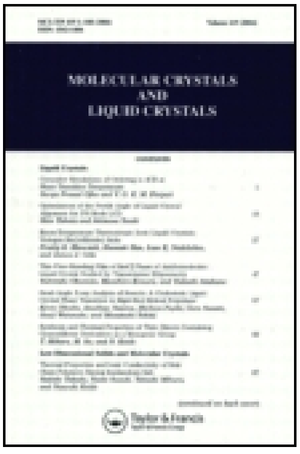

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Liquid Crystals with Magnstic and Polar Clusters

S. A. Pikin [a]

[a] Institute of Crystallography, Academy of Sciences of USSR, Moscow, 117333, USSR

Version of record first published: 20 Apr 2011.

To cite this article: S. A. Pikin (1984): Liquid Crystals with Magnstic and Polar Clusters, Molecular Crystals and Liquid Crystals, 102:5, 125-128

To link to this article: http://dx.doi.org/10.1080/01406568408072060

Mol. Cryst. Liq. Cryst. 102 (Letters), pp. 125-128
0140-6566/84/1025-0125$18.50/0

LIQUID CRYSTALS WITH MAGNETIC AND POLAR CLUSTERS

S.A.PIKIN
Institute of Crystallography, Academy of Sciences of USSR, Moscow II7333, USSR

(Received for Publication June 1, 1984)

ABSTRACT The behaviour of liquid crystals (LC) with added anisotropic particles under the action of electric fields, magnetic fields and mechanical stresses is described.

Up to now LC with proper ferromagnetic properties are unknown. Besides as a rule LC are diamagnetic, i.e. LC molecules have no paramagnetic dipole moment. It was shown theoretically[I] and experimentally[2] that LC with anisotropic ferromagnetic particles possess the macroscopic magnetization if the dimensions of particles are large in comparison with the molecular dimensions.

In this paper the behaviour of the LC system with added small anisotropic particles under the action of the magnetic and electric fields and also the mechanical stresses is described. It is assumed in the case under consideration that in general the particles have the magnetic ($\underset{\sim}{m}$), electric ($\underset{\sim}{p}$) and steric ($\underset{\sim}{s}$) dipole moments, the dimensions of particles are comparable with the dimensions of LC molecules, the time of the orientational relaxation of particles is comparable with the time of the molecular orientational relaxation but much smaller than the lifetime of the magnetic state of particles τ . The magnetic state of particles is determined by the exchange interaction of paramagnetic atoms in clusters. The magnetic moment $\underset{\sim}{m}$ is oriented along the fixed axis of the particle during the long time τ if the exchange energy is larger than the temperature and the number of atoms is sufficiently large.

It is well known[3-6] that small particles of magnetite Fe_3O_4 and the aerozoles of Ni and $-Fe_2O_3$ with average dimensions 30-100 Å are the ferromagnetic monodomains and besides these aerozoles behave as the paramagnetic gas. Thus one can expect that in some lyotropic and polymer LC such particles obey the assumptions mentioned above. Consequently in the appropriate systems the thermodynamically quasi-equilibrium states are possible with the finite macroscopic averages

$$\overline{(\underset{\sim}{m}\underset{\sim}{p})},\ \overline{(\underset{\sim}{m}\underset{\sim}{s})},\ \overline{(\underset{\sim}{m}[\underset{\sim}{p}\underset{\sim}{s}])} \qquad (1)$$

though there are zero averages $\bar{\underset{\sim}{m}} = \bar{\underset{\sim}{p}} = \bar{\underset{\sim}{s}} = 0$ in such systems. Here the averaging is made over all the particles and over the time $t < \tau$. It is necessary to note that in full equilibrium state half of particles have for example positive sign of the averages but another half have the negative one because in general the projections $\pm m$ of $\underset{\sim}{m}$ on $\underset{\sim}{s}$ or $\underset{\sim}{p}$ are equally probable. But for the time $t < \tau$ one can create macroscopic nonzero averages (1) artificially by appropriate combinations of external actions; these states have the lifetime τ after switching off external fields.

The macroscopic characteristics of the system under consideration enter into coefficients of thermodynamic expansions. The expansions of the density of thermodynamic potential Φ for described quasi-equilibrium states include the invariants (relatively to the time inversion and operations of symmetry for specific LC) which depend on external fields and order parameters of LC. The most simple invariants in Φ are for example

$$c\overline{(\underset{\sim}{m}\underset{\sim}{p})}(\underset{\sim}{E}\underset{\sim}{H}), \qquad c\overline{(\underset{\sim}{m}\underset{\sim}{s})}H_i\frac{d\sigma_{ik}}{dx_k}, \qquad (2)$$

$$c\overline{(\underset{\sim}{m}\underset{\sim}{s})}(\underset{\sim}{H}\underset{\sim}{n}\,\mathrm{div}\,\underset{\sim}{n}), \qquad c\overline{(\underset{\sim}{m}\underset{\sim}{s})}(\underset{\sim}{H}[\underset{\sim}{n}\,\mathrm{rot}\,\underset{\sim}{n}]), \qquad (3)$$

$$c\overline{(\underset{\sim}{m}[\underset{\sim}{p}\underset{\sim}{s}])}(\underset{\sim}{E}\underset{\sim}{H})(\underset{\sim}{n}\,\mathrm{rot}\,\underset{\sim}{n}) \qquad (4)$$

and others where c is the concentration of particles, $\underset{\sim}{n}$ is the director, $\underset{\sim}{E}$ and $\underset{\sim}{H}$ are the electric and magnetic fields, σ_{ik} is the stress tensor.

One can see from the equations (2) that in the systems under consideration the external electric field or nonhomogeneous mechanical stress can induce the macroscopic magnetization $\mathbf{M} = - d\Phi/d\mathbf{H}$:

$$\mathbf{M} \sim c(\overline{\mathbf{mp}})\mathbf{E} \quad \text{and} \quad M_i \sim c(\overline{\mathbf{ms}})\frac{d\sigma_{ik}}{dx_k} \quad . \tag{5}$$

On the contrary the homogeneous external magnetic field induces the macroscopic electric polarization $\mathbf{P} = - d\Phi/d\mathbf{E} \sim c(\overline{\mathbf{mp}})\mathbf{H}$ and the surface mechanical deformation $u_{ik} = - d\Phi/d\sigma_{ik}$. In accordance with the equations (3) the external magnetic field can induce in nematics the flexomagnetic orientational deformation, i.e. the nonhomogeneous perturbation of the director distribution $\mathbf{n}(\mathbf{r})$:

$$\left|\frac{dn_i}{dx_k}\right| \sim \frac{c}{K}(\overline{\mathbf{ms}})H \tag{6}$$

where K is the Frank constant; this effect is analogous to the well known flexoelectric effect[7]. The equation (4) shows that in the nematic the combination of magnetic and electric fields causes arising of the spiral orientational macrostructure which is to the cholesteric one; the corresponding rotation power for the light polarization is given by the equation

$$\varphi \sim \frac{c}{K}(\overline{\mathbf{m}[\mathbf{ps}]})(\mathbf{EH}). \tag{7}$$

It is necessary to emphasize that all these effects take place in absence of the spontaneous macroscopic magnetization. The necessary conditions for the phenomena are the anisotropy of shape of magnetic particles and (or) existence of the permanent electric dipole moment of the particles. It is possible to create described macroscopic states with the lifetime τ by the mechanical bend or electric polarization of LC layers and by the following application of sufficiently strong magnetic field. If the dimensions of particles are large in comparison with molecular dimensions the thermal averaging $\bar{\mathbf{s}} = \bar{\mathbf{p}} = \bar{\mathbf{m}} = 0$ takes no place because of large energy of LC orientational perturbations which should be overcame to reorientate the particles. In last a case the macroscopic magnetization $\underset{\sim}{M} = c\bar{\underset{\sim}{m}}$ remains constant that was observed in lyotropic LC[2] .

Described phenomena are interesting if one considers physical properties of such complex systems as lyotropic and polymer LC in biomembranes . For example changes of the membrane electric potential or the nonhomogeneous mechanical deformations of the membrane can induce (in accordance with (5)) the macroscopic magnetization $\underset{\sim}{M}$ interacting with the external magnetic field $\underset{\sim}{H}$. One can expect that there are different situations in the biomembrane: the interaction of $\underset{\sim}{M}$ and $\underset{\sim}{H}$ can be favourable or unfavourable for the spreading of electric and mechanical perturbations. On the other hand the external magnetic field must induce (in accordance with (6)) appreciable macrostructure perturbations and a change of the electric state of the membrane. Existence of equally oriented anisotropic magnetic clusters in bacterium with the curved shape[8] and other biological objects may be a manifestation of described physical properties of the complex LC systems.

REFERENCES

1. F.Brochard and P.G. De Gennes, J. de Phys. (Paris), 31, 691 (1970).
2. L. Liebert and A. Martinet, IEEE Transactions on magnetics, MAG-16, 266 (1980).
3. Ch. Kittel, Phys. Rev., 70, 965 (1946).
4. R. Haul and Th. Schöon, Zs. Electrochem., 45, 663 (1939).
5. D. Beischer and A. Winkel, Naturwiss., 25, 420 (1937).
6. W.C. Elmore, Phys. Rev., 54, 1092 (1938); 60, 593 (1941).
7. R.B. Meyer, Phys. Rev. Lett., 22, 918 (1969).
8. R.B. Frankel, R.P. Blakemore and R.S. Wolfe, Science, 203, 1355 (1979).