Behaviour of Ferronematics under Electric and Magnetic Fields

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The behaviour of a ferronematic with positive magnetic and electric anisotropies, subjected simultaneously to electric and magnetic fields is investigated. The ferronematic was assumed to be planar oriented and the external magnetic and electric fields were considered perpendicular to the nematic director. We found the phase diagram relating the transition from the planar to homeotropic alignment when both electric and magnetic fields are acted simultaneously. This is described in the plane [E, B] by an ellipse. The halfaxes of these ellipses are given by the critical fields for electric and magnetic Freedericksz transitions.

Keywords: ferronematic, Freedericksz transitions, phase diagrams

Brochard and de Gennes were the first to examine the phenomena occurring in nematic liquid crystals (NLC) containing magnetic particles [1]. These were described by a microscopical spatial distribution of the nematic director **n** and by a local magnetization **M**=M_s f**m,** where M_s is the saturation magnetization of the magnetic particle, f their volume fraction and **m** the magnetic moment of the magnetic particle. Assuming that **m** is parallel to **n** and using a continuum theory, Brochard and de Gennes found that the critical field for the magnetic Freedericksz transition B_c is dramatically decreased. Such mixtures were obtained experimentally and termed ferronematics [2, 3].When investigating thermotropic ferronematics it was discovered that the critical field was increased [4, 5], the theory of Brochard and de Gennes being valid only in case of liotropic nematics [6].

To overcome these difficulties in understanding the thermotropic feronematic behaviour, Burylov and Raikher [7] developed another approach relying on the assumption that the anchoring energy W, determining the orientation of the nematic molecule on the surface of a ferroparticle, is finite. It resulted that, in the equilibrium state, **m** was perpendicular to **n.** Using a continuum theory they showed that the critical field for magnetic Freedericksz transition was increased in good agreement with many experimental findings [5, 8, 9].

In the last decade the interest in ferronematics has increased as they promise to provide an optical device technology based on magnetic switching [10-13].

In this paper the behaviour of a ferronematic when subjecting it simultaneously to both electric and magnetic fields is investigated. We assumed that the ferronematic has a positive magnetic anisotropy $\chi_a > 0$ and a positive dielectric anisotropy $\varepsilon_a > 0$. The external fields are oriented perpendicular to the nematic director, which means that we considered a planar texture for the ferronematic.

Theoretical part

We assume the ferronematic encapsulated into a liquid crystal cell with thickness d was previously chemically processed to obtain a planar alignment. The magnetic field **B** and the electric field **E** are oriented perpendicular to the cell plates. The orientations of the nematic director **n** and magnetic moment **m** of the magnetic particle are shown in figure 1 both in the absence and in the presence of external fields. The deviations exhibited by **n** and **m** are described by the angles β and θ according to

$$\mathbf{n} = 1_x \cos\theta + 1_z \sin\theta$$

$$\mathbf{m} = -1_x \sin\beta + 1_z \cos\beta$$

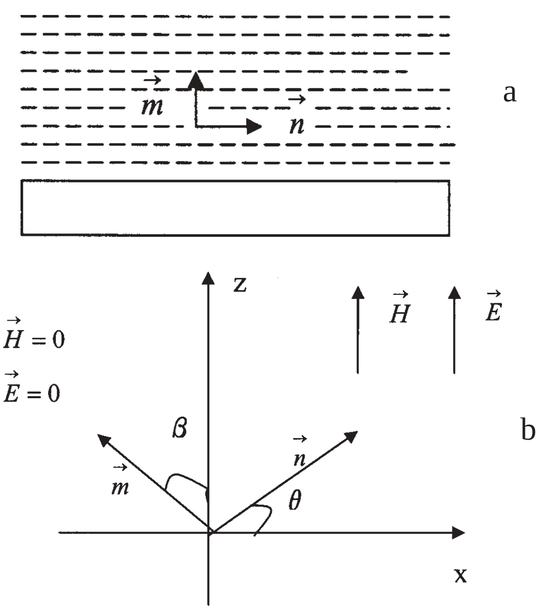

Fig.1. The orientation of nematic director **n** and magnetic moment **m** in the absence (a) and presence (b) of external fields

Under such circumstances the free energy density of the ferronematic is given by

$$F = \frac{1}{2}(K_1 \cos^2\theta + K_3 \sin^2\theta)(\frac{\partial\theta}{\partial z})^2 - \frac{1}{2}\mu_o^{-1}\chi_a B^2 \sin^2\theta - \frac{1}{2}\varepsilon_0\varepsilon_a E^2 \sin^2\theta - fM_s B\cos\beta + \frac{fW}{a}(-\sin\beta\cos\theta + \cos\beta\sin\theta)^2 \quad (1)$$

In equation 1 K_1 and K_2 are the bend and splay elastic constants, χ_a the magnetic anisotropy, ε_a the dielectric constant , f the atomic fraction of the magnetic powder, a the mean diameter of the magnetic powder and W the magnetic surface energy of the magnetic particle-nematic boundary.

To minimize the free energy density we considered first the Euler-Lagrange equations:

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$$\frac{\partial}{\partial z}\left(\frac{\partial F}{\partial\left(\frac{\partial \beta}{\partial z}\right)}\right)-\frac{\partial F}{\partial \beta}=0 \qquad (2)$$

$$\frac{\partial}{\partial z}\left(\frac{\partial F}{\partial\left(\frac{\partial \theta}{\partial z}\right)}\right)-\frac{\partial F}{\partial \theta}=0 \qquad (3)$$

Equation 2 gives

$$fM_sB\sin\beta+2\frac{fW}{a}(-\sin\beta\cos\theta+\cos\beta\sin\theta)(-\cos\beta\cos\theta-\sin\beta\sin\theta)=0 \qquad (4)$$

If small deviation angles are considered ($\sin\theta \cong \theta$, $\sin\beta \cong \beta$, $\cos\theta \cong \cos\beta \cong 1$) the relationship simplifies to

$$f[M_sB\beta+\frac{2W}{a}(\theta-\beta)(-\beta\theta-1)]=0$$

Assuming $\theta\beta \cong 0$ we finally get

$$\beta=\frac{2W\theta}{2W+M_sBa} \qquad (5)$$

Equation (3) gives

$$(K_1\cos^2\theta+K_3\sin^2\theta)\frac{\partial^2\theta}{\partial z^2}+\mu_0^{-1}\chi_aB^2\sin\theta\cos\theta+\varepsilon_0\varepsilon_aE^2\sin\theta\cos\theta$$
$$-\frac{2fW}{a}(\sin\beta\sin\theta+\cos\beta\cos\theta)(-\sin\beta\cos\theta+\cos\beta\sin\theta)=0 \qquad (6)$$

For small deviation angles equation 6 simplifies to

$$K_1\frac{\partial^2\theta}{\partial z^2}+(\mu_0^{-1}\chi_aB^2+\varepsilon_0\varepsilon_aE^2)\theta+\frac{2fW}{a}(\theta-\beta)=0 \qquad (7)$$

Substituting β from equation 5 into equation 7 and assuming that $2W / M_sBa << 1$ we get

$$K_1\frac{\partial^2\theta}{\partial z^2}+(\mu_0^{-1}\chi_aB^2+\varepsilon_0\varepsilon_aE^2+\frac{2Wf}{a})\theta=0 \qquad (8)$$

Equation 8 is a second order differential equation with constant coefficients similar to the following

$$\frac{\partial^2\theta}{\partial z^2}+A^2\theta=0 \qquad (9)$$

Where

$$A^2=\frac{1}{K_1}[\mu_0^{-1}\chi_aB^2+\varepsilon_0\varepsilon_aE^2-\frac{2fW}{a}];A^2>0 \qquad (10)$$

A possible solution of this equation is the following

$$\theta=C_1\sin Az+C_2\cos Az \qquad (11)$$

where the coefficients may be determined from the boundary conditions $\theta(0)=\theta(d)=0$. From $\theta(d)=0$ we get $C_2=0$ and from $\theta(d)=0$ it results $C_1\sin Ad=0$.

Therefore $Ad=\pi$, which shows that the relationship (10) may be written as

$$\frac{\pi^2}{d^2}=\frac{1}{K_1}[\mu_0^{-1}\chi_aB^2+\varepsilon_0\varepsilon_aE^2-\frac{2fW}{a}] \qquad (12)$$

After some operations one can express equation 12 into another form

$$\frac{B^2}{\frac{\mu_0}{\chi_a}\left(\frac{2fW}{a}+K_1\frac{\pi^2}{d^2}\right)}+\frac{E^2}{\frac{1}{\varepsilon_0\varepsilon_a}\left(\frac{2fW}{a}+K_1\frac{\pi^2}{d^2}\right)}=1 \qquad (13)$$

This is the equation of an ellipse with the halfaxes

$$B_c^2=\frac{\mu_0}{\chi_a}(K_1\frac{\pi^2}{d^2}+\frac{2fW}{a}) \qquad (14)$$

$$E_c^2=\frac{1}{\varepsilon_0\varepsilon_a}(K_1\frac{\pi^2}{d^2}+\frac{2fW}{a}) \qquad (15)$$

Results and Discussion

The halfaxes B_c and E_c correspond to the critical fields for magnetic and electric Freedericksz transitons, respectively. Equation 14 is identical to the one obtained by Burylow and Raikher and proved to be in good agreements with the experimental findings. As for equation 15, no experimental results were reported until now.

It is important to notice that when pure nematics are considered (f=0, the critical fields for Freedericksz transitions resulting from equations 14 and 15 are lower than the ones obtained for ferronematics.

Considering usual values for liquid crystal parameters such as $K_1=7.4 \cdot 10^{-12}$N, $W=5 \cdot 10^{-7}$N, $a=3 \cdot 10^{-4}$m, $\chi_a=7 \cdot 10^{-7}$, $\varepsilon_a=2.25$ we plotted the function given by equation 13. The results obtained for different cell thicknesses are shown in figure 2 . In this way we obtained phase diagrams relating transitions from the planar to homeotropic alignment (Freedericksz transitions) of the ferronematic in the presence of both electric and magnetic fields.

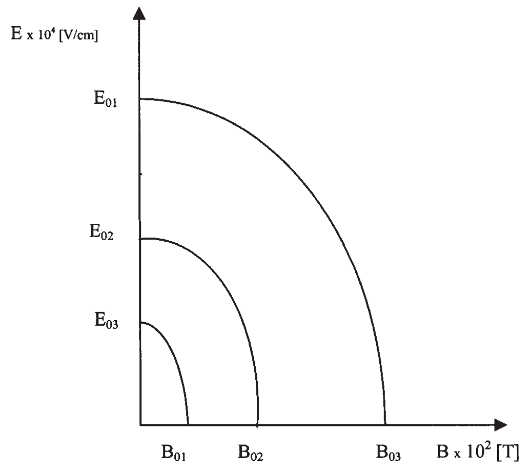

Fig.2. Phase diagrams of transitions between planar and homeotropic alignments arising in ferronematics embedded in cells with different thicknesses ($d_1=10^{-4}$m, $d_2=5 \cdot 10^{-4}$m, $d_3=10^{-3}$ m) when subjected to both electric and magnetic fields

Conclusions

When a ferronematic is subjected simultaneously to an electric and magnetic field the critical fields for Freedericksz transition may be obtained from a phase diagram which proved to be described by an ellipse. This is an indication that when both magnetic and electric field are acted on a ferronematic the planar-homeotropic transition is obtained by using electric and magnetic fields smaller than the critical ones. This result may be useful for some applications.

References

1.BROCHARD, F., DE GENNES, P.G., J.Physique 31, 1970, p. 691
2.CHEN, S.H., AMER, N.M., Phys.Rev.Lett. 51, 1983, p. 2298
3. RAULT, J., CLADIS, P.E., BURGER, J., Phys.Lett. 32A, 1971, p. 1970
4.CHEN, S.H., CHANG, S.H., Mol.Cryst.Liq.Cryst. 144, 1987, p. 350
5.KONERACKA, H., KELLONEOVA,V., KOPCANSKY, P., KUCZYNSKI, T., J. Magn.Magn.Mater, 140-144, 1995, p. 1445
6.FIGUERIDO NETO,A.M, SABA, N.M.F., Phys.Rev.A34, 1986, p. 3483
7.V.BURYLOV, S., RAIKHER,YU J.Magn.Magn.Mater, 122, 1993, p. 62
8. MOÞOC, C., PETRESCU,E., Mod.Phys.Lett. 12, 1998, p. 529
9.MOTOC, C., PETRECU,E., DASCALU, C.,Proc. SPIE, 3407, 1998, p. 950
10.SHIVATSA, S.K., RANGANATH, G.S., Phys.Rev.E, 51, 1999, p. 5639
11.RAIKHER, YU.L., STEPANOV, V.I., J.Magn.Magn.Mater. 201, 1999, p.163
12. BERESNOV, V., Europhysics Lett. 41, 1998, p. 507
13. PETRESCU, E., MOTOC, C., et al., Rev Chim.(Bucureºti), **57**, nr. 5, 2006, p. 533

Manuscript received: 4.05.2007

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VOL. I - "BIOCHIMIE- FUNDAMENTE"', autor: ALFA XENIA LUPEA, Editura Academiei, Bucureºti, 599 pag.
VOL II - "BIOCHIMIE- FOTOSINTEZA, REGLAJUL HORMONAL, INFORMAÞIA GENETICÃ", autori AUREL ARDELEAN ºi ALFA XENIA LUPEA, Editura Academiei Române, Bucureºti 2007, 432pag.

Biochimia, ca ºtiinþã de sine stãtãtoare, s-a constituit în a doua parte a secolului al XIX-lea, deºi procesele biochimice existau dintotdeauna, dar cunoaºterea, aplicarea ºi mai ales explicarea lor au progresat odatã cu evoluþia omului. Astãzi, acumulãrile ºtiinþifice sunt imense ºi totuºi se revine permanent cu explicaþii bazate pe tehnici ºi metode din ce în ce mai perfecþionate, atât în domeniul biologiei cât ºi al chimiei deoarece biochimia este o ºtiinþã interdisciplinarã. Aceste considerente generale justificã necesitatea publicãrii de cãrþi (enciclopedii, cursuri etc.) care sã prezinte sistematizat acumulãrile ºtiinþifice pe mãsura progreselor înregistrate în domeniul biochimiei, ºtiinþã care stã la baza vieþii ºi care în condiþiile actuale de protejare a mediului, impun a fi luate mãsuri de cãtre om, pentru pãstrarea cât mai mult posibil a echilibrului natural pe Terra.

În acest context se înscrie ºi apariþia cãrþii "BIOCHIMIE- FUNDAMENTE"- vol. I ºi "BIOCHIMIE- FOTOSINTEZA, REGLAJUL HORMONAL, INFORMAÞIA GENETICÃ" apãrutã la Editura ACADEMIEI ROMÂNE, Bucureºti, 2007, autori ALFA XENIA LUPEA ºi AUREL ARDELEAN. Lucrarea se adreseazã specialiºtilor în domeniu precum ºi studenþilor de la facultãþile cu profil de biochimie. Având competenþe profesionale în domeniul chimiei organice, dar ºi al biochimiei ºi biologiei, autorii, profesori universitari, au reuºit sã prezinte subiectele abordate din toate punctele de vedere într-o formã pe cât de bogatã în informaþii "la zi", pe atât de sistematizatã, ceea ce permite cititorului o înþelegere a domeniului abordat ºi o utilizare a datelor în explicarea complexelor procese ºi fenomene biochimice.

Cele opt capitole ale primului volum ºi zece ale celui de-al doilea volum sunt: vol I. 1. Arhitectura celularã, 2. Termodinamica în biochimie, 3. Elemente minerale ºi apa, 4. Proteine, 5. Hidraþi de carbon, 6. Lipide, 7. Enzime, 8. Vitamine ºi coenzime; vol II. 1. Privire de ansamblu asupra cãilor metabolice ºi strategiilor metabolismului energetic, integrarea ºi stocarea în organe specializate la vertebrate, 2. Fotosinteza ºi alte procese ce implicã lumina, 3. Bazele moleculare ale acþiunii hormonilor, 4. Nucleotide ºi acizi nucleici, 7. Secvenþialitatea acizilor nucleici, 8. Replicarea, repararea ºi recombinarea ADN-ului, 9. Transcrierea geneticã ºi prelucrarea ARN, 10. Translaþia ºi biosinteza proteinelor. Sunt prezentate 16 anexe care au ca scop sã completeze ºi rezumeze cunoºtinþele de mare utilitate pentru cititori.

Valoroasã este ºi prezentarea bibliografiei consultate de cãtre autori la alcãtuirea acestei importante, actuale ºi utile lucrãri, care va servi drept bazã studenþilor ºi specialiºtilor în efectuarea, explicarea ºi elaborarea de noi lucrãri ºtiinþifice care sã contribuie la progresul în domeniu.

Prof. Dr. Ing. Angela Lupu