400\ \mathrm{dyn/cm^2}$ [corresponding to $V \approx 1\ \mu\mathrm{m/s}$ and Eq. (12)] is fulfilled. Consequently, loops are close to equilibrium at room temperature and their shape can be reasonably analyzed using the static Eq. (3) (as performed in Ref. [7]).

The situation becomes more complicated when working at higher temperature. Indeed, E decreases and tends towards zero while μ strongly increases as the nematic phase is approached. By contrast, η decreases but does not go to zero at the transition. Consequently, $E/\mu \eta N d$ decreases and goes to zero when temperature increases while ΔP remains finite (we recall that ΔP is imposed by the meniscus). As a consequence, the higher the temperature, the more difficult it is to satisfy the condition given in Eq. (12).

In our experiments, we quickly met this limitation in spite of our efforts to make meniscus as big as possible, so as to reduce ΔP and the velocity. This is visible in Fig. 4 where we display E_{fit}/b as a function of the vertical velocity v_{vert} of the dislocation at point P (see Fig. 1). In this graph E_{fit} is the value of the line tension found from the best fit with the static shape given by Eq. (3). It is worth noting that the theoretical shape always fits perfectly to the experimental one (within the resolution of the microscope). We also note that v_{vert} decreases when the loop grows because the pressure difference $\Delta P = \Delta P_0 + \rho g z_P$ at point P of height $z_P < 0$ decreases. On the other hand, E_{fit} is not constant, but systematically increases when v_{vert} decreases. This effect is more important at high temperature because condition (12) becomes more difficult to satisfy. Since we are not able to solve the nonlocal hydrodynamic problem of a growing loop theoretically, we linearly extrapolate E_{fit}/b to zero vertical velocity and take this value for the line tension E/b. The limit $v_{\mathrm{vert}} \to 0$ cannot be reached experimentally because it corresponds to point P at $z_P = -\Delta P_0/\rho g$, which is usually below the bottom side of the frame.

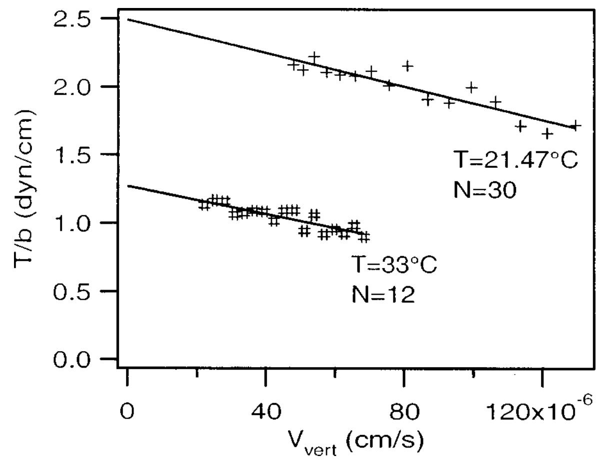

FIG. 4. Two examples of linear extrapolation to zero vertical velocity of the line tension found from the best fit to the static shape given by Eq. (3).

This procedure seems artificial but can be justified from an experimental point of view. Indeed, we checked that it gives a value of the line tension compatible with that found by measuring the critical radius of nucleation in an horizontal film (this method gives $E/b \approx 2.5 \pm 0.3$ dyn/cm at 28 °C [6] to compare with $E/b = 2.1 \pm 0.2$ dyn/cm in vertical films). Moreover, the extrapolated values are much less dispersed at each temperature than the direct values obtained for different films of equal thickness. That means that the procedure makes sense even if we cannot prove it theoretically.

In Fig. 5, E/b is displayed as a function of the number of layers N at $T=33\,^\circ\mathrm{C}$. It slowly increases when N decreases in qualitative agreement with theoretical predictions of Sec. II.

In Fig. 6, E/b is displayed as a function of temperature T. Unfortunately, it was impossible to perform all measurements at the same thickness. For this reason, we give the number of layers for each point. That is important because the surface correction to the line tension is not negligible, as we have just seen. As expected, the line tension decreases when the temperature increases. However, it clearly differs from zero at T_c, the bulk nematic-smectic-*A* transition temperature (given by the dotted vertical line in the graph). This effect is due to the finite thickness of the films and to the increase of the smectic-order parameter at the free surfaces [15]. In other words, the surfaces act as an external field that changes the transition temperature (which becomes T_N, a function of N and of the pressure ΔP). Because $T_N > T_c$

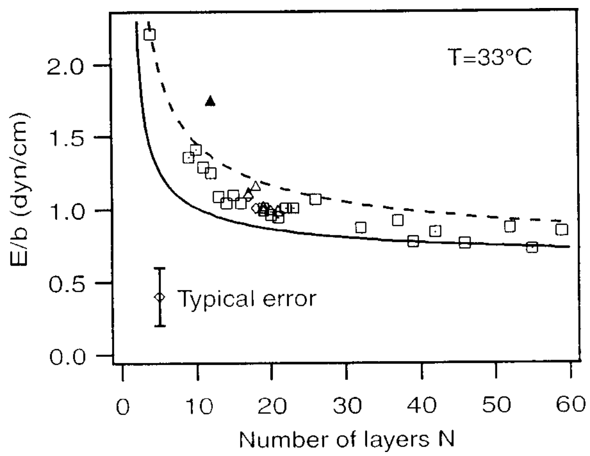

FIG. 5. Line tension E/b as a function of the film thickness N. Empty squares, triangles, and diamonds correspond to elementary dislocations in three different films at $T=33\,°C$. The full triangle corresponds to the dislocation of Burgers vectors $b=60\,Å$ (two layers) shown in Fig. 1 at $T=33\,°C$. The solid curve (for elementary dislocations) has been displayed by taking $E_\infty/b=0.56$ dyn/cm [obtained from Eq. (14)] and by calculating the surface correction $\delta E_s(N)/b$ from Eq. (6) with values of K and B experimentally measured in bulk samples at $T=33\,°C$ (see the Appendix). The dotted line is the prediction for a dislocation of Burgers vector $b=60\,Å$ at the same temperature.

(typical temperature shift will be given in Sec. VI), the layer compressibility B (and thus also the line tension of the dislocations) differs from 0 at T_c.

Before discussing further this problem, we present new experimental results on the contact angle θ between the loop and the edge of the meniscus (see Fig. 1) and we explain why we were not able to perform line tension measurements far above T_c.

V. CONTACT ANGLE θ BETWEEN THE LOOP AND THE MENISCUS

This angle is defined in Fig. 1. It is independent of the growth velocity and of the size of the loop within experimental errors (Fig. 7).

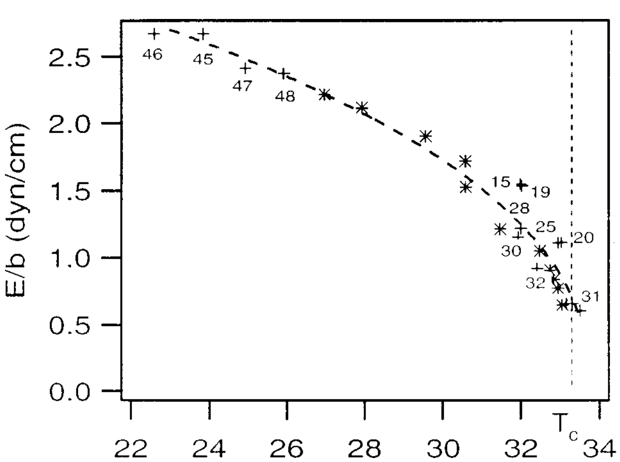

FIG. 6. Line tension E/b as a function of temperature T measured in five different films. The thickness of the film (given as its number of layers) is given for a few points. The stars correspond to films of thicknesses close to 80 layers (± 10 layers). The dashed line is just a guide for the eye.

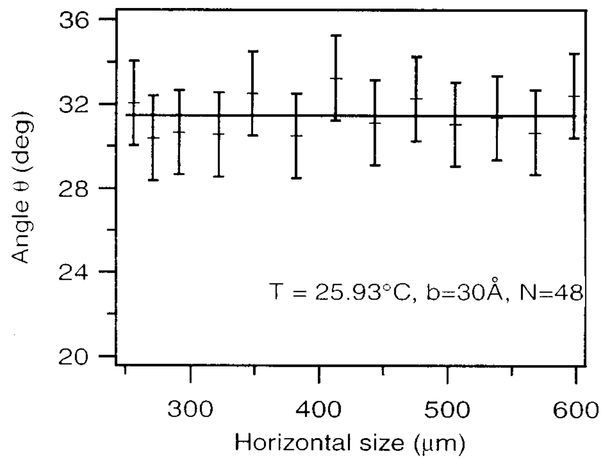

FIG. 7. Contact angle θ as a function of the horizontal size of the loop measured between its two vertical parts ($T=25.93\,°C$ and $N=48$).

On the other hand, Figs. 8 and 9 show that θ increases when the film thickness increases and when the temperature increases. The angle also decreases when the Burgers vector of the dislocation increases, though we did not perform systematic measurements as a function of b. Finally, θ can be larger than 90° when films are overheated above T_c. In this case, loops grow fast as the mobility of the dislocation is typically 5 times larger than it is at 28 °C [14]. As a consequence, the two contact points quickly propagate along the top meniscus (Fig. 10) and reach the vertical sides of the frame before the shape of the loop is stabilized (it takes more and more time because the line tension is small and the loop is very large). It is worth noting that above T_c, a film can be stable (even if its meniscus has melted in the nematic phase) because we still need to heat it locally with the heating wire to nucleate loops and to decrease the thickness of the film. An interesting observation is that the nucleation becomes easier on the meniscus (heterogeneous nucleation) than in the middle of the film when $\theta>90°$. Finally, we observed that θ continues to increase when the temperature increases (systematic measurements are difficult to perform because films can break easily). We even suspect that at some temperature T_N, for which the film becomes unstable with re-

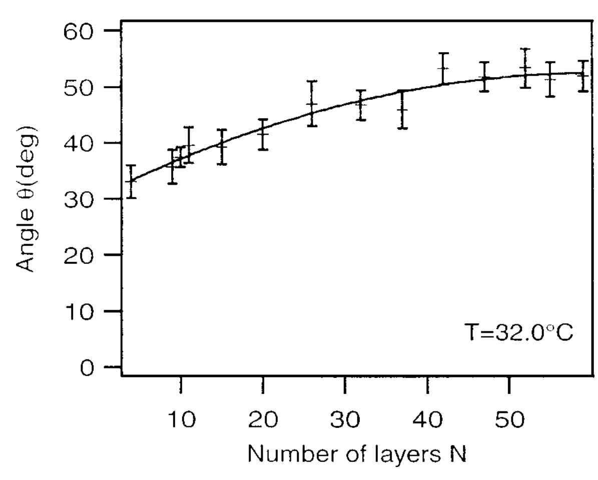

FIG. 8. Contact angle θ as a function of the number of layers N at $T=32\,°C$.

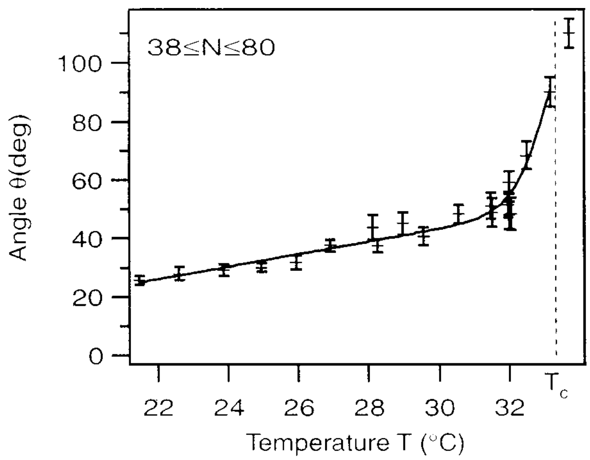

FIG. 9. Contact angle θ as a function of temperature.

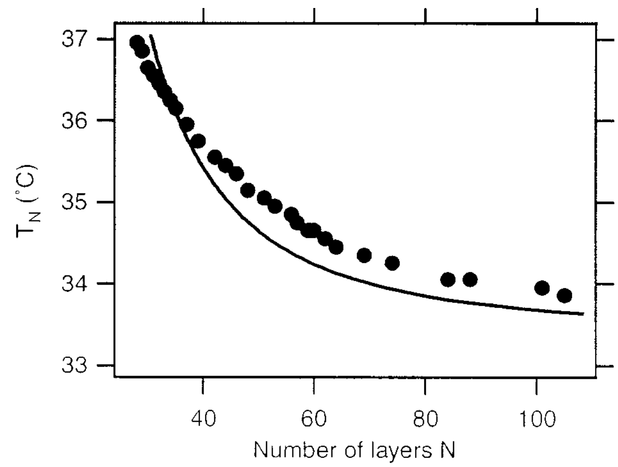

FIG. 11. Thinning transition temperature T_N as a function of number of layers N for a film with $\Delta P = 70\,\mathrm{dyn\,cm^{-2}}$ (from Ref. [15]). The solid line is the best fit from Eq. (13) with $\mathcal{A} \approx 0.26$ and $\mathcal{B} \approx 1.2\times 10^8\,\mathrm{dyn^{-1}\,cm^2}$.

spect to spontaneous thinning from N layers to $N-1$ layers, θ should reach 180°. Such a situation resembles a wetting transition close to a critical point. We emphasize that the smectic-order parameter, and thus the compressibility modulus, strongly decreases in the middle of the film thickness at T_N, which is also the effective transition temperature we were speaking about in the previous section.

VI. DISCUSSION

We will show in a forthcoming paper [15] that T_N can be measured in horizontal films as a function of N and ΔP. We have found that T_N decreases when N increases and decreases when ΔP increases in good agreement with the theoretical prediction of Gorodetskiĭ *et al.* [16]:

$$N = \mathcal{A}\frac{a\sinh[\mathcal{B}\sqrt{(T_N-T_c)/T_c}/\Delta P]}{\sqrt{(T_N-T_c)/T_c}}, \tag{13}$$

where $\mathcal{A}$ and $\mathcal{B}$ are material constants. The best fit of our experimental data to this equation gives $\mathcal{A} \approx 0.26$ and $\mathcal{B} \approx 1.2\times 10^8\,\mathrm{dyn^{-1}/cm^2}$ (Fig. 11) [15]. These experiments allow us to predict T_N in vertical films providing ΔP is known. In general, $\Delta P \approx 400\,\mathrm{dyn/cm^2}$ in the vicinity of the topside of the frame where measurements are done. This estimation of ΔP comes from the observation that dislocations slow down when they approach the bottom side of the frame, which means that $\Delta P \approx 0$ at this level (situated 4 mm lower than the top side of the frame). With $\Delta P = 400\,\mathrm{dyn/cm^2}$ we calculate $T_{80}-T_c \approx 0.3\,°\mathrm{C}$, $T_{40}-T_c \approx 2\,°\mathrm{C}$, and $T_{20}-T_c \approx 6\,°\mathrm{C}$ (see Fig. 11). These estimates give an idea of the importance of the surface effects for typical thicknesses. In thin films ($N \approx 20$) surface effects and the associated variations of B are important within $\pm 6\,°\mathrm{C}$ around T_c, whereas in thick films ($N \approx 80$), these effects are important only within $\pm 0.3\,°\mathrm{C}$ around T_c.

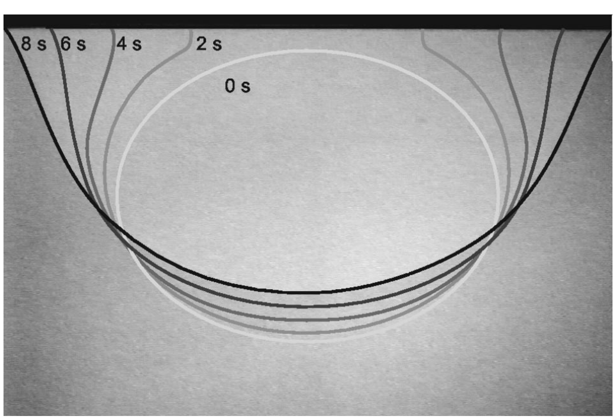

FIG. 10. Superimposition of five pictures showing the rapid evolution of a dislocation loop in an overheated film at $T > T_c$. For clarity, loop contours have been underlined. Time interval between two pictures is $2s$. Angle θ is larger than $\pi/2$. The two contact points quickly propagate along the top part of the meniscus and reach the vertical sides of the frame before the ''equilibrium shape'' has been reached. The line tension measurement becomes impossible.

This indicates that, in thick films and far enough from T_c (typically 0.3 °C below T_c in films of 80 layers or more and 2 °C below T_c in films of 40 layers), the compressibility modulus is very close to that measured in bulk samples. In this limit, the theoretical predictions of Sec. II, where we implicitly assumed that B is the bulk modulus, are valid. It is thus possible to calculate $\delta E_s/b$ for each dislocation providing that B and K are known as a function of temperature. We measured these constants in a creep cell described in Ref. [17] using the same methods as in Ref. [6]. We found that K is approximately constant:

$$K = (5.2\pm 0.3)10^{-7}\ \mathrm{erg/cm}, \tag{14}$$

whereas B can be fitted to a power law (Fig. 12)

$$B = B^0 t^{\beta}, \tag{15}$$

where t is the reduced temperature $t = (T_c - T)/T_c$, $T_c = 33.4\,°\mathrm{C}$, $B^0 = (4.35\pm 0.04)10^8\,\mathrm{erg/cm^3}$, and $\beta = 0.328 \pm 0.005$. These values are compatible with previous measurements of B [18–20] and K [21–23].

We then calculated the theoretical values of the surface correction $\delta E_s/b$ for the dislocations observed in thick films. By subtracting this correction from the experimental value of

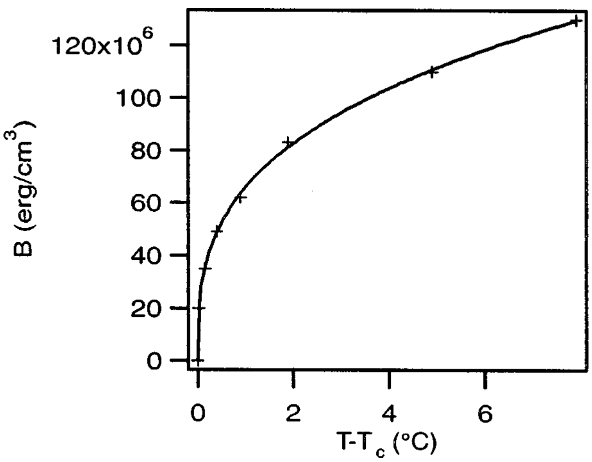

FIG. 12. Compressibility modulus B as a function of temperature. The solid line is the best fit to a power law [Eq. (15)] with $B=(4.35\pm0.04)10^8$ erg/cm^3 and $\beta=0.328\pm0.005$.

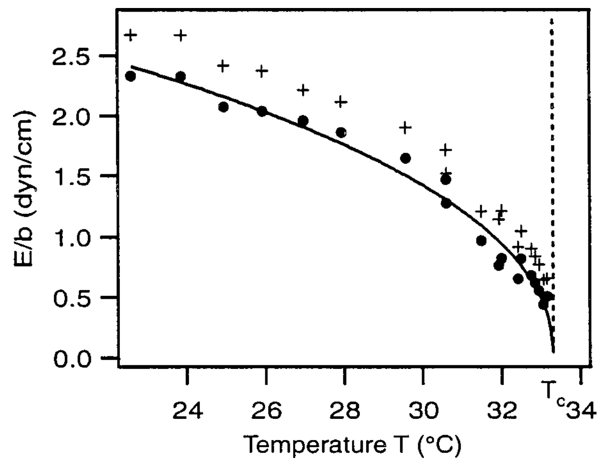

FIG. 13. Line tension of elementary dislocation measured in thick films (40 to 80 layers) as a function of temperature (crosses). Filled circles correspond to line tension in an infinite medium. The solid line is the best fit to a power law [Eq. (16)] with $T_c=33.30\pm0.15$ °C, $E_\infty^0/b\approx11.04\pm0.04$ dyn/cm, and $\zeta\approx0.45\pm0.02$.

the line tension, we obtained the line tension E_∞/b for bulk dislocations. These data are given in Fig. 13. The best fit to a power law gives

$$E_\infty/b=(E_\infty^0/b)t^\zeta, \tag{16}$$

where t is the reduced temperature $t=(T_c-T)/T_c$ with $T_c=33.30\pm0.15$ °C, $E_\infty^0/b=11.04\pm0.04$ dyn/cm, and $\zeta=0.45\pm0.02$. The value of T_c is in agreement (within experimental errors) with that measured in a bulk sample ($T_c=33.4$ °C). As expected E_∞/b goes to zero at T_c. Because K and B are known [Eqs. (14) and (15)] we can deduce the cutoff energy γ_c and the core radius r_c as a function of temperature. It gives

$$\gamma_c=\gamma_c^0/bt^\xi, \tag{17}$$

with $\gamma_c^0/b=10.4\pm0.4$ erg/cm^2 and $\xi=0.70\pm0.05$ and

$$r_c/b=(r_c^0/b)t^\delta \tag{18}$$

with $r_c^0/b=0.265\pm0.010$ and $\delta=-0.25\pm0.03$.

As expected, γ_c goes to zero at T_c, whereas r_c slowly diverges and is of the order of the Burgers vector.

In thin films, the situation is more complicated near T_c because B depends on the film thickness and even on the position within the film thickness, being maximal at the free surfaces and minimal in the middle. As a consequence, the surface correction calculated from Eq. (7) by taking the bulk value for B must be systematically smaller than the correction observed experimentally. This is what we observe in Fig. 5 where we displayed the theoretical values of E/b. As expected, the theoretical values of the line tension calculated at $T=33$ °C for dislocations of Burgers vector b and $2b$ by taking the bulk value for B [Eq. (15)] and the above expression for E_∞/b [Eq. (16)] are systematically smaller than values found experimentally. In addition, the shift between theoretical and experimental values increases when the film thickness decreases. This proves that B increases on average when the film thickness decreases.

VII. CONCLUSION

In conclusion, we have proposed a method to measure the line tension of a dislocation in a vertical free-standing film. Particular precautions must be taken to avoid convection and temperature gradients that can strongly deform the dislocation. In particular, there is a strong interaction between the dislocation loop and the heating wire used to nucleate it. This interaction must be eliminated before measuring the line tension.

We have then showed that surface effects change the line tension in two ways: first, they introduce a surface correction that depends on the surface tension of the liquid crystal; second, they change the transition temperature and simultaneously the bulk elastic modulus. This is the reason why the line tension does not approach zero at T_c, the bulk transition temperature.

Finally, we have deduced from our data in thick films the critical behavior of both the line tension and the core size of bulk dislocations. An unsolved question is the role of hydrodynamic effects in the film and their influence on the measured line tension. We think that our extrapolation procedure gives correct values within ±20%, but a systematic error cannot be excluded. This shift should not significantly change the temperature dependencies of the line tension and of the core radius, nor of the associated critical exponents. Nevertheless, we think that numerical simulations of the loop dynamics in a vertical film would be an interesting problem to solve.

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