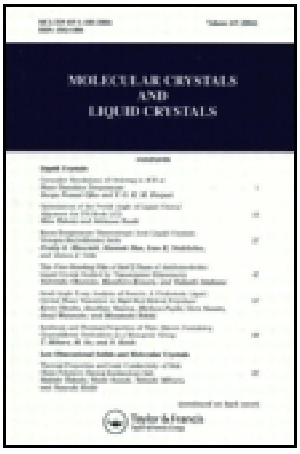

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The Capacitance Response of a Homogeneous Parallel Aligned Nematic Sample to Electric and Magnetic Fields

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THE CAPACITANCE RESPONSE OF A HOMOGENEOUS PARALLEL ALIGNED NEMATIC SAMPLE TO ELECTRIC AND MAGNETIC FIELDS

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INTRODUCTION

The linearised theory of Gruler et al.[1] (hereafter referred to as G.S.M.), which gives the initial slopes of the capacitance voltage (C.V.) and capacitance magnetic field intensity (C.H.) curves of homogeneous, parallel aligned nematic samples with zero surface tilt, has formed the basis of many determinations of their splay and bend elastic constants[2]. This letter describes an investigation of the range over which this theory is valid and discusses the implications of our findings for the experimental determination of the elastic constants of nematic materials.

THEORY

The first order analysis of the C.V. curve given by G.S.M. has been extended to second order to give the result

$$\frac{C - C_{\perp}}{C_{\perp}} = \alpha v + \beta v^2 + 0(v^3) \tag{1}$$

where

$$\alpha = \frac{2\gamma}{1 + \gamma + \kappa} \tag{2}$$

and

$$\beta = \frac{\gamma}{2(1 + \gamma + \kappa)^3} \left\{ 5(\kappa^2 + \gamma^2) - 2(\gamma + \kappa + \gamma\kappa) - 7 \right\} \tag{3}$$

Here $v = (V - Vc)/Vc$, where V is the potential difference across the nematic sample and is greater than V_c, the Fréedericksz transition voltage. C and $C_{\perp}$ are the capacitances of the distorted and undistorted samples respectively;

$\kappa = (k_{33} - k_{11})/k_{11}$ and $\gamma = (\epsilon_{\parallel} - \epsilon_{\perp})/\epsilon_{\perp}$, using the conventional notations for elastic constants and permittivities. The slope of the C.V. curve at threshold is given by α while β determines the initial deviation from linearity. C.V. curves for materials with a variety of elastic constants and permittivities and zero surface tilt were also computed from the full expressions given by G.S.M.; three such curves, with their initial slopes normalized to unity are shown in Figure 1, together with the normalized linear G.S.M. result.

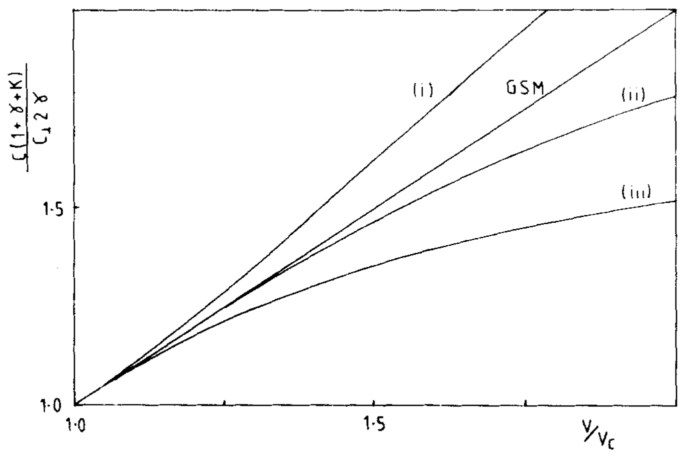

FIGURE 1

The different behaviours of these curves can be understood in terms of the result given in (1). The slopes of curves (i) ($\kappa = 0.5$, $\gamma = 5.0$) and (iii) ($\kappa = 0.5$, $\gamma = 0.2$) deviate from unity at small values of v(≈ 0.05) as would be expected from the non-vanishing values of β corresponding to these material parameters. In curve (i), for which $\beta > 0$, the slope increases from unity until a point of inflection is induced by higher order terms in the expansion (1). (The coefficient of the v^3 term in (1) was found to be negative in all cases where a polynominal was fitted to a C.V. curve). Similarly the slope of curve (iii), for which $\beta < 0$, decreases steadily from unity with increasing v. When $\beta = 0$, as is the case in curve (ii) ($\kappa = 0.5$, $\gamma = 1.5$), the point of inflection seen in (i), is located at the origin and the curve shows an extended linear portion.

While the second order analysis given here is not complete, the criterion based on the sign of β is sufficient to account for the presence or absence of a point of inflection in C.V. curves. It should also be noted that C.V. curves of nematic materials with a small positive β (showing a barely discernible point of inflection just above Vc) exhibit fairly long "pseudo-linear" portions. This accounts for the surprisingly wide range over which the linear theory of G.S.M. is, at first sight, valid for these materials. Although the expression for (β/γ) given in (3) is symmetrical in γ and κ, nematic materials exhibit a much larger spread in γ (0 to 4) than in κ (0 to 1); the sign of β is therefore usually determined by the magnitude of γ. The general rule, which follows from the expression for β, that points of inflection are found in C.V. curves of high γ materials but are absent from those of low γ materials is well borne out in practice.

A similar analysis of the capacitance response to an applied magnetic field of intensity H yields the result

$$\frac{C - C_1}{C_1} = \alpha' h + \beta' h^2 + O(h^3) \qquad (4)$$

where

$$\alpha' = \frac{2\gamma}{1+\kappa} \qquad (5)$$

and

$$\beta' = -\frac{[4\gamma^2 + \gamma(7 - 5\kappa)]}{2(\kappa + 1)^2} \qquad (6)$$

$h = (H-Hc)/Hc$ where Hc is the critical Frēedericksz magnetic field intensity. As β' is negative for $\gamma > 0$, $\kappa < 1.4$, the C.H. curves of positive nematic materials with typical elastic constants will have the same form as curve (iii) of Figure 1. This expectation is borne out by computed C.H. curves.

EXPERIMENTAL

The C.V. curves of homogeneous, parallel aligned nematic samples have been measured to confirm the theoretical findings of the previous section. 25μm thick nematic layers were aligned by 100 Å of SiO evaporated at 30° incidence, and their capacitance measured at 1kHz with the active area spaced from a guard electrode by a 10μm gap. A conventional capacitance bridge was used with the voltage across the nematic sample being measured directly using a high impedance instrumentation amplifier as a buffer. Permittivities measured with this system are accurate to within 1%. The C.V. data were then analysed using a two-parameter non-linear least squares fitting programme, giving V_c to $\frac{1}{2}$% accuracy and (κ + 1) to within 5%. Figures 2 and 3 show the two observed extremes of departure from the G.S.M. linear expression. In both figures the points are experimental, the continuous curves are computed from the appropriate values of γ and κ and the straight lines represent the G.S.M. linear expression. Figure 2 shows a point of inflection typical of large γ and positive β in ROTN403 from Hoffman-La Roche. A low γ mixture comprising 10% by weight of 5CB from

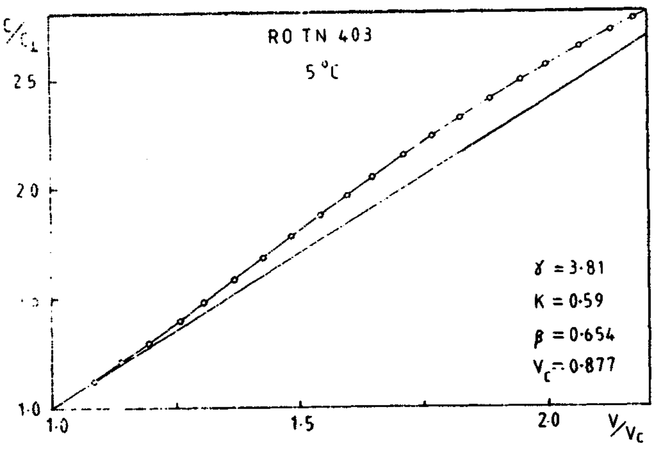

FIGURE 2

BDH Chemicals Ltd in ZLI1052 from E Merck is shown in Figure 3, and the form is typical of low γ and negative β, showing no point of inflection.

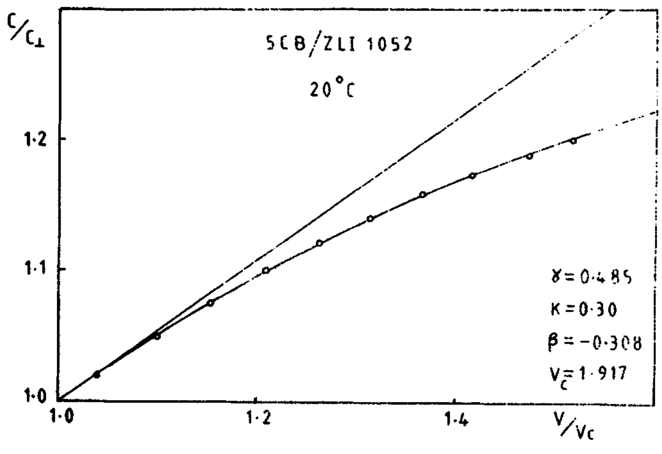

FIGURE 3

DISCUSSION

We have shown by both calculation and experiment that the linearised G.S.M. theory only describes the behaviour of the C.V. and C.H. curves over a very limited range of V and H above threshold. The arguments we have presented can also be applied quite readily, with suitable modifications, to the behaviour of the birefringence/voltage and birefringence/magnetic field intensity curves described by Gruler et al.[1], and used by some workers to determine nematic liquid crystal elastic constants. In view of the limited range over which the linearised theory holds for these curves, considerable care should be exercised in their analysis to determine elastic constants. A curve with a point of inflection (e.g. Figure 2) might, on visual inspection, be taken to show too high a critical field and to have too high an initial slope, while a curve such as that shown in Figure 3 might be taken to show too low a critical field and initial slope. In both cases these errors would tend to compound in the determination of κ from an expression such as (2), while the error in the critical field would lead to a corresponding error in k_{11}. These arguments tend to support the use of two-parameter non-linear least squares fitting programmes of the type first described by Deuling[3] in the extraction of the splay and bend elastic constants from the capacitance and birefringence responses of nematic liquid crystals to applied electric and magnetic fields.

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