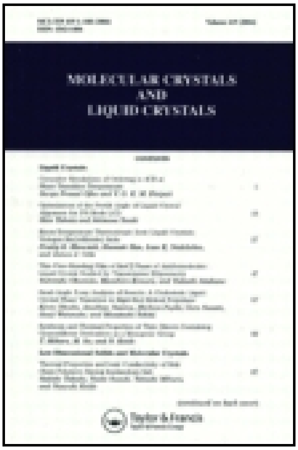

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We study here the behaviour of S=+1 and S=-1 disclinations in SmC films submitted to a rotating electric field. In agreement with Cladis et al. experiments we observe that a S=+1 disclination submitted to large enough torque leaves the centre of the film and is orbiting around a target-like pattern. A single S=-1 disclination submitted to a torque behaves differently: independently of the applied torque, it stays in the centre of the film. We explain this difference as due to the presence (S=+1) and the absence (S=-1) of energy barriers with respect to the phase winding.

I. CLADIS' ORBITING DISCLINATIONS

Recently, Cladis et al. [1,2] studied behaviour of S=+1 disclinations in SmC films submitted to a torque exerted by a rotating electric field. They have shown that above a certain threshold value of the applied torque, the disclination is leaving the centre of the film and is orbiting around a target-like pattern formed in the centre of the film.

Using the experimental set-up developed for studies of topological flows and described in details in the accompanying paper [3], we have reproduced the Cladis et al. experiments. This is illustrated in fig.1. The disclination contains a dust particle in its core. The role of the dust particle is essential in our experiments : it exerts an anchoring action on the director field $\mathbf{c}(r=r_i)$ and blocks the phase $\varphi(r=r_i)$ at a constant value $W\pi$. As explained in ref. [3], the winding number W can be chosen arbitrarily by a suitable treatment : winding of the phase of a "fresh" disclination followed by several hours ageing process during which the dust particles accumulate in the disclination core and block the phase. As shown in fig.1.1, in the absence of the external torque the two extinction brushes visible between slightly decrossed polars form a spiral which is very tight in the centre and much less at the periphery.

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This pattern is characteristic of the logarithmic configuration

$$\varphi(r) = \varphi_{ns}(r) + S\psi = W\pi \ln \frac{(r/R)}{(r_i/R)} + S\psi \qquad (1)$$

which satisfies the Laplace equation $\Delta\varphi=0$ expressing the equilibrium condition - the vanishing of the elastic torque.

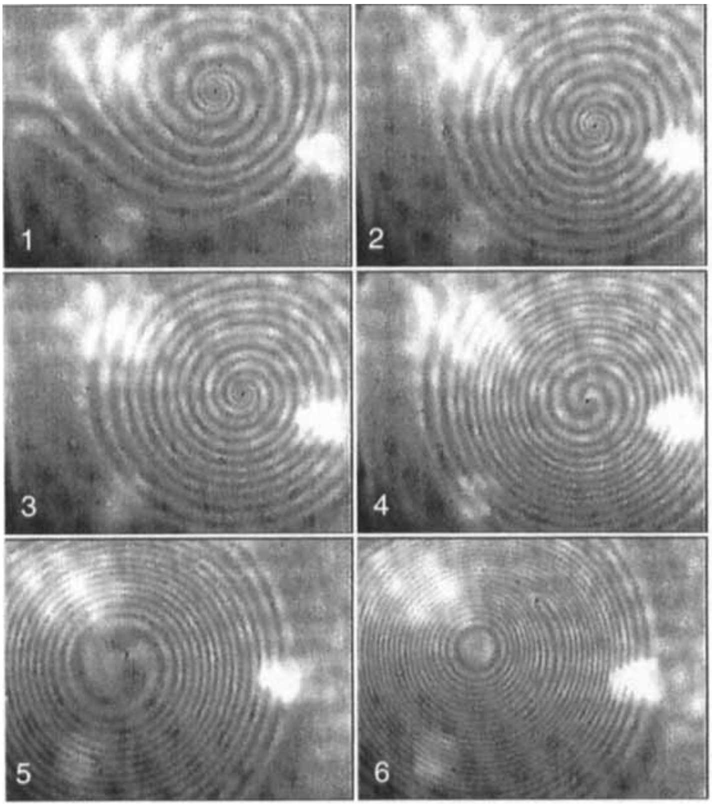

FIGURE 1 : Behaviour of a S=+1 disclination in a rotating electric field.

This blocked disclination is then submitted to the rotating electric field generated by three electrodes (white spots in fig.1) supplied with a three-phase AC voltage. Due to the action of the torque exerted by the rotating field on the director, the disclination changes progressively its configuration from the logarithmic to the parabolic one (figs.1.2-1.4). As explained in ref [3], due to the presence of topological flows, some fraction of the external is dissipated and only the remaining fraction $\tilde{\Gamma}$ distorts the phase field, accordingly to the equation (eq.(26) in ref. [3]) :

$$K\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi}{\partial r}\right)=-\Gamma\left(1-\frac{\gamma_1}{4\eta}\right)=-\tilde{\Gamma} \tag{2}$$

In the approximation of the position-independent torque and in the circular geometry, this change in the conformation of the disclination can be expressed as a change in the non singular contribution to the phase field :

$$\varphi_{ns}(r)=(W\pi)\left[\alpha\frac{ln(r/R)}{ln(r_i/R)}+\beta\frac{R^2-r^2}{R^2-r_i^2}\right] \tag{3}$$

where $\beta=1-\alpha$ is proportional to the applied the torque. For a critical value of the effective torque $\tilde{\Gamma}_{crit}$, $\beta=1$ and the configuration becomes purely parabolic. Theoretically, for $\Gamma>\tilde{\Gamma}_{crit}$, the logarithmic contribution should appear again with the negative sign. Experiments show however that this configuration with reversed logarithmic contribution is unstable. As shown in fig.1.5 and 1.6, the disclination leaves the centre of the pattern and starts to circulate around the target-like pattern. As explained by Cladis et al.[2], in the steady state, the phase is continuously created in the centre of the target at rate $\omega=d\varphi/dt$ (the periodic changes of the light intensity from dark to bright indicate that the director **c** rotates there with a constant angular velocity ω). Simultaneously, the disclination circulates around the target pattern with the same angular velocity and acts a phase sink absorbing 2π at each revolution. The non singular part of the phase field corresponding to this steady state can be represented as :

$$\varphi_{ns}(r,t)=(W\pi)\beta\frac{R^2-r^2}{R^2-r_i^2}+\omega t\ g(r) \tag{4}$$

where $g(r<r_o)=1$ and $g(r>r_o)=0$, with r_o corresponding to the radius of the disclinations orbit. The radius of the orbit r_o is such that

$$\varphi_{ns}(r_o)=W\pi \tag{5}$$

In other words, the disclination with the blocked phase leaves the centre of the parabolic phase field where the phase $\beta W\pi$ is larger than $W\pi$ and reaches the position where the phase is appropriate that is to say $W\pi$.

II. BEHAVIOUR OF A S=-1 DISCLINATION SUBMITTED TO A TORQUE

As explained in the accompanying paper [3], the system of electrodes creating the rotating electric field can be translated in the plane of the film and positioned precisely below one disclination or below a group of disclinations. In principle, due to the anchoring of the director field at the meniscus, one S=+1 disclination situated in the centre of the film or one S=+2 disclination situated at the edge of the film correspond to the equilibrium configuration. However, immediately after the process of film drawing, the director field can contain a large number of S=+1 and S=-1 disclinations whose total topological charge is S=+1. Due to large dimensions of the film of the order of a few mm, the relaxation toward the global equilibrium configuration is very slow and needs several hours. Therefore, it is possible to apply the rotating field to one S=-1 disclination or to a group of disclinations and to study the evolution into a local steady state.
The observed behaviour of S=-1 disclination is very different from that of the S=+1 disclinations. It is illustrated by a series of three photographs shown in fig. 2. The director field contains there four S=-1 disclinations. In the first photograph (fig.2, top) two S=-1 disclinations are situated in the centre of the pattern. The third and fourth S=-1 disclination is situated at some distance from the centre. The evolution of this configuration is shown in the next two photographs below : the third and fourth disclinations converge toward the centre of the pattern. In the last photograph of the series (fig.2, bottom) the third disclination already reached the centre of the pattern while the fourth one is still converging.

The phase field $\varphi(\mathbf{r},t)$ in these photographs can be deduced from the shape of the extinction brushes which have spiral shapes as in the case of the S=+1 disclination but for the same sense of the rotation of the field, they the spirals are reversed with respect to the case of the S=+1 disclination. If the rotating field is applied to one isolated S=-1 disclination, it stays in the centre of the field and rotates as a whole unless the steady state is reached. The rotation of the S=-1 disclination results in the winding the phase : the non singular part of the phase field is created . Analytically, this can be expressed as:

$$\varphi(r,\psi,t) = \varphi_{ns}(r,t) + S\psi = \varphi_o(t)\frac{R^2 - r^2}{R^2} - \psi \tag{6}$$

In the steady state, the phase φ_0 in the centre of the disclination reaches the value determined by the balance of the elastic and the effective torque (eq.(2)).

In the case of a group of S=-1 disclinations, the steady state configuration is a little more complex : 1°- they converge slowly to the centre of the pattern, 2°- they form there a regular polygon rotating as a whole around a small target pattern.

The angular velocity of this "constellation" in the steady state depends on the number n of disclinations. If the angular velocity of the director in the centre of the target pattern is Ω, then the angular velocity of the polygon is $\omega=\Omega/n$.

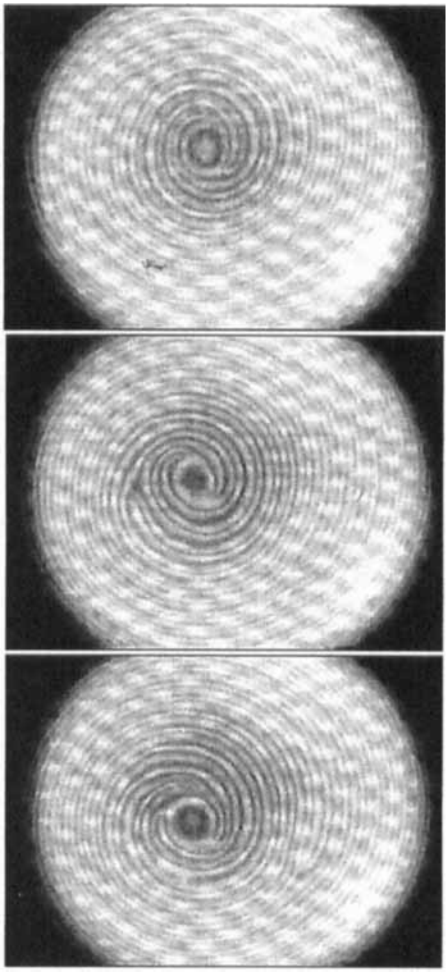

FIGURE 2: Behaviour of a group of S=-1 disclinations in the rotating electric field.

This means that, as in the case of the S=+1 disclination, the phase created in the centre of the target pattern is annihilated by disclinations orbiting around it. However, in contradistinction with the case of S=+1 disclination, the radius of the orbit does not results from the phase blockage in the disclination core but from repulsion between disclinations of the same sign.

III. CONCLUSIONS

We have shown here that the S=-1 disclinations behave in the rotating electric field differently than the S=+1 disclinations. For a large enough external torque, the S=+1 disclinations are orbiting around a target-like pattern and the radius of the orbit depends on the torque. This is mainly due to the fact that the phase in the centre of the S=+1 disclinations is blocked (either due to the elastic anisotropy or to the anchoring on a inclusion). For the S=-1 disclinations, the phase in their centre is free because a rotation of a S=-1 disclination as a whole changes the phase. For this reason, an isolated S=-1 disclination stays in the centre of the pattern, no matter what the external torque is. For a group of the S=-1 disclinations, the formation of the target pattern and simultaneous orbiting of disclinations is observed but this results from the repulsion between disclinations and not from the phase blockage.

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[3] C. Chevallard, J.-M. Gilli, T. Frisch, I.V. Chikina and P. Pieranski, "Magic spiral submitted to an external torque", Proceedings of the 17th ILCC, Strasbourg, 1998.