

C H A P T E R V I

HIGH STRENGTH DEFECTS IN NEMATIC LIQUID CRYSTALS

6.1 INTRODUCTION

The schlieren texture of nematic liquid crystals is characterised by a set of points at which the director orientation is discontinuous. These points correspond to disclination lines viewed end on. Between crossed polarisers these points are connected by dark brushes which are regions in which the director is either parallel or perpendicular to the plane of polarisation of the incident light (see for e.g., Fig.1.12).

A mathematical analysis of the actual configuration around the disclinations was given by Oseen (1933) and Frank (1958). (See also the recent review by Chandrasekhar and Ranganath 1986). Nehring and Saupe (1972) have made experimental observations on the Schlieren textures and developed the theory further. The continuum theory of elastic deformations forms the basis of such mathematical treatments. The director \vec{n} changes its orientation continuously around a disclination. This curvature of the director costs elastic energy. The actual configuration around the defects can be obtained by minimising the free energy density. We now give a brief summary of the theory.

We introduce a space fixed Cartesian coordinate system (x, y, z)

with the z-axis perpendicular to the plane of the nematic layer. A planar structure with \vec{n} lying in the x-y plane is assumed. The components of \vec{n} are $\cos \psi$, $\sin \psi$, 0, where ψ is the angle between \vec{n} and the x-axis.

The elastic free energy density is given by

$$F_d = \frac{1}{2} [K_{11} (\text{div } \vec{n})^2 + K_{22} (\vec{n} \cdot \text{curl } \vec{n})^2 + K_{33} (\vec{n} \times \text{curl } \vec{n})^2] \quad (6.1)$$

When anisotropy of elastic constants is considered it is very difficult to obtain exact solutions corresponding to the director configurations around the defects. Nehring and Saupe (1972) have obtained only perturbation solutions taking into consideration a small elastic anisotropy. If a one constant approximation is considered, i.e., $K_{11} = K_{22} = K_{33} = K$, it is easy to obtain solutions for the director configurations. Eqn. (6.1) can then be written as

$$F_d = \frac{1}{2} K [(\text{div } \vec{n})^2 + (\text{curl } \vec{n})^2] \quad (6.2)$$

The minimisation of F_d results in the following equation of equilibrium (the Euler-Lagrange equation)

$$[\partial F / \partial n_{i,j}]_j - \partial F / \partial n_i = 0 \quad (6.3)$$

where $n_{i,j} = \partial n_i / \partial x_j$; ($i, j = 1, 2$, where $x_1 = x$, $x_2 = y$ and $n_1 = n_x$, $n_2 = n_y$) which yields

$$\psi_{,xx} + \psi_{,yy} = 0 \quad (6.4)$$

The solutions of this equation are $\psi = \text{constant}$ corresponding to a uniform director orientation and

$$\psi = s\alpha + c \quad (6.5)$$

corresponding to the disclinations called wedge disclinations. Here $\alpha = \tan^{-1}(y/x)$ and c is a constant. It is clear that ψ becomes multiple valued at the centre of the defect and hence leads to a singularity at that point. In order to maintain continuity on going in a closed circuit around a disclination, the director has to match with its original orientation. Considering the apolarity of the director, $s = 1/2 m$, where $m = \pm 1, 2, \dots$. s is called the strength of the disclination line. For integral values of s the director rotates by even multiples of π on making a full turn around the disclination line and for half integral values of s the director rotates by odd multiples of π .

The director configurations around defects of various strengths are sketched in Fig. 6.1. For $s \neq +1$ the structure of the disclination is independent of the constant c . A change Δc only causes a rotation of the structure around the z -axis by an angle $\Delta c/(1-s)$, but for $s = +1$ a change in c changes the structure around the singularity. $c \neq m \frac{\pi}{2}$ (where m is an integer) corresponds to logarithmic spirals, $c = m\pi$ to an all radial and $c = (m + \frac{1}{2})\pi$ to a all circular

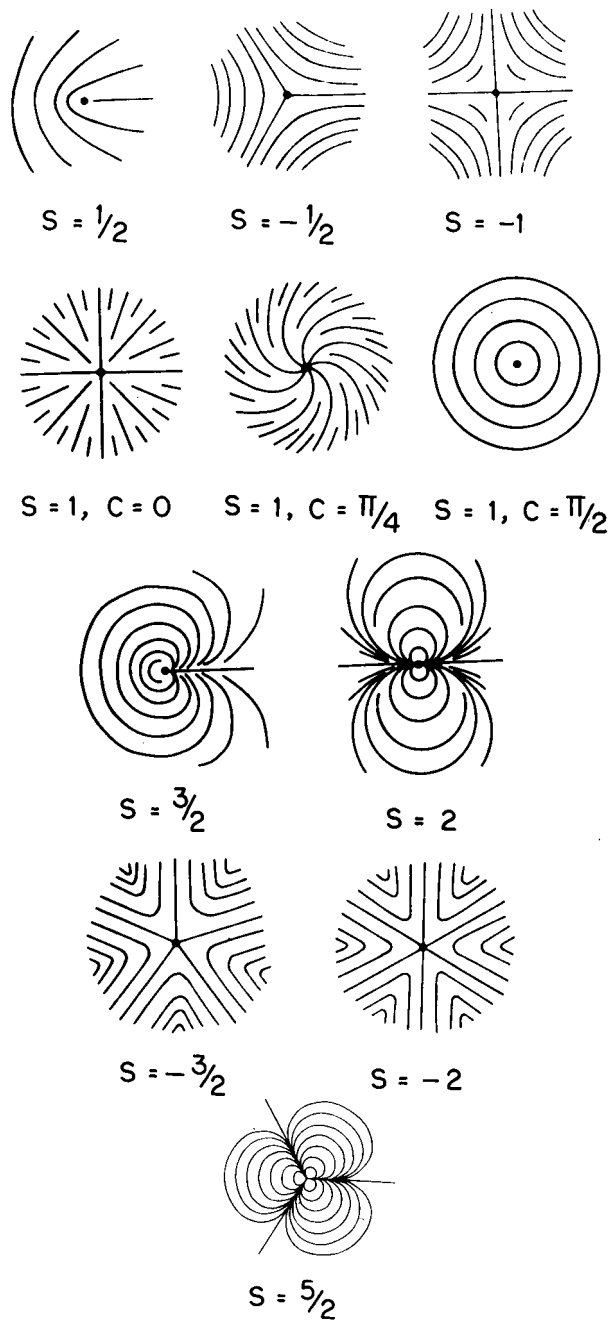


Figure 6.1. Schematic diagram of the director fields around disclinations of various strengths, according to eqn (6.5).

arrangement in the x-y plane. However when elastic anisotropy is considered the only configuration allowed for the $s = +1$ defect is either the purely radial or the purely circular configurations (Dzyaloshinskii 1970, Cladis and Kleman 1972, Nehring and Saupe 1972).

6.2 ENERGY OF AN ISOLATED DISCLINATION LINE

We now calculate the deformation energy' per unit length of an isolated disclination line (Nehring and Saupe, 1972). Considering the cylindrical coordinate system and assuming that a core region extends from the origin to r_c the deformation energy per unit length

$$W = \int_{r_c}^R \int_0^{2\pi} F_d(r) r dr d\alpha$$

From Eqns. (6.2) and (6.5)

$$W = W_c + \pi K s^2 \ln R/r_c \quad (6.6)$$

W_c is the energy of the core and R is the size of the sample. Assuming that W_c makes a relatively small contribution, W has a logarithmic divergence with the size of the sample. For a given R and r_c the elastic energy carried by a defect is proportional to s^2 , thus disclinations with $s = \pm 1$ cost four times the energy of those with $s = \pm \frac{1}{2}$ in this approximation. This means that all defects of strength $|s| > \frac{1}{2}$ should spontaneously break up to

form a number of defects of strength $s = \pm \frac{1}{2}$ only.

However experimentally $s = \pm 1$ disclinations are frequently seen and are found to be quite stable. This problem was resolved by Cladis and Kleman (1972) and Meyer (1973A). They noted that if the director is allowed to collapse in the third dimension over a radius R , such that it points along the z -axis at the origin, the total energy is reduced and the core can be dispensed with. We consider a long circular cylinder of radius R containing a nematic liquid crystal. Let us take the case of an $s = +1$ disclination line. This can have either a radial distribution or a circular distribution of the director. In the cylindrical coordinate system, the components of \vec{n} for the pure splay (radial) case are $n_r = \cos \theta$, $n_z = \sin \theta$ and $n_\phi = 0$ and for the pure bend (circular case) are $n_r = 0$, $n_\phi = \cos \theta$ and $n_z = \sin \theta$ (Fig. 6.2). θ is a function of the radius.

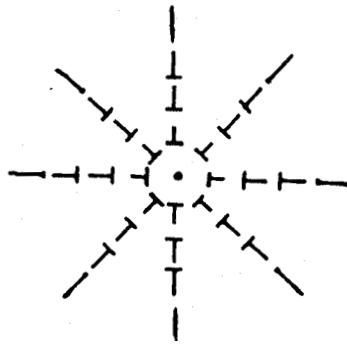
In the one constant approximation the free energy per unit length of the cylinder for both cases is given by

$$F = \pi K \int_{r_c}^R [\cos^2 \theta - 2r \sin \theta \cos \theta \frac{d\theta}{dr} + r^2 (\frac{d\theta}{dr})^2] \frac{dr}{r} \quad (6.7)$$

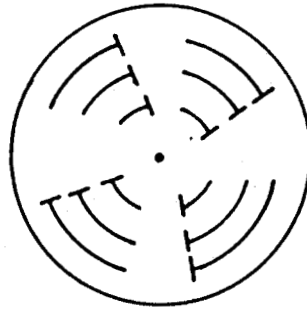
The Euler-Lagrange equation is

$$\frac{d}{dr} (r \frac{d\theta}{dr}) = - \frac{\sin \theta \cos \theta}{r} \quad (6.8)$$

This has the general solution



$S = +1$
Splay



$S = +1$
Bend

Figure 6.2

Collapse of the director at the centre of the $S = +1$ disclinations. Nails signify that the director is tilted with respect to the plane of the paper.

6.4 ANISOTROPY OF ELASTIC CONSTANTS

Anisotropy of elastic constants ($K_{11} \neq K_{22} \neq K_{33}$) changes the solution for the director field around a single defect (Nehring and Saupe 1972) as also the configuration and the energy of interaction between the pair of defects. Ranganath (1980) has shown that depending on the anisotropy, specific values of c should be favoured. This is due to the presence of angular forces which can be computed as follows.

Considering the anisotropy of elastic constants, F_d given by Eqn. (6.1) can be written as

$$F_d = \frac{1}{2}K [(\nabla\psi)^2 + \epsilon\{(\psi_y^2 - \psi_x^2) \cos 2\psi - 2\psi_x\psi_y \sin 2\psi\}] \quad (6.18)$$

where

$$K = \frac{K_{11} + K_{33}}{2}, \quad \epsilon = \frac{K_{11} - K_{33}}{K_{11} + K_{33}}$$

and partial differentiation is indicated by the suffixes x or y . (The director is confined to the x - y plane.)

The equation of equilibrium is obtained by minimising the free energy. Therefore

$$\begin{aligned} \psi_{xx} + \psi_{yy} = \epsilon [& (\psi_{xx} - \psi_{yy} + 2\psi_x\psi_y) \cos 2\psi \\ & - (\psi_x^2 - \psi_y^2 - 2\psi_{xy}) \sin 2\psi] \end{aligned} \quad (6.19)$$

where ψ is as defined before. If ϵ is small the solution $\psi = \psi^0 + \epsilon\phi$ is assumed where

$$\psi^0 = \sum_i s_i \tan^{-1} \frac{y - y_i}{x - x_i} + c$$

for a collection of defects of strength s_i at (x_i, y_i) . Neglecting second and higher powers of ϵ ,

$$\nabla^2 \phi = [(\psi_{xx}^0 - \psi_{yy}^0 + 2\psi_x^0 \psi_y^0) \cos 2\psi^0 - (\psi_x^0{}^2 - \psi_y^0{}^2 - 2\psi_{xy}^0) \sin 2\psi^0] \quad (6.20)$$

The free energy is

$$F_d = \frac{K}{2} \left[(\nabla\psi^0)^2 - \epsilon [(\psi_x^0{}^2 - \psi_y^0{}^2) \cos 2\psi^0 + 2\psi_x^0 \psi_y^0 \sin 2\psi^0] + 2\epsilon(\nabla\psi^0 \cdot \nabla\phi) \right] \quad (6.21)$$

The total elastic energy is given by

$$W = \iint F_d(x, y) \, dx \, dy \quad (6.22)$$

The angular part of the energy is

$$F' = -\epsilon \frac{K}{2} \iint [(\psi_x^0{}^2 - \psi_y^0{}^2) \cos 2\psi^0 + 2\psi_x^0 \psi_y^0 \sin 2\psi^0] \, dx \, dy \quad (6.23)$$

For a pair of like or unlike disclinations one can write Eqn. (6.23) as

$$F' = -\epsilon \frac{K}{2} \iint [(\theta_x^2 - \theta_y^2) \cos 2(\theta + c) + 2\theta_x \theta_y \sin 2(\theta + c)] \, dx \, dy \quad (6.24)$$

where

$$\theta = s \left[\tan^{-1} \left(\frac{y}{x-d} \right) \pm \tan^{-1} \left(\frac{y}{x+d} \right) \right]$$

and

$$\theta_x = \frac{\partial \theta}{\partial x}, \quad \theta_y = \frac{\partial \theta}{\partial y} \quad (6.25)$$

The positive sign is taken for like singularities and negative sign for unlike singularities. The angular force is

$$g = - \frac{\partial F'}{\partial c} \quad (6.26)$$

In the presence of elastic anisotropy an angular force is experienced which takes the configurations to the allowed values of c .

The two cases shown in Fig. (6.4) indicate that in the presence of elastic anisotropy only a particular configuration with a specific value of c is allowed. Let us consider a pair of defects of strength $1/2$. When splay is of lower energy $c = \pi/2$ and the configuration is as shown in Fig. 6.4, i.e., the line joining the defects is perpendicular to the unperturbed director. When bend is of lower energy $c = 0$ and the line joining the defects is parallel to the unperturbed director. Therefore depending on the sign of ϵ the pattern changes to the one energetically allowed and one defect may be forced to rotate round the other till the allowed c value is reached.

As seen before, if the planar solution is assumed, an energy proportional to s^2 is obtained. This leads to the result that

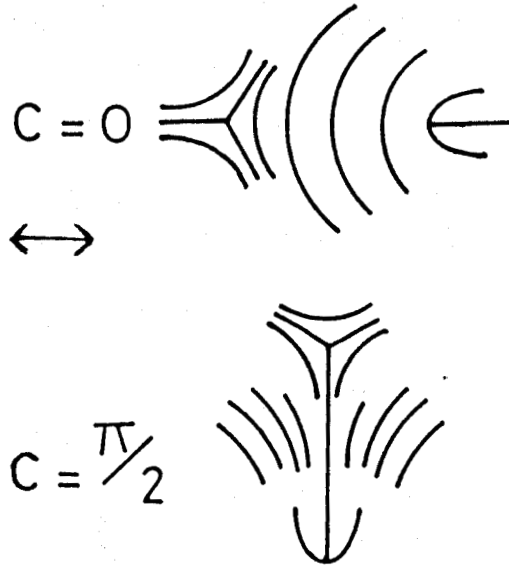


Figure 6.4

The director pattern for $(+1/2, -1)$ pairs in two extreme cases when $c = 0$ and $c = \pi/2$.

only defects of strength $s = \pm 1/2$ should be stable. However, considering the collapse of the director it has been shown that defects with $s = \pm 1$ can also be stable. In general if the escape into the third dimension is considered for integral defects, the energy is proportional to s . The energy of a defect of integral strength $s > 1$ is equal to the sum of the energies of s defects of unit strength. For example, a defect with $s = +2$ has an energy equal to the sum of the energies of two defects with $s = +1$, i.e., two defects with $s = +1$ can combine to form a defect with $s = +2$. Therefore in principle defects with integral values of s greater than 1 should also be stable. However the energy needed to generate these defects is higher than the energy required to create an individual defect with $s = \pm 1$. Thus defects with strength $s = \pm 1$ occur more frequently. Indeed experimental observations of only defects of strength $s = \pm 1$ or $s = \pm 1/2$ had been reported until recently. (For e.g., see Nehring and Saupe 1972, de Gennes 1975, Chandrasekhar 1977).

6.5 HIGH STRENGTH DEFECTS

During the course of our study of the phase diagrams of systems consisting of mesomorphic and non-mesomorphic compounds we discovered some unusual defects. Usually such mixtures exhibit a strong depression in the I-N transition temperature and a large coexistence range of I and N phases (see for e.g., Martire 1979). This

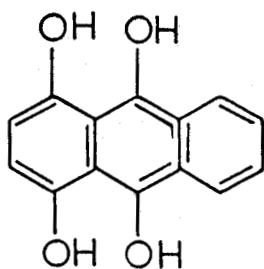
was true in the mixtures studied by us also. Interestingly as the sample was cooled further and the nematic phase was fully formed we found stable defects of strength $s = \pm 3/2$ and $s = \pm 2$. This is the first report of 'high strength' defects in thermotropic liquid crystalline systems. We now discuss our experimental studies.

6.6 EXPERIMENTAL STUDIES

The non-mesomorphic compound used in the mixtures studied by us is leucoquinizarin (1,4,9,10 tetrahydroxy anthracene (THA)). THA has a melting point of 147°C. The molecules of this compound are rigid and flat. Detailed observations which are reported below were done on mixtures containing the nematogens p-octyloxy-p'-cyano-biphenyl (8OCB), p-cyanophenyl-p'-n-heptyl benzoate (CPHB) and p-cyanobenzylidene-p'-octyloxylaniline (CBOOA). The structural formula and transition temperatures of the compounds are given in Fig. 6.5.

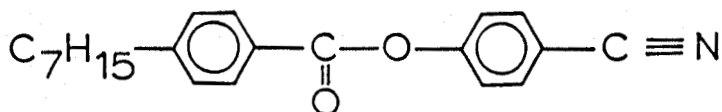
In particular the mixtures with the following compositions were studied in detail.

- 1 12 wt % of THA and 88 wt % of CPHB (Mixture I)
- 2 20 wt % of THA and 80 wt. % of 8OCB (Mixture II)
- 3 25 wt % of THA and 75 wt % of CBOOA (Mixture III).



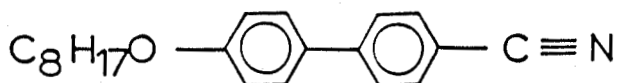
K 147 °C I

1,4,9,10 Tetrahydroxy anthracene (THA)



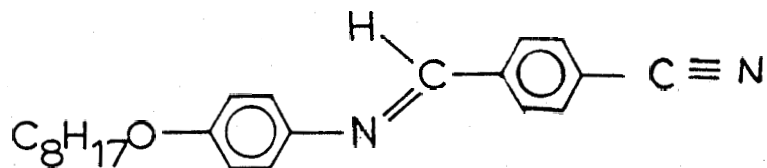
K 43.5 °C N 56.0 °C I

p - cyanophenyl p-n-heptylbenzoate (CPHB)



K 53.3 °C S_A 66.9 °C N 79.7 °C I

p - octyloxy - p' - cyano biphenyl (80CB)



K 73.0 °C S 82.5 °C N 106.9 °C I

n-p-cyanobenzylidene - p-n-octyloxy aniline (CBOOA)

Figure 6.5

Structural formula and transition temperatures of compounds used in the experimental studies.

All the observations were made using a Leitz Ortholux Polarizing Microscope (Model II Pol BK) in conjunction with a Mettler FP52 hot stage. The samples were taken between a slide and coverslip which were not treated to give any specific alignment.

Addition of 10 to 20 wt % of THA reduces the I-N transition temperature of the nematogens by 20 to 30°C. There is a large coexistence region of about 20°C of the isotropic and nematic phases. As the sample is cooled from the I phase, initially nematic droplets with the bipolar structure are formed. This indicates that the droplets have a tangential boundary condition of the director (Dubois-Violette and Parodi 1969). As these coalesce, there is a strong tendency to exhibit the Schlieren texture (for e.g., see Fig. 6.3a). When the whole field of view is covered with the nematic phase defects of strength $s = \pm 3/2$ and $s = \pm 2$ can be seen. Usually they are quite stable and remain unaltered down to the crystallisation temperature. We have checked that in certain cases the high strength defects are intact, even after a few days, on leaving the sample undisturbed.

Normally the high strength defects occur in a relatively isolated configuration (Figs. 6.6 and 6.7). Both positive and negative defects are equally probable. Figs. 6.8a and 6.8b show a defect of strength $+3/2$ at two different settings of the crossed polarisers. Sometimes the high strength defects occur as an inversion wall of the first kind (Fig. 6.9) (Nehring and Saupe 1972,



Figure 6.6. A relatively isolated $+3/2$ defect in Mixture II at 53.2°C , crossed linear polarisers (x 1920).

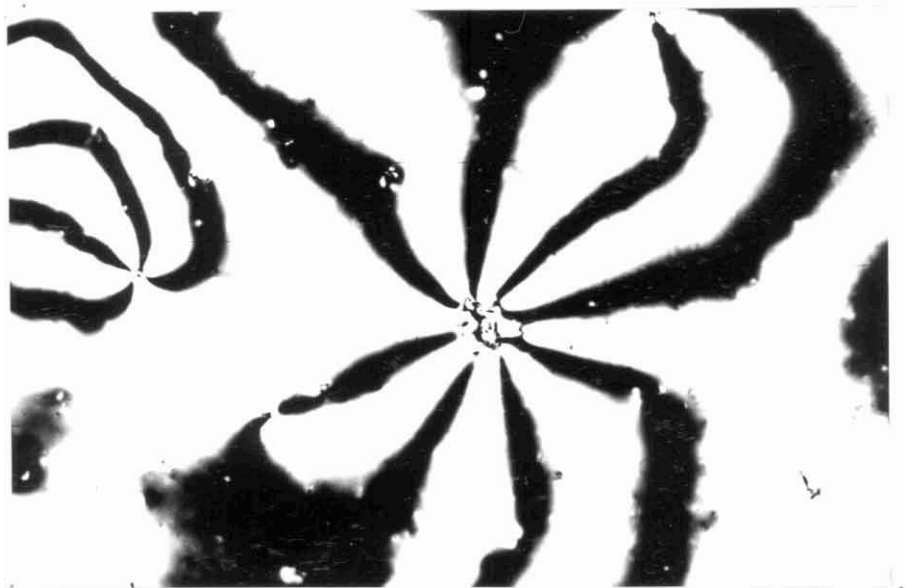


Figure 6.7. A relatively isolated $+2$ defect in Mixture II at 53°C , crossed linear polarisers (x 1920).

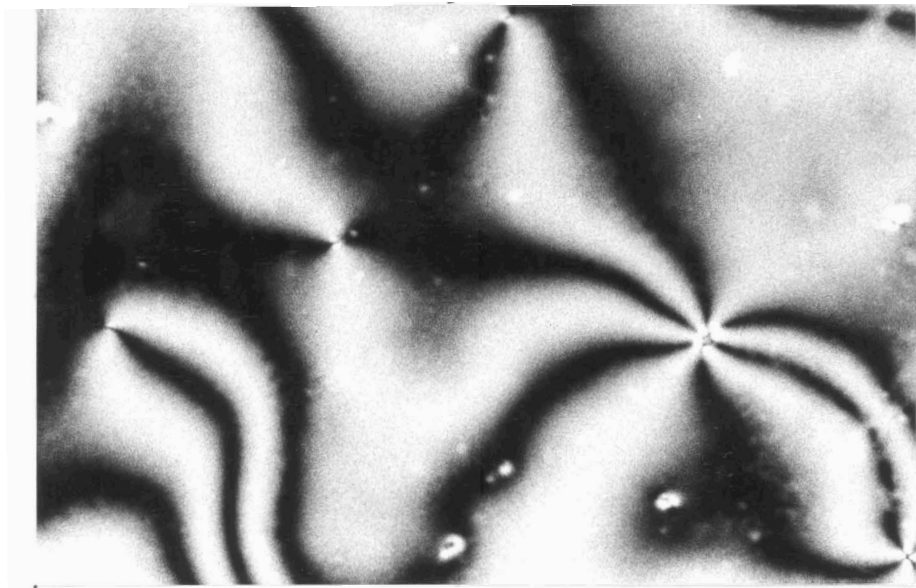


Figure 6.8a. A $+3/2$ defect in Mixture I at 36.1°C ,
Crossed linear polarisers ($\times 866$).

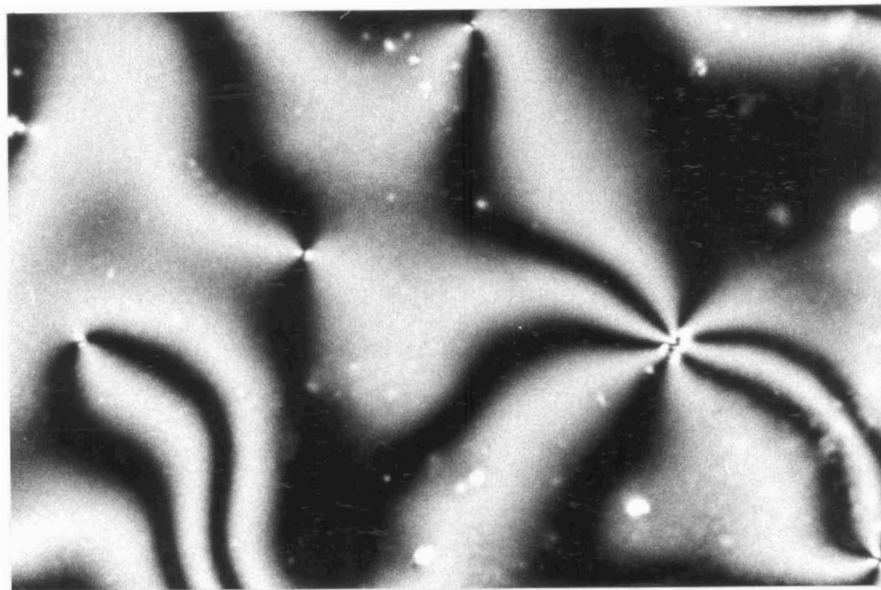


Figure 6.8b. The same $+3/2$ defect, shown in Fig.6.8a,
polarisers rotated in the clockwise direction by 60°
on going from 6.8a to 6.8b.



Figure 6.9. An inversion wall of the first kind with a $-3/2$ disclination, in Mixture I at 28°C , crossed linear polarisers (x500).



Figure 6.10. 12 brushes around an isotropic droplet in Mixture III at 57°C , crossed linear polarisers (x857).

see Chapter I).

Quite often, before the nematic phase is fully formed, a large number of brushes (up to fourteen) could be seen emerging from an isotropic droplet surrounded by a nematic region. In Fig. 6.10 we can see 12 brushes around the isotropic droplet. This is topologically equivalent to a defect of strength 3. If the director is assumed to make a constant angle with the N-I interface, such a drop should be topologically equivalent to a defect of strength 1 (Meyer 1973B, Ranganath 1977). However Ericksen (1970) has pointed out the possibility that the angle made by the director with the interface need not necessarily be constant and the cross section of the isotropic region need not even be circular if the elastic anisotropy is also taken into account. In such a case the isotropic droplet is no longer topologically equivalent to a defect of strength 1. This indicates that in the samples studied by us the angle made by the director at the N-I interface around an isotropic droplet is not a constant.

Observations with monochromatic light ($\lambda = 5893 \text{ \AA}$) and between crossed circular polarizers did not reveal dark closed rings around the centre of the defects with strength $3/2$, i.e., there was no visible collapse of the director in the third dimension. This agrees with the prediction of the topological arguments. Therefore we can expect that these defects also have singularities at the centre. The line energy in that case is given by Eqn. (6.6).

Therefore the elastic energy carried by a defect with $s=3/2$ would be considerably reduced if it splits into defects of lower strength. Such a splitting could be observed once in a way. Figs. 6.11a and 6.11b show the splitting of a defect with $s=+3/2$ into two defects with $s=+1$ and $s=+1/2$ respectively. But most often the defects with strength $\pm 3/2$ and ± 2 remained intact on heating until the isotropic phase set in. Detailed observations on the centres of the defects with $s=\pm 2$ were not possible as the centres of these defects were never clear (see for e.g., Fig. 6.7).

In all the samples studied by us though the number of defects with $s=\pm 1$ and $s=\pm 1/2$ was always larger, a considerable number of high strength defects was also observed (Fig. 6.12). Because of the relative stability of these high strength defects quite often we could see pairs of these defects. In Fig. (6.13a) a pair of defects with strengths $s=+3/2$ and $s=-3/2$ can be seen. Figs. 6.13b and 6.13c show the same pair of defects when the polarizers have been rotated by 45° and 90° respectively with respect to that in Fig. 6.13a. Six dark brushes are seen to emanate from each of the defect centres. In Figs. 6.14a and 6.14b a pair of defects of strength $+2$ and -2 is seen: eight brushes emerge from each defect centre. The distance between the two defects is $\leq 10 \mu\text{m}$ in the case of both types of pairs. This separation is of the same order as in pairs of ± 1 and $\pm 1/2$ defects. Since the number of dark brushes emerging from the two defects is large and also



Figure 6.11a. A $+3/2$ defect (indicated by an arrow) in Mixture I at 36.2°C , crossed linear polarisers (x 920).



Figure 6.11b. Same area of the sample as in Fig. 6.11a at 38.7°C . Note that the $+3/2$ defect has split into a $+1$ and a $+1/2$ defect (x 920).

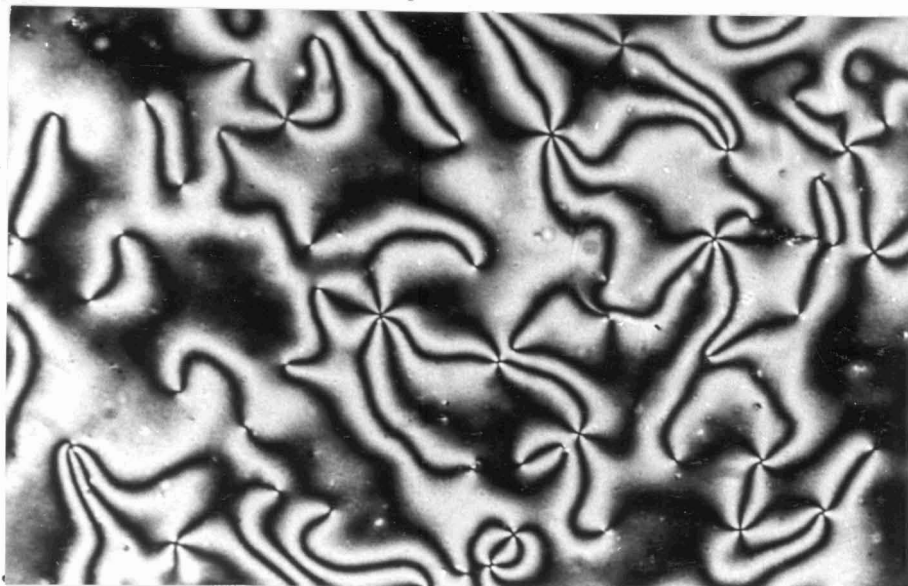


Figure 6.12. Three defects of strength $3/2$ are visible in the field of view, the sample is Mixture I at 36.5°C , crossed linear polarisers ($\times 470$).

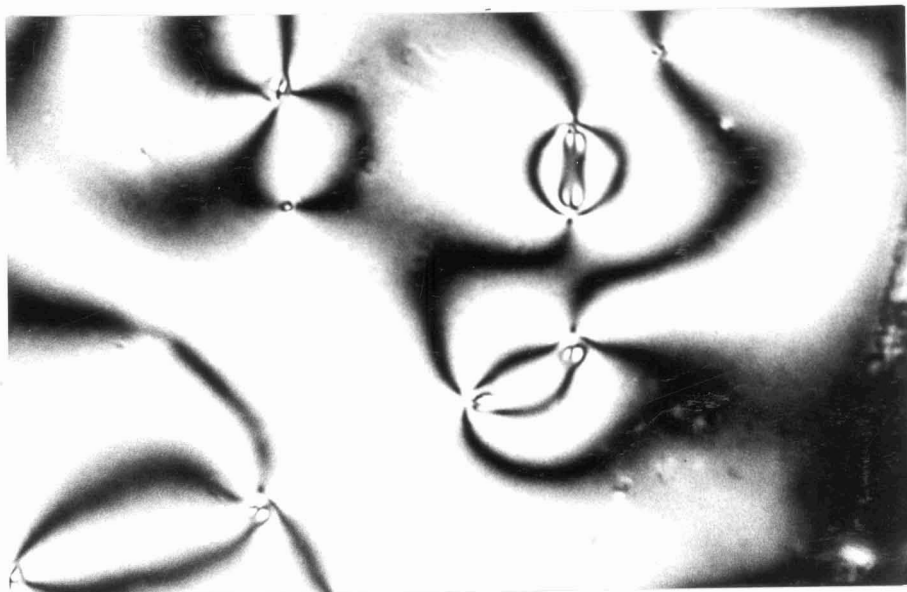


Figure 6.13a. A $+3/2$ and $-3/2$ pair of defects in Mixture I, crossed linear polarisers, illumination with monochromatic light ($\lambda = 5893 \text{ \AA}$) ($\times 3700$).

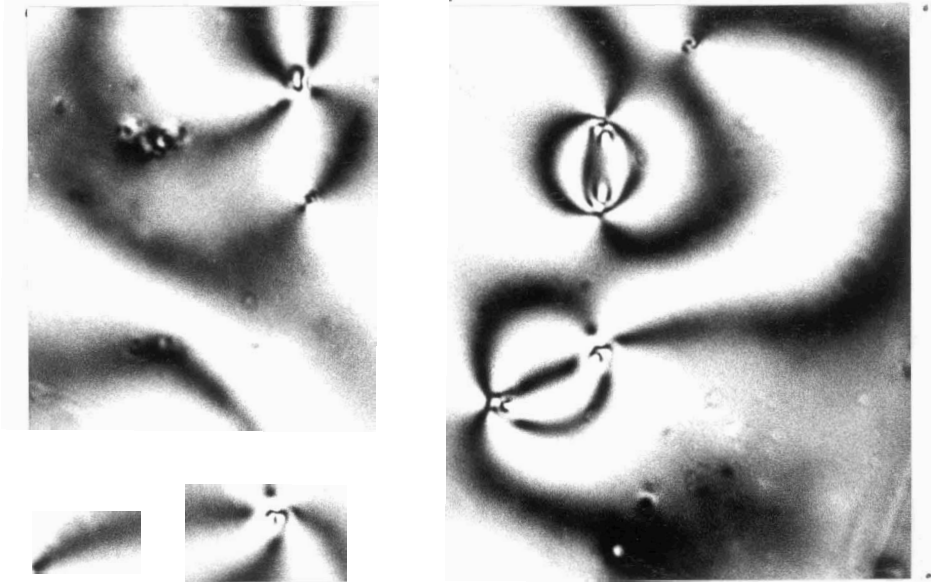


Figure 6.13b. The same pair of $+3/2$ and $-3/2$ defects as in Fig.6.13a. Polarisers rotated clockwise by 45° on going from Fig. 6.13a to Fig. 6.13b.

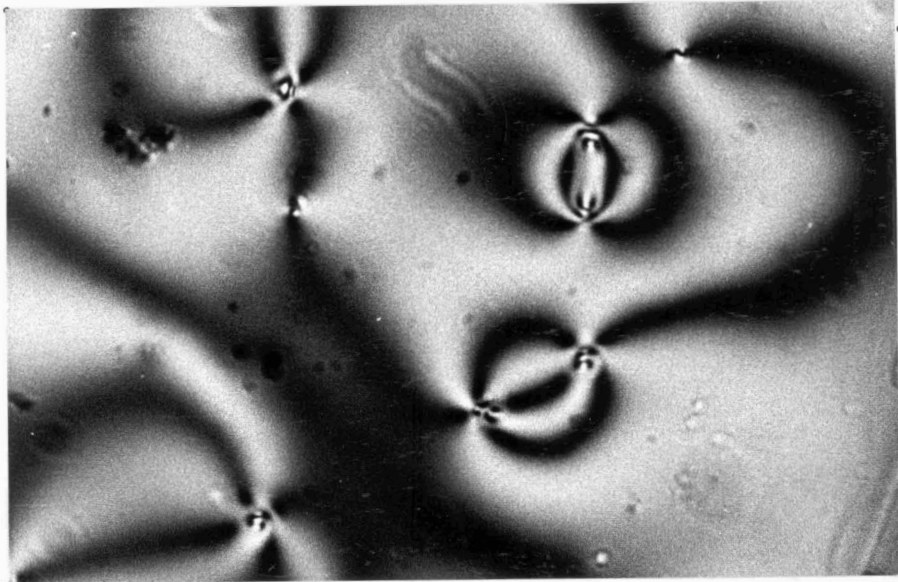


Figure 6.13c. The same pair of $+3/2$ and $-3/2$ defects as in Fig.6.13b. Polarisers rotated clockwise by 45° on going from Fig. 6.13b to Fig.6.13c.

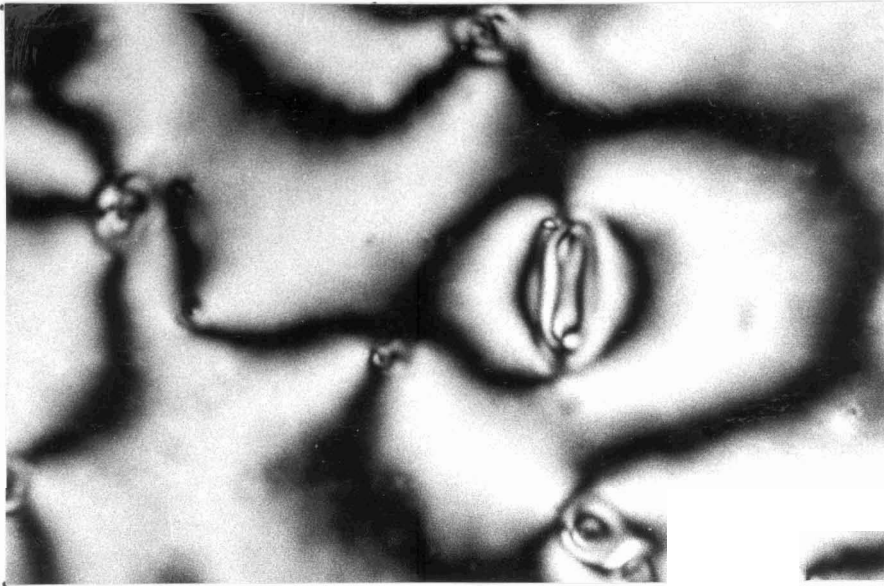


Figure 6.14a. A +2 and -2 pair of defects in Mixture I between crossed linear polarisers, illumination with monochromatic light (x3867).

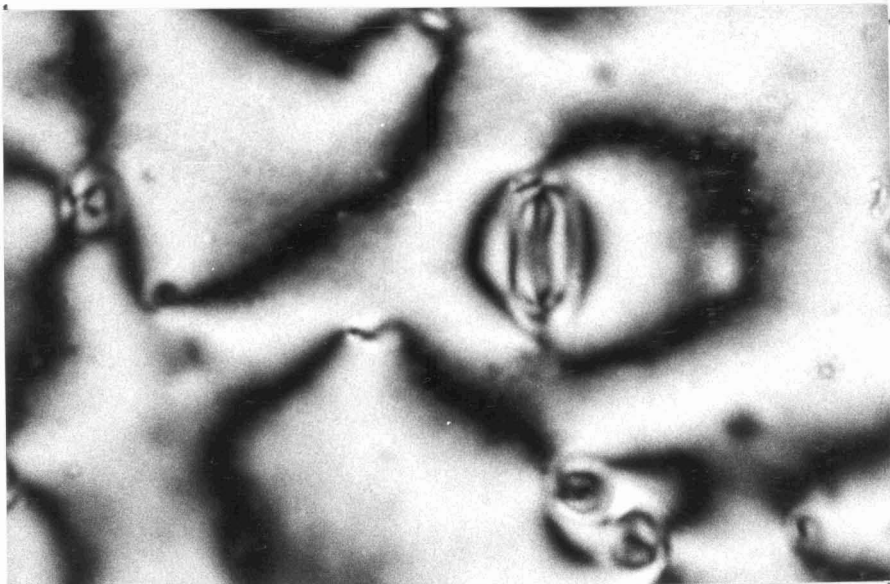


Figure 6.14b. Same pair of +2 and -2 defects as in Fig. 6.14a, polarisers rotated clockwise by 45° on going from 6.14a to 6.14b.

as these brushes are very close to each other in the region between the two defects (see Figs. 6.13 and 6.14) very careful observations are necessary to determine the strength of the defects in these pairs. In some cases only specific orientations of the polarisers make their identification possible. The polarisers have been rotated on going from Fig. 6.14a to Fig. 6.14b and all the dark brushes are more clearly seen in Fig. 6.14b.

Considering a one constant approximation the director configurations around the pairs of defects is defined by Eqn. (6.16). Using a suitable algorithm these configurations were computer generated for different values of c . (A few examples are shown in Figs. 6.15 and 6.16). If the defects are isolated and the director orientation far away from the defects is uniform, an exact value of c can be obtained by matching the pattern of dark brushes emerging from the centres of the defects for various settings of the polarisers with the director configurations obtained as mentioned above. But the samples studied by us were not treated to give any specific orientation of the director and also the pairs of defects were connected to various other defects. Other neighbouring defects have an influence on the configurations adopted by the director around any given pair of high strength defects. Therefore an exact determination of the value of c is not possible. However a rough estimate can be obtained by matching the pattern of dark brushes in the region between the two defects in a pair,

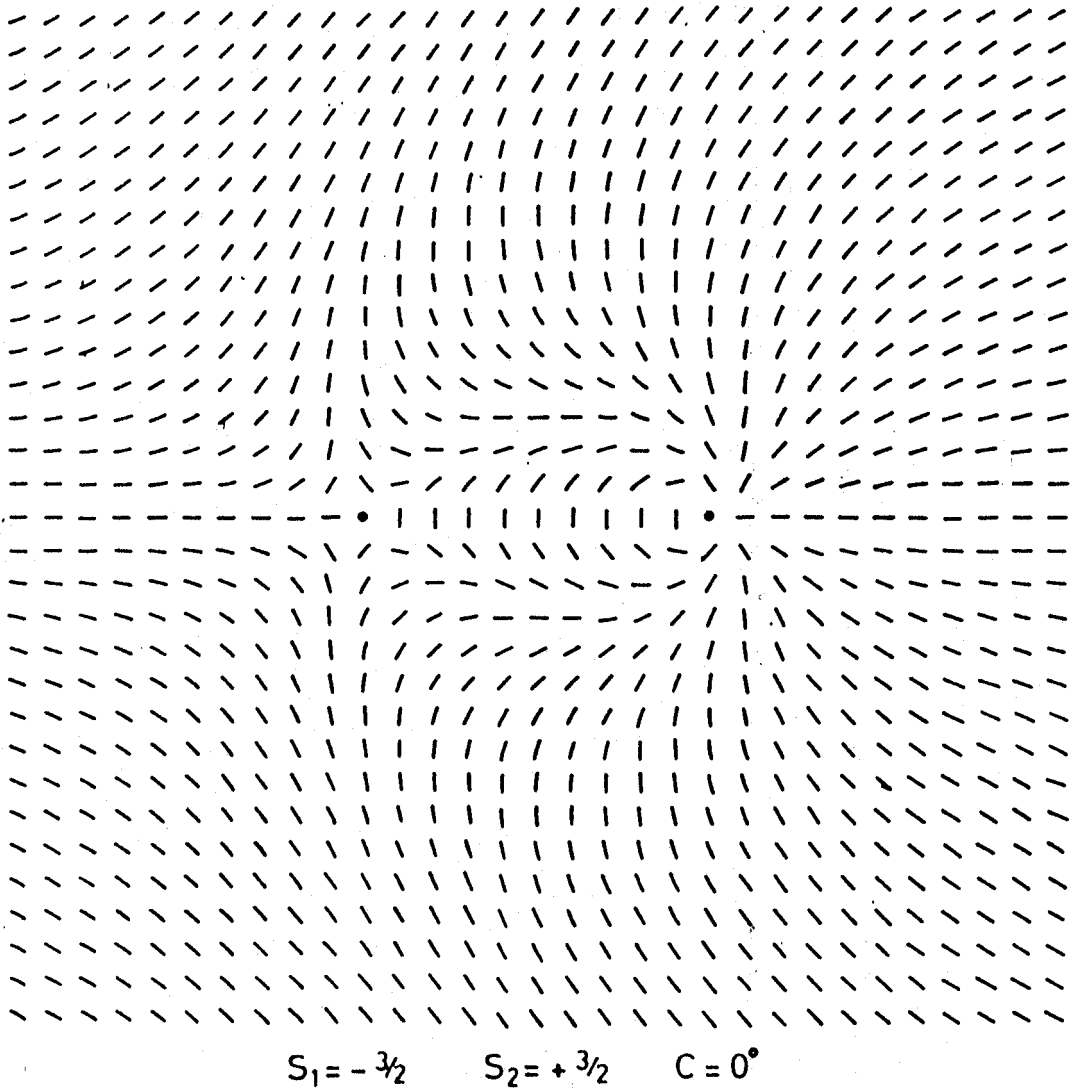


Figure 6.15a

The director fields in the neighbourhood of a pair of defects of strength $+3/2$ and $-3/2$ according the Eqn. (6.16) for $c = 0^\circ$.

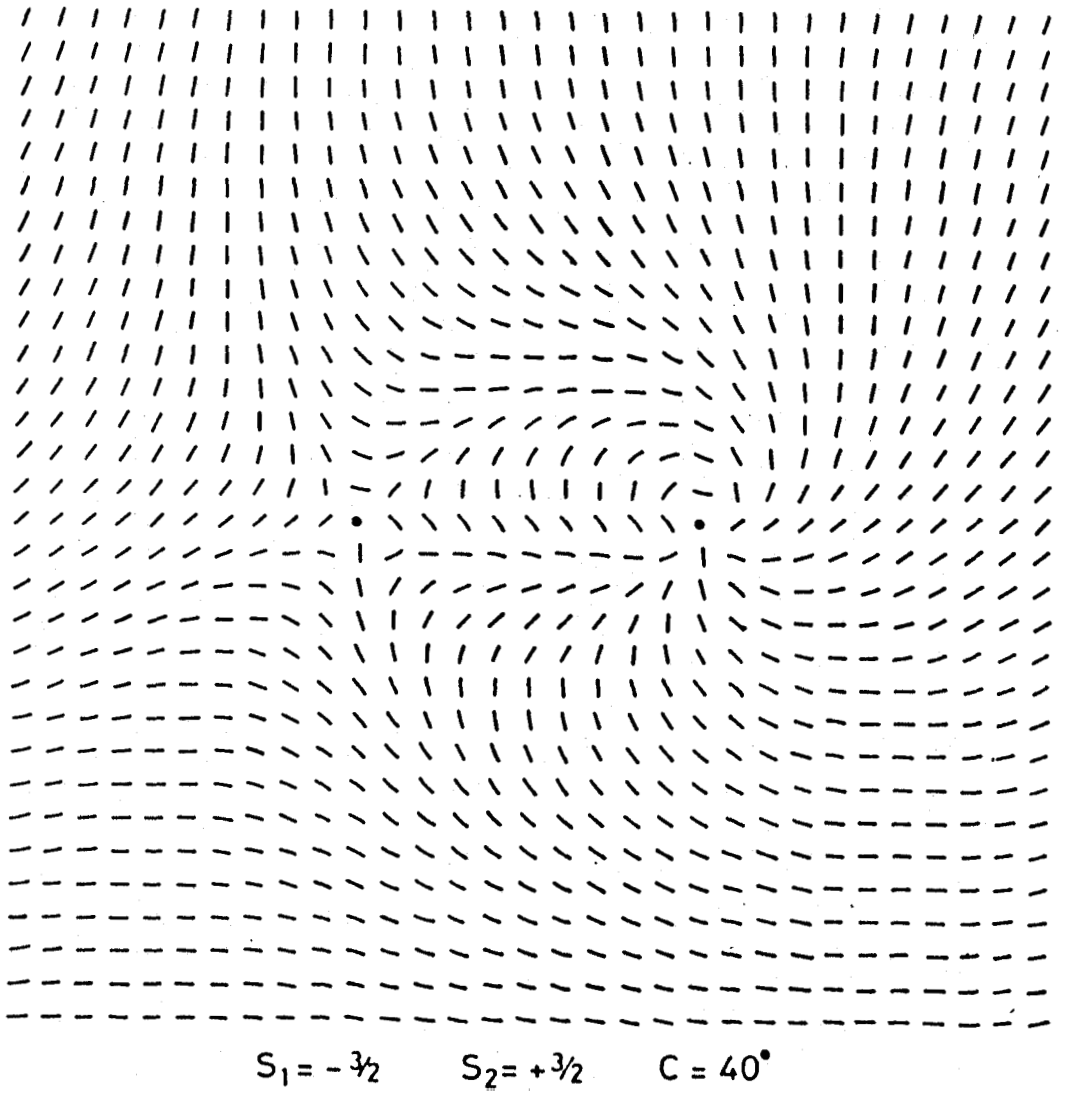


Figure 6.15b

The director fields in the neighbourhood of a pair of defects of strength $+3/2$ and $-3/2$ according to Eqn. (6.16) for $c = 40^\circ$.

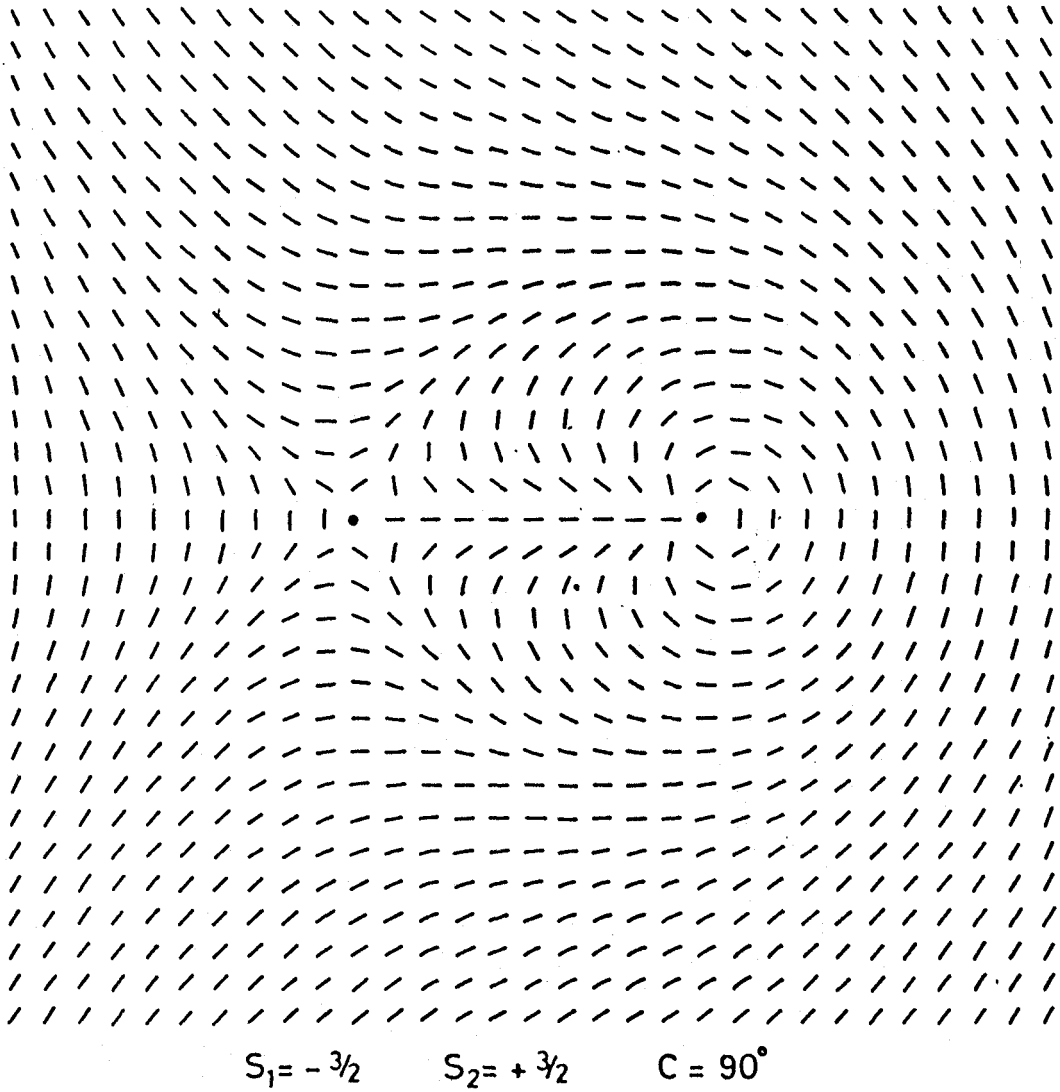


Figure 6.15c

The director fields in the neighbourhood of a pair of defects of strength $+3/2$ and $-3/2$ according to Eqn. (6.16) for $c = 90^\circ$.

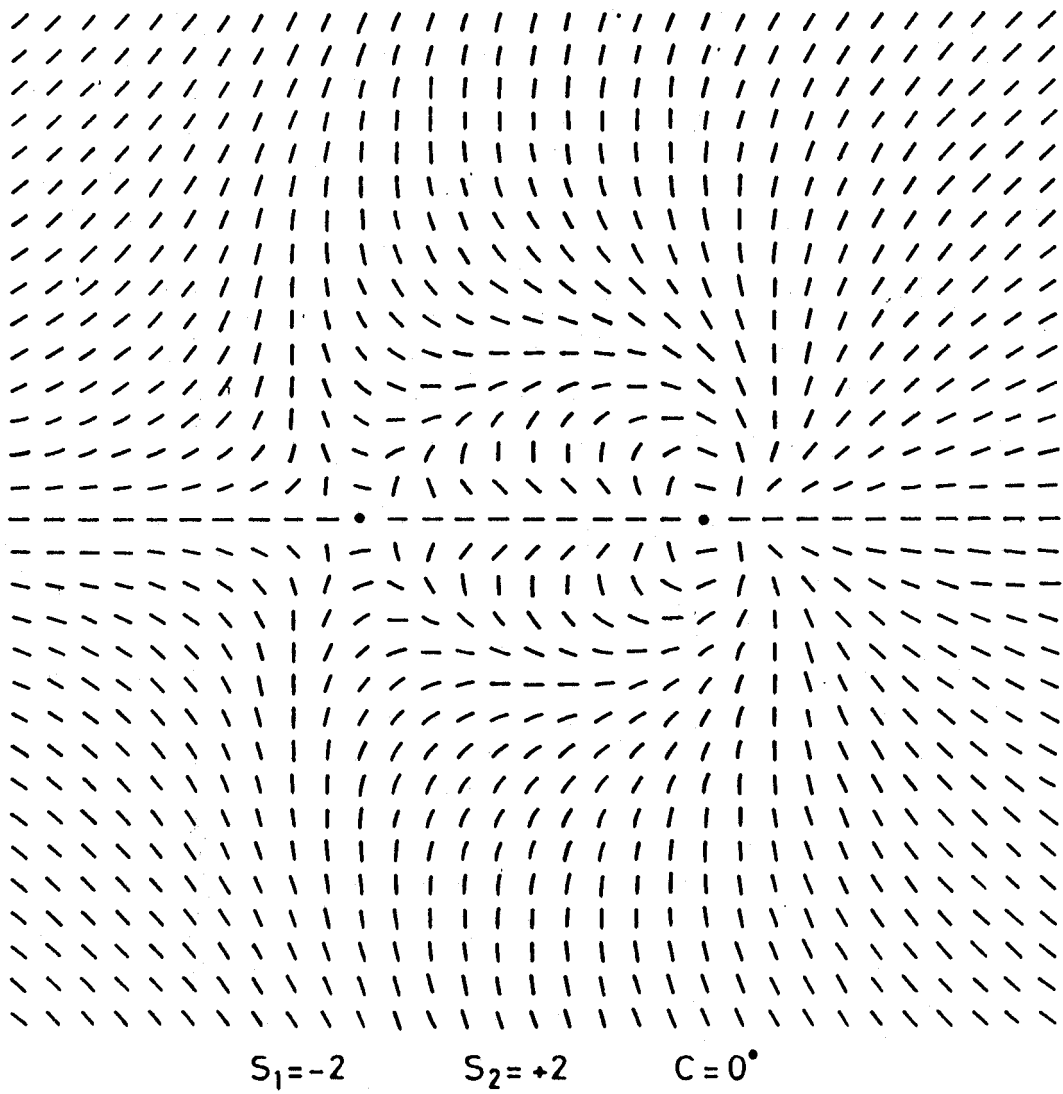


Figure 6.16a

The director fields in the neighbourhood of a pair of defects of strength +2 and -2 according to Eqn. (6.16) for $c = 0^\circ$.

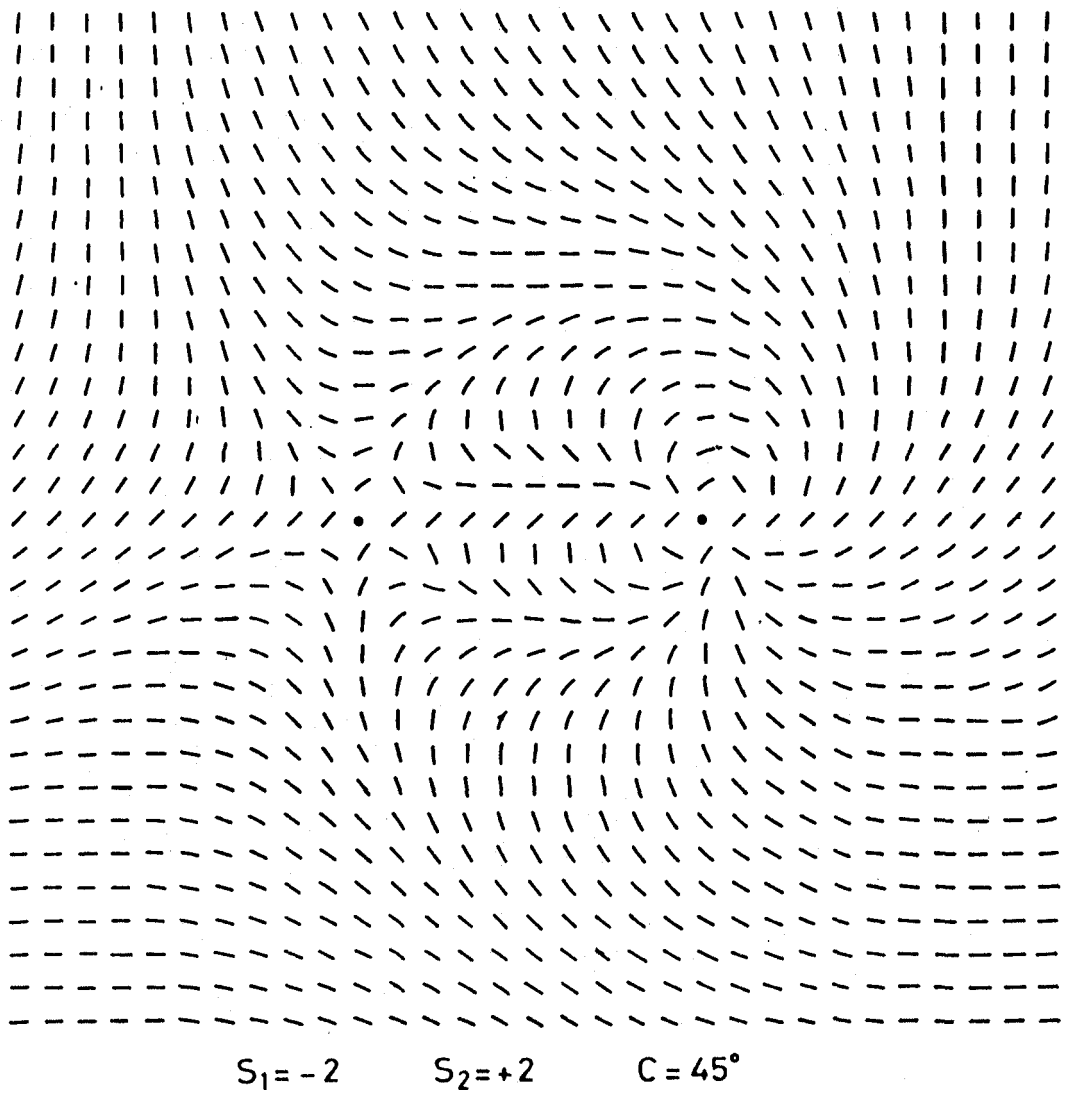


Figure 6.16b

The director fields in the neighbourhood of a pair of defects of strength +2 and -2 according to Eqn. (6.16) for $c = 45^\circ$.

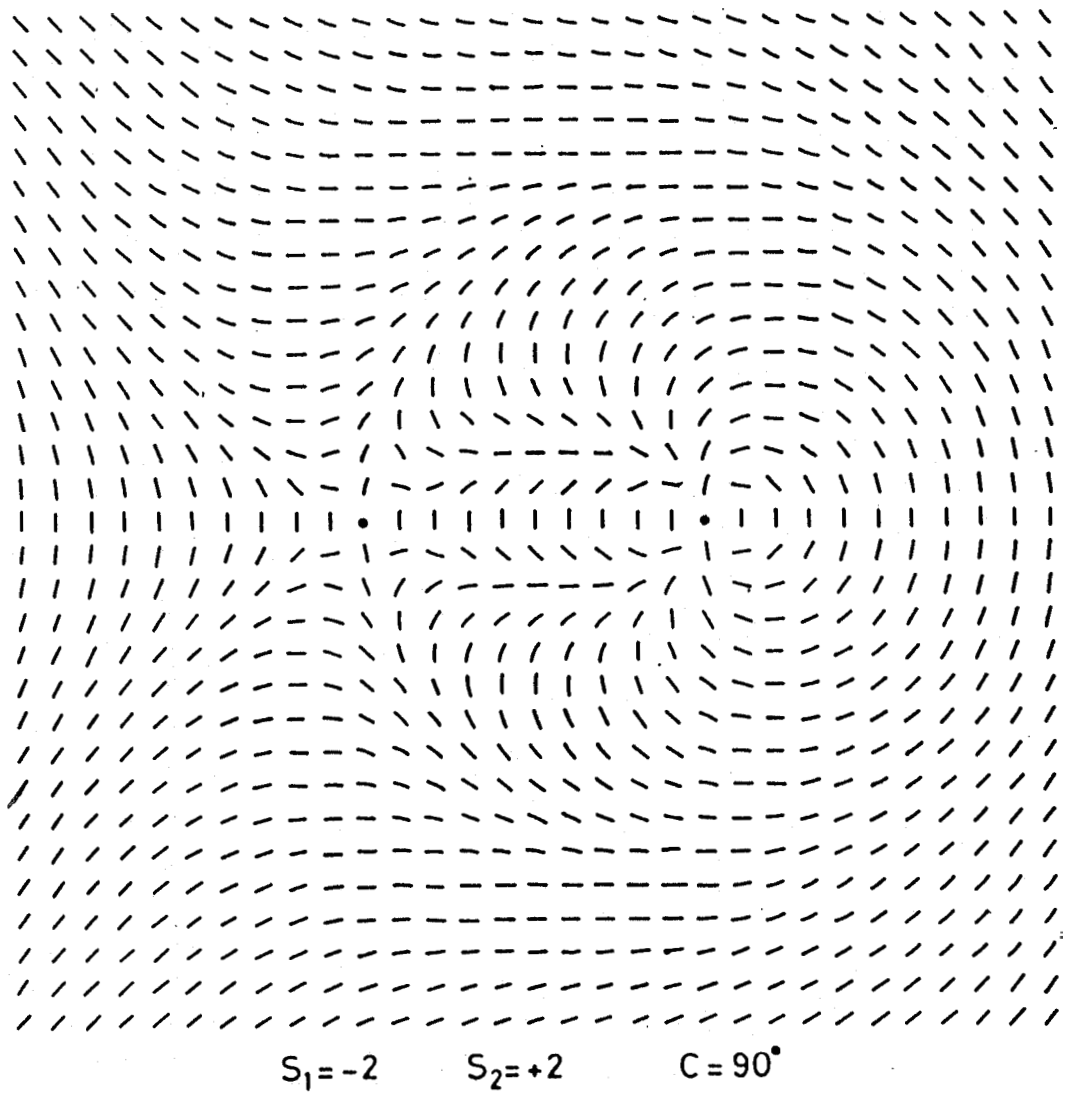


Figure 6.16c

The director fields in the neighbourhood of a pair of defects of strength +2 and -2 according to Eqn. (6.16) for $c = 90^\circ$.

with the director configurations plotted for different values of c . In the case of both types of pairs, i.e., with $s = +3/2$ and $-3/2$ and $s = +2$ and -2 a value of c close to zero was found to be preferred. This preference to adopt these configurations indicates that the splay costs less energy, i.e., $K_{33} > K_{11}$ which is normally the case with the type of compounds used in the mixtures studied. (For e.g., see Madhusudana and Pratibha 1982A).

The pairs of defects have a tendency to annihilate each other as the isotropic phase is approached. For e.g. the pair of defects with $s = +3/2$ and $-3/2$ in Fig. 6.17a is found to have been annihilated as the temperature is increased (Fig. 6.17b). However at lower temperatures the pairs of high strength defects are found to be stable as in the case of ± 1 and $\pm 1/2$ defects.

Ranganath (1983) has discussed the motion of the disclination pairs. A relative motion of the two disclinations s_1 and s_2 due to a variation in the separation D between the two disclinations has been considered and the entropy generated ($=Q$) has been calculated. He has derived an expression for the friction coefficient by assuming that the disclination velocities are so small that no real fluid velocity is excited. If u is the uniform velocity of motion the frictional coefficient is given by $\eta = Q/u^2$. The friction coefficient is found to increase as two unlike defects (i.e., defects with $s_1 = -s_2$) move towards each other. Therefore the friction opposes the effects of elasticity. Thus at lower

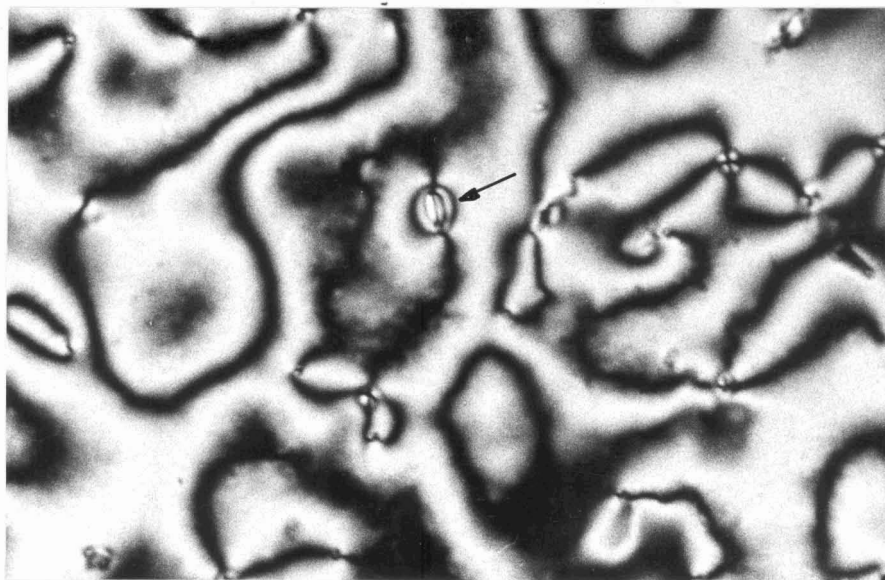


Figure 6.17a. A pair of defects of strength $+3/2$ and $-3/2$ in Mixture I at 43.8°C , crossed linear polarisers (x863).

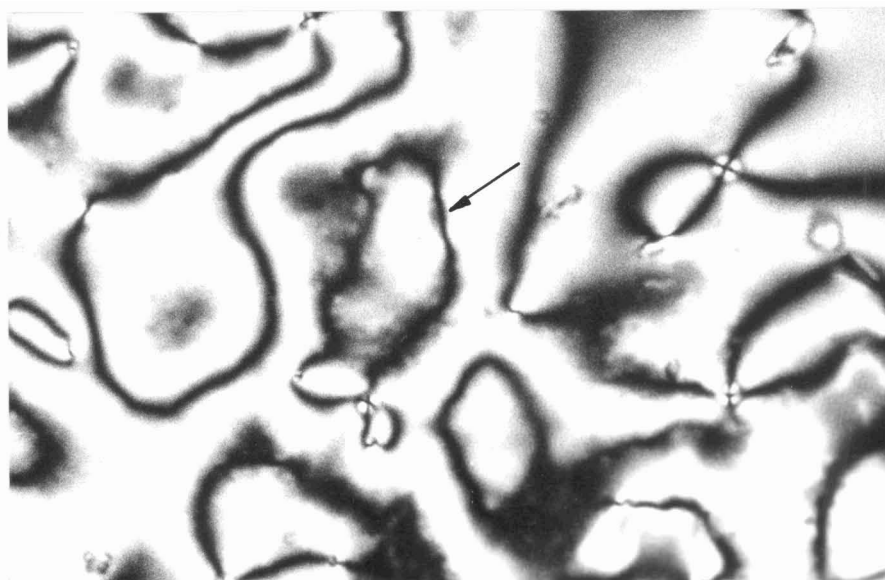


Figure 6.17b. Same sample area as in Fig. 6.17a at 45.1°C , the pair of defects have annihilated each other with the increase in temperature (x863).

temperature the high strength defects forming a pair do not move closer and are found to be stable. But as the temperature is increased the viscosity decreases and the defects can move closer and annihilate each other.

As mentioned before the core of these defects is supposed to be in the isotropic phase. In fact on heating the sample from the nematic phase, the isotropic phase starts, at the centre of the defects with strength equal to $\pm 3/2$. As the temperature is increased further the isotropic region is enlarged. The decrease in the N-I transition temperature around the centres of these defects indicates that the non-mesomorphic compound is in greater concentration in these regions. This has an analogy in the solid state where impurities present interstitially or substitutionally may diffuse to the neighbourhood of dislocations and lock them in position (For e.g., Kittel 1953). The stability of these high strength defects could be due to the concentration gradient near the centre. Indeed these high strength defects have been found to occur only in mixtures. We have made careful observations on pure nematogens used in our studies of high strength defects and found that these defects of strength $s = \pm 3/2$ and $s = \pm 2$ do not occur in single component systems.

At about the same time that we reported the discovery of the high strength defects (Madhusudana and Pratibha 1982B), Lee and Labes (1982) found apparent high strength defects in a rather

different system. They used emulsified mixtures of pentyl cyanobiphenyl or MBBA with the lyotropic liquid crystal system di-sodium cromoglycate + ethylene glycol. After a special preparation of the sample and removal of the coverslip, defects of strength up to 4 were observed. However unlike in the systems studied by us these defects were unstable as the microemulsion itself broke up after several minutes (1-20 min.). More recently stable defects of strength $\pm 3/2$ have been observed (Suresh 1986) in a mixture of the non-mesomorphic compound 4'-n-heptyl-4-bromobiphenyl and the mesomorphic compound 4,4'-di-n-heptyloxyazoxy benzene. The defects of strength ± 2 in this system were however not stable and in due course of time dissociated into two like defects of strength +1 or -1.

6.7 CONCLUSION

We have observed stable high strength defects with $s = \pm 3/2$ and $s = \pm 2$ in thermotropic nematic mixtures. Pairs of these high strength defects have also been observed. Our own observations and the other studies on high strength defects show that these defects occur only in mixtures. In fact pure components composing these mixtures do not have a tendency to form the high strength defects. The relative stability of these defects could therefore be due to a concentration gradient close to the centres of these defects.

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