Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713926090

Magnetohydrodynamic effects in nematic liquid crystals

S. K. Khoo[a]; G. R. Luckhurst[b]
[a] Department of Chemistry, University of Malaya, Kuala Lumpur, Malaysia [b] Department of Chemistry, University of Southampton, Southampton, England

To cite this Article Khoo, S. K. and Luckhurst, G. R.(1993) 'Magnetohydrodynamic effects in nematic liquid crystals', Liquid Crystals, 15: 5, 729 — 732
To link to this Article: DOI: 10.1080/02678299308036491
URL: http://dx.doi.org/10.1080/02678299308036491

LIQUID CRYSTALS, 1993, VOL. 15, NO. 5, 729–732

Magnetohydrodynamic effects in nematic liquid crystals

by S. K. KHOO
Department of Chemistry, University of Malaya,
Pantai Valley, 59100 Kuala Lumpur, Malaysia

and G. R. LUCKHURST*
Department of Chemistry, University of Southampton,
Southampton, SO9 5NH, England

(*Received 7 May 1993; accepted 19 July 1993*)

The behaviour of a nematic liquid crystal when it is spun about an axis orthogonal to a magnetic field is predicted to be controlled by the critical angular velocity, Ω_C. For spinning speeds below Ω_C theory shows that the director makes an increasing angle with the field until at Ω_C this angle is 45°. Above Ω_C the director should rotate with an angular velocity slightly less than that of the sample. Observation in both regimes allows Ω_C to be determined; since it depends on the ratio of the diamagnetic anisotropy to the rotational viscosity coefficient of the nematic, this ratio can be measured. However, an experimental investigation by Eastman *et al.* [1], suggests that the theoretical relationship between Ω_C and this ratio may be in error by a factor of about four. We have reanalysed their data in an attempt to check this important claim and have found that there is in fact good agreement between theory and experiment.

The director in a nematic sample is predicted to exhibit an intriguing magnetohydrodynamic behaviour when it is spun about an axis orthogonal to a magnetic field, provided the diamagnetic anisotropy $\Delta\chi$ is positive [2]. For angular velocities Ω below some critical value Ω_C the director is predicted to make an angle ϕ with respect to the magnetic field given by

$$\sin 2\phi = \Omega/\Omega_C. \tag{1}$$

When the angular velocity is equal to Ω_C the angle ϕ adopts its maximum value of 45°. Above Ω_C the director is further predicted to rotate with an average angular velocity ω which, because of magnetic friction, is less than that of the sample and is given by

$$\omega = (\Omega^2 - \Omega_C^2)^{1/2}. \tag{2}$$

In these expressions the critical angular velocity is predicted to be

$$\Omega_C = \Delta\chi B^2/2\mu_0\gamma_1, \tag{3}$$

where B is the magnetic flux density, μ_0 is the magnetic constant and γ_1 is the rotational viscosity coefficient of the nematic phase.

The predictions of the theory, both qualitative and quantitative have been tested in a series of magnetic resonance experiments. Thus the director has been observed to change its orientation with respect to the magnetic field as the angular velocity of the

* Author for correspondence.

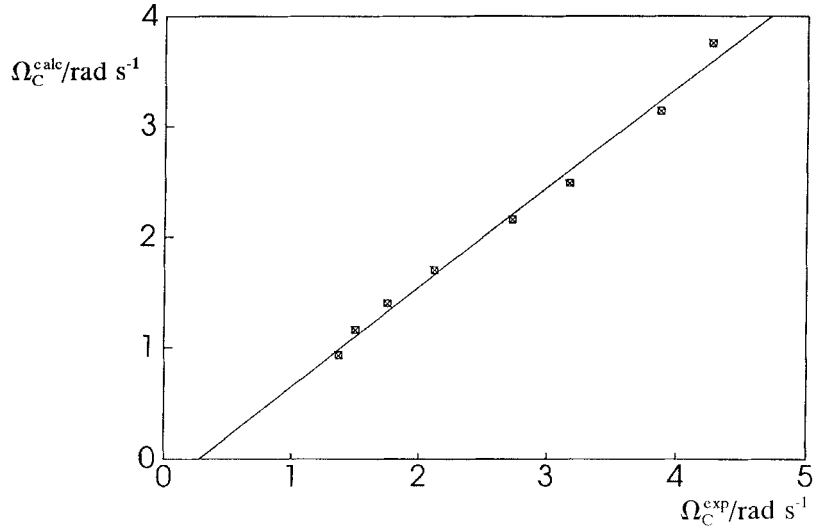
0267–8292/93 $10·00

sample is increased [2, 3]. However, the maximum angle of 45° is not reached, because the director departs from its original uniform alignment to an increasing extent as the angular velocity increases [4]. Indeed, above the critical angular velocity, the stable state of the nematic is found to be one with the director randomly distributed in a plane perpendicular to the spinning axis [4]. The predicted rotation of the director can, however, be observed if a static sample is accelerated rapidly to an angular velocity in excess of Ω_C [2, 5]. The initial, resultant rotation of the director does not persist, but soon decays to a random, two-dimensional distribution. In the regime of angular velocities below about $0{\cdot}8\,\Omega_C$ where the director is more or less uniformly aligned, the dependence of the angle made with respect to the magnetic field on the angular velocity is found [3, 4] to be in agreement with equation (1). Similarly, the angular velocity, ω, of the director in the regime above Ω_C is also well-predicted by equation (2) [1, 2]. Further the critical angular velocities determined for essentially the same nematogenic mixture by different groups working in the regime above [1] and that below Ω_C [4] are observed to be in relatively good agreement. In addition, the quadratic dependence of the critical angular velocity on the magnetic flux density given by the theory is found to be in accord with experiment [1].

One further test of the theory is to compare the values of Ω_C determined from the spinning experiments and those calculated via equation (3) using results for $\Delta\chi$ and γ_1 determined from other experiments. Eastman *et al.* [1], have attempted such a test for Merck Phase IV [6] doped with a trace quantity of the spin probe di-*t*-butylnitroxide so that the rotation of the director above Ω_C can be studied using ESR spectroscopy. Then, using published values for $\Delta\chi$ [7] and γ_1 [8] for pure Phase IV they calculated Ω_C. They discovered that the experimental value was about a quarter of that calculated. Although the presence of the spin probe is likely to alter the values of $\Delta\chi$ and γ_1 from those of the pure solvent, such changes are expected to be far too small to account for the major disagreement between theory and experiment, especially if the comparison is made at corresponding temperatures.

Given the nature of the theory and its previous success in accounting for the other magnetohydrodynamic behaviour of a spinning nematic, we decided to check the comparison made by Eastman *et al.* [1]. In making such comparisons, especially when electromagnetic quantities are involved, some care must be taken with the units. We have chosen to use the International System of Units (SI) which accounts for the appearance of the magnetic constant μ_0 in the equation for Ω_C. In the SI scheme, the units for the angular velocity are $\mathrm{rad\,s^{-1}}$, the volume anisotropic diamagnetic susceptibility $\Delta\chi$ is dimensionless, B the magnetic flux density is expressed in T ($\equiv \mathrm{kg\,s^{-2}\,A^{-1}}$) and the rotational viscosity coefficient γ_1 has units of Pa s. Finally the magnetic constant is $4\pi \times 10^{-7}\,\mathrm{N\,A^{-2}}$.

The rotational viscosity coefficient for Phase IV has been determined by measuring the specific viscous torque on the sample subject to a rotating magnetic field [8]. This method has the advantage that it does not require a knowledge of the anisotropic diamagnetic susceptibility. This quantity has, however, been measured for Phase IV by using the Guoy method which yields the molar susceptibility [7] and so we require the specific density to convert it to the volume susceptibility. Fortunately the density for Phase IV has been measured, although the results have not been published [9]. We have calculated the critical angular velocity for Phase IV from these various data for a range of shifted temperatures ($T_{NI} - T$). This point of comparison was used to compensate for the slight differences in the nematic–isotropic transition temperature of the various samples for which the measurements had been made. This was of particular



A comparison of the critical angular velocity for Merck Phase IV determined directly by Eastman *et al.* [1], (Ω_C^{exp}) and that calculated from the material constants via equation (3) (Ω_C^{calc}).

The data for the rotational viscosity coefficient γ_1 [8], the molar anisotropic diamagnetic susceptibility $\Delta\chi$ [7] and the density ρ [9] used to calculate the critical angular velocity Ω_C.

$(T_{NI}-T)$/K	γ_1/Pa s^{-1}	$\Delta\chi/10^{-9}$ m^3 mol^{-1}	$\rho/10^3$ kg m^{-3}
5	0·0152	0·345	1·0816
8	0·0195	0·369	1·0843
13	0·0265	0·397	1·0886
17	0·0322	0·416	1·0916
23	0·0428	0·435	1·0963
28	0·0539	0·449	1·1002
33	0·0673	0·462	1·1039
38	0·0861	0·473	1·1077

importance for our comparison with the experimental values of Ω_C measured by Eastman *et al.* [1], where the addition of the nitroxide spin probe depresses T_{NI}. The data used in our calculations are listed in the table for the shifted temperatures at which Ω_C had been measured directly. The results for Ω_C are plotted in the figure against those determined from the spinning experiment. We see that as theory predicts there is a linear relationship between the two quantities; the slope of the best fit line is $0{\cdot}90 \pm 0{\cdot}08$ and the intercept is $-0{\cdot}04 \pm 0{\cdot}02$. These values are close to the theoretical predictions of 1 and 0; this agreement is rather good given the combination of quantities measured for Phase IV in three different experiments to calculate Ω_C and the use of a spin doped sample to measure the critical angular velocity directly. We do not understand how Eastman *et al.* [1] came to find such poor agreement between theory and experiment although they give no details of their calculation. Nonetheless, we conclude that the theoretical expression for Ω_C is well-founded so that the spinning experiment provides a reliable route to the determination of the ratio of material constants $\Delta\chi/\gamma_1$.

We thank Professor F. Schneider (Universitat Siegen) for sharing his measurements of the specific density of Merck Phase IV with us. We are also grateful to Professor G. Kothe for an enlightening exchange of correspondence on electromagnetic units.

References

[1] EASTMAN, M. P., FREIHA, B. A., KESSEL, B., and ALLEN CHANG, C., 1986, *Liq. Crystals*, **1**, 147.
[2] LESLIE, F. M., LUCKHURST, G. R., and SMITH, H. J., 1972, *Chem. Phys. Lett.*, **13**, 368.
[3] DIEHL, P., and KETRAPAL, C. L., 1968, *Molec. Phys.*, **14**, 283. EMSLEY, J. W., LINDON, J. C., LUCKHURST, G. R., and SHAW, D., 1973, *Chem. Phys. Lett.*, **19**, 345.
[4] CARR, S. G., LUCKHURST, G. R., POUPKO, R., and SMITH, H. J., 1975, *Chem. Phys.*, **7**, 278.
[5] EMSLEY, J. W., KHOO, S. K., LINDON, J. C., and LUCKHURST, G. R., 1981, *Chem. Phys. Lett.*, **77**, 609.
[6] Merck Phase IV is a mixture of the isomers 4-methoxy-4′-*n*-butylazoxybenzene and 4′-methoxy-4-*n*-butylazoxybenzene.
[7] KNEPPE, H., REIFFENRATH, V., and SCHNEIDER, F., 1982, *Chem. Phys. Lett.*, **87**, 59.
[8] KNEPPE, H., SCHNEIDER, F., and SHARMA, N. K., 1982, *J. chem. Phys.*, **77**, 3203.
[9] SCHNEIDER, F. (private communication).