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Electric Field Induced Texture Changes in Certain Nematic/Cholesteric Liquid Crystal Mixtures†‡

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Abstract—In dielectrically positive mixtures of the nematic N4 with cholesteryl-chloride an unusual texture transition was observed which can be applied in a storage effect. The variation of several characteristic parameters of these mixtures with concentration and temperature was measured.

We report about some observations on an unusual electric field assisted texture transition in certain dielectrically positive nematic/cholesteric LC-mixtures and present some measurements characterising these mixtures.

1. Texture transitions

The nematic component used was the Merck-substance N4 for which $\Delta\epsilon = \epsilon_{\parallel} - \epsilon_{\perp} \approx -0{,}3$ due to a dipolemoment that makes a large angle with the long axis of the molecule. The cholesteric component was cholesteryl-chloride (CC) for which $\Delta\epsilon = 3$. CC has a dipolemoment parallel to the long molecular axis.[1]

We want to anticipate that in these mixtures $\Delta\epsilon$ changes sign to positive values at about 3 weight % CC concentration which is much lower than one would expect.

The following description of the behaviour of the LC in an electric field (sandwich cell, tinoxide electrodes) relates to mixtures with 3 to

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about 20 weight % CC and for AC-frequencies higher than about 200 Hz (cut-off frequency) where electrohydrodynamic effects were absent. In the experimentally investigated frequency range between 0,2–30 kHz all observations and measurements were independent of frequency.

Two kinds of orientation of the LC at the substrate walls were used: uniformly parallel orientation achieved by rubbing with diamond paste and perpendicular orientation generated by wetting with a lecithin/ethanol solution.

In the experimentally covered layer thickness range from 5 to 25 μm the LC mixtures spontaneously showed the transparent planar cholesteric texture for both kinds of wall orientation. When the substrate walls were wetted by lecithin additionally a typical periodic pattern of disinclinations appeared. An example of this pattern is shown in Fig. 1. This disinclination pattern clearly indicates essentially perpendicular orientation of the molecules at the substrate walls.[2] The disinclinations cause only a slight reduction of the optical transmission. The optical rotatory dispersion of the planar texture, which was measured in the visible spectrum, was in quantitative agreement with the De Vries formula, for both cases of wall orientation.

When a high enough field is applied to the cell the focal-conic texture is established. When the field is switched off this texture is " stored " for several minutes up to many weeks depending on pitch and sample thickness.

When a critical field given by the De Gennes formula[3] (cgs-units)

$$F_c = \frac{\pi^2}{p}\left(\frac{4\pi k_{22}}{\Delta\epsilon}\right)^{1/2} \quad (1) \qquad (p = \text{pitch})$$

is reached the homeotropic nematic texture is induced. The appearance of the texture near F_c is shown in Fig. 2. In the field induced nematic state a uniaxial conoscopic figure is observed under the microscope. The sign of the birefringence, checked with a first-order-red plate, was positive indicating homeotropic orientation.

If the LC is in the homeotropic nematic state and the field is switched off abruptly the LC quickly returns to the planar cholesteric texture. For samples not thicker than about 15 μm the planar texture is completely and uniformly established within 50 ms up to a

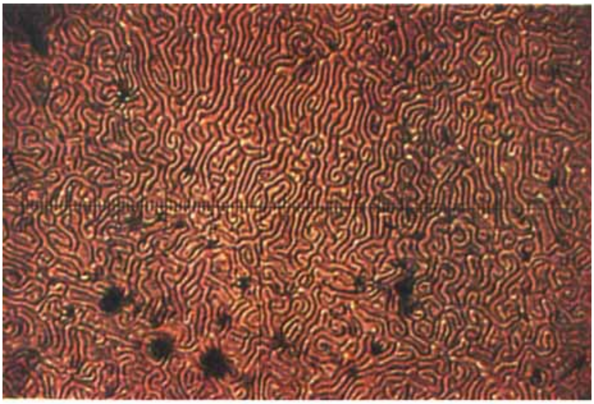

Figure 1. Disclination pattern in the planar texture in N4 + 6% CC; perpendicular orientation at the boundaries of the substrate; layer thickness 7.4 μm; crossed polars: 3.1 μm per scale division.

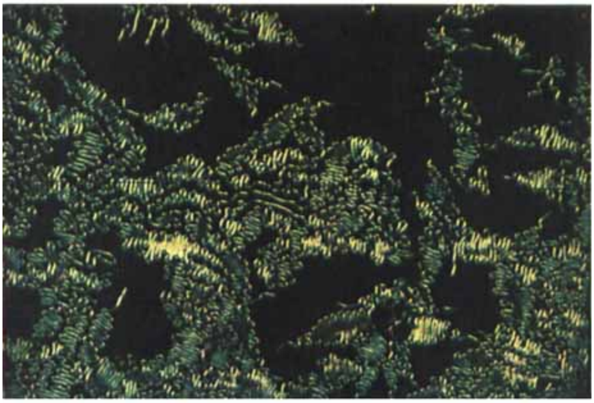

Figure 2. Field induced texture in N4 + 6% CC close to F_c; crossed polars; 6.2 μm per scale division: black areas: homeotropic nematic.

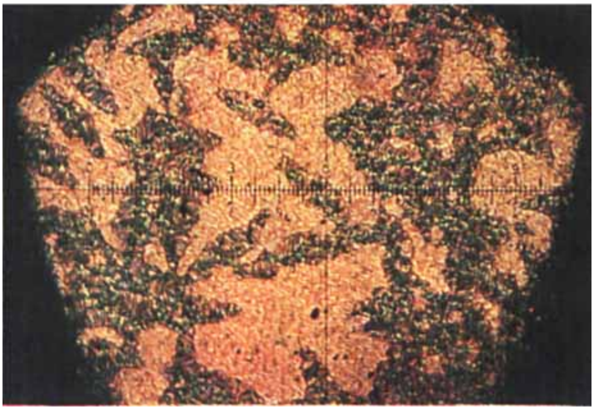

Figure 3. Texture which is observed when the field is quickly switched off in a state like that shown in Fig. 2; only previously nematic areas return to the planar cholesteric texture (red).

few seconds depending on pitch and sample thickness. This unusual texture " switching " is observed for both kinds of boundary alignment (∥ and ⊥). Perpendicular alignment at the surface favors the uniformity of the planar end-state.

When a sample is only partly brought into the field induced nematic state (as shown in Fig. 2) which can be achieved by increasing the field very slowly, and the field is then switched off, only the areas with nematic alignment will return to the planar texture. The other parts show the focal-conic texture. This is shown in Fig. 3. For device application the described behaviour means that a field induced and " stored " light scattering focal-conic texture can be switched to the transparent planar texture by applying a short pulse that surmounts F_c.

2. Measurements

We measured the two dielectric constants $\epsilon_\perp$ and $\epsilon_\parallel$ of the LC mixtures in dependence of the CC-concentration ($\epsilon_\perp$ in the planar texture with parallel boundary alignment; $\epsilon_\parallel$ in the field induced nematic state). The results are shown in Fig. 4. The measurements were done in transparent cells with 10 cm^2 active electrode area (tin oxide). The ϵ-values were determined at 300 Hz. For the measurement of the dielectric increment $\Delta\epsilon$ an additional field of higher frequency was applied to the sample (an example is given in the insert of Fig. 4. In this case the cell area could be made smaller without reduction of the accuracy of measurement). The $\epsilon_\perp$-value for 100% CC was taken from reference 1; the corresponding $\epsilon_\parallel$-value was extrapolated from values given in this reference.

The sagging of the $\epsilon_\perp$-curve in thicker samples, which increases with sample thickness may possibly be attributed to a tilt of the molecules with respect to the helix axis.[1] This tilt can be absent in very thin samples due to the stronger aligning effect of the substrate walls, leading to a linear ϵ-variation.

The abrupt increase of $\epsilon_\parallel$ at very low CC-concentration may be attributed to the decrease of the order parameter of the field induced nematic phase. One has to take into consideration that in the field induced nematic state the torque which the field exerts on the dipole-moments of the N4 molecules does not vanish and that also without

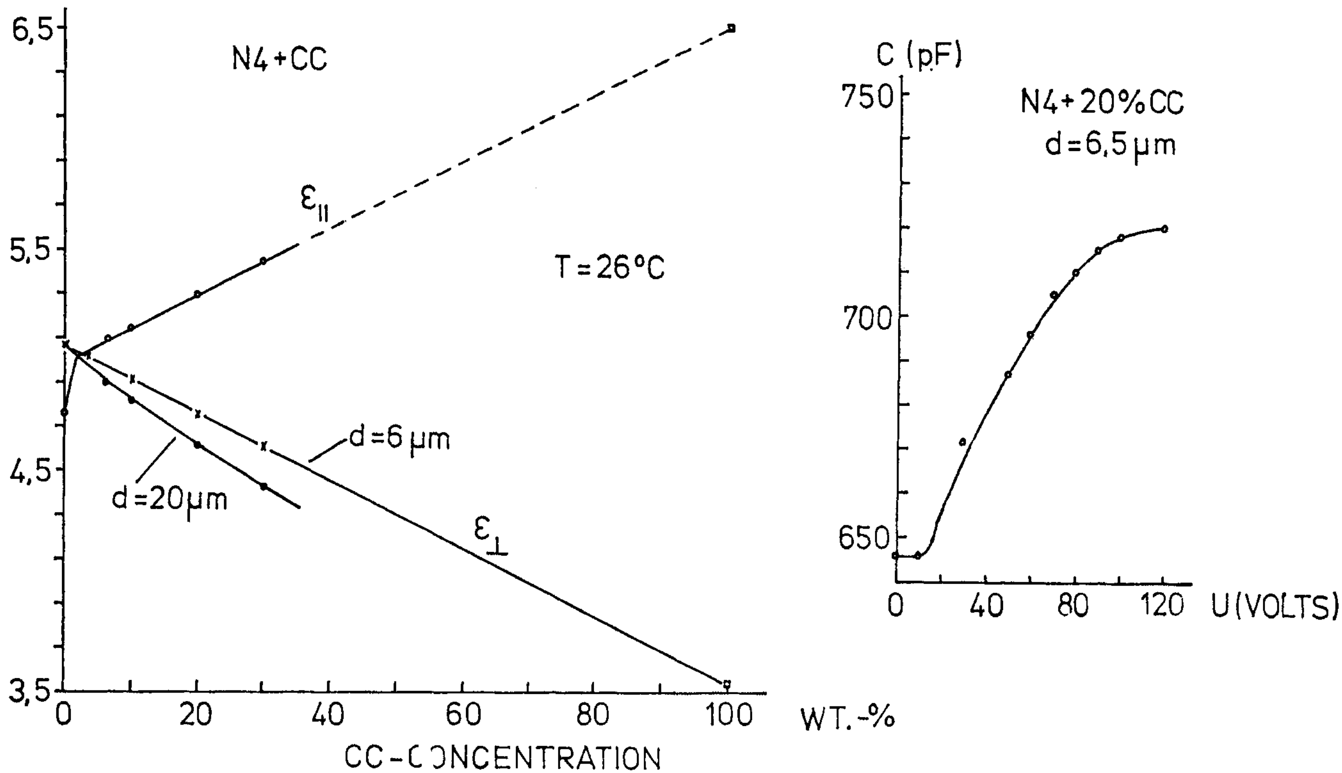

Figure 4. Dielectric constants versus weight % CC in N4 + CC; insert: capacity change with voltage during the texture transistions planar → focal–conic → nematic.

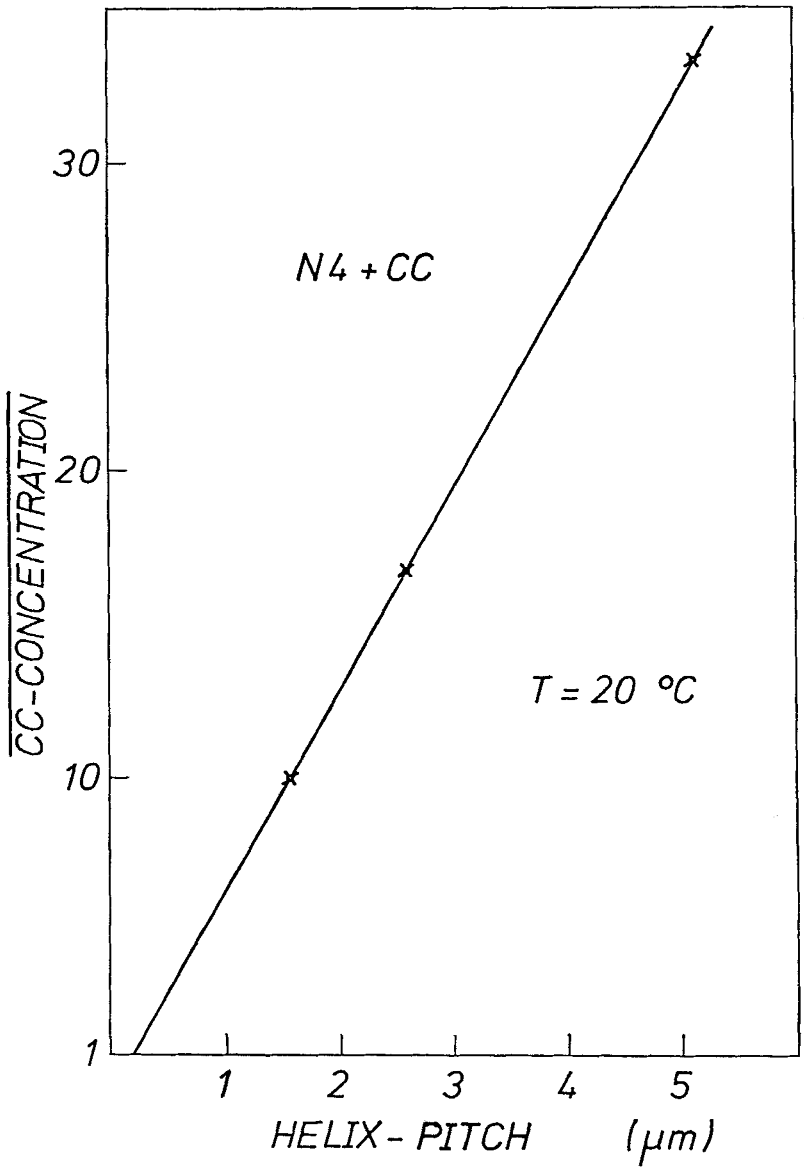

Figure 5. Inverse CC-concentration versus helix-pitch in N4 + CC measured by the Cano wedge method and by IR absorption.

field the order may be lower due to the different orientations of the dipoles of the two components. A strong confirmation for this kind of reasoning is given by the experimental observation that the birefringence Δn of the mixture observed in the field induced nematic phase is strongly reduced. For example, in a N4 + 6% CC mixture we observed a Δn-reduction of about 20% compared to that of 100% N4 (CC: $\Delta n \approx 0{,}05$[4]; N4: $\Delta n \approx 0{,}24$).

From the pitch versus CC-concentration dependence given in Fig. 5, which shows the usual $p \sim 1/c$ variation and from the $\Delta\epsilon$ on C variation of Fig. 4 which is simply $\Delta\epsilon \sim (C - C_0)$ for $\Delta\epsilon \geqslant 0$ where C_0 is the CC-concentration for vanishing $\Delta\epsilon$, Eq. (1) gives

$$F_c \sim \frac{1}{p\Delta\epsilon^{1/2}} = \frac{C}{(C - C_0)^{1/2}}$$

This function has a minimum for $C = 2C_0$. Thus by measuring the F_c versus CC-concentration we have a second independent determination of C_0. The result is shown in Fig. 6 for $\|$ (upper curve) and $\perp$ alignment (lower curve) at the surface. Both measurements of C_0 yield the same value $C_0 \approx 3$ weight % CC.

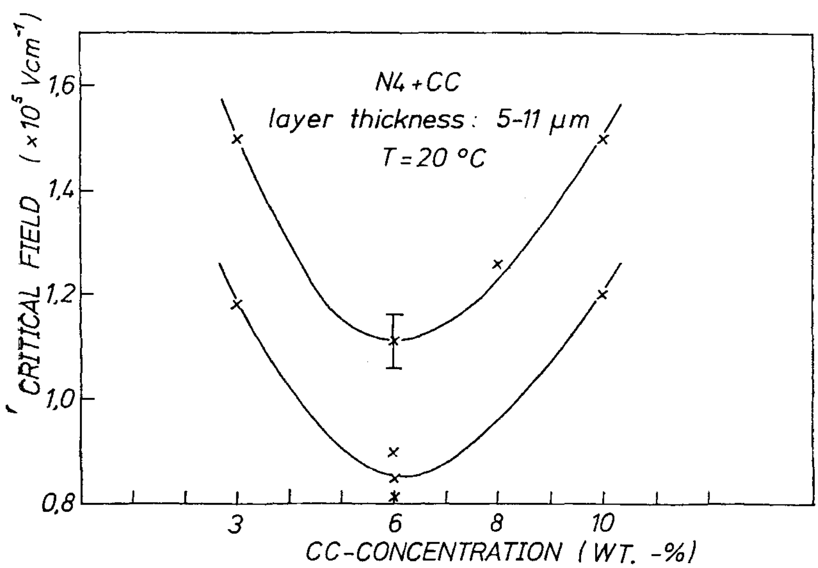

Figure 6. Critical field strength for induced nematic texture versus CC-concentration; upper curve: $\|$ alignment at the surface; lower curve: $\perp$ alignment.

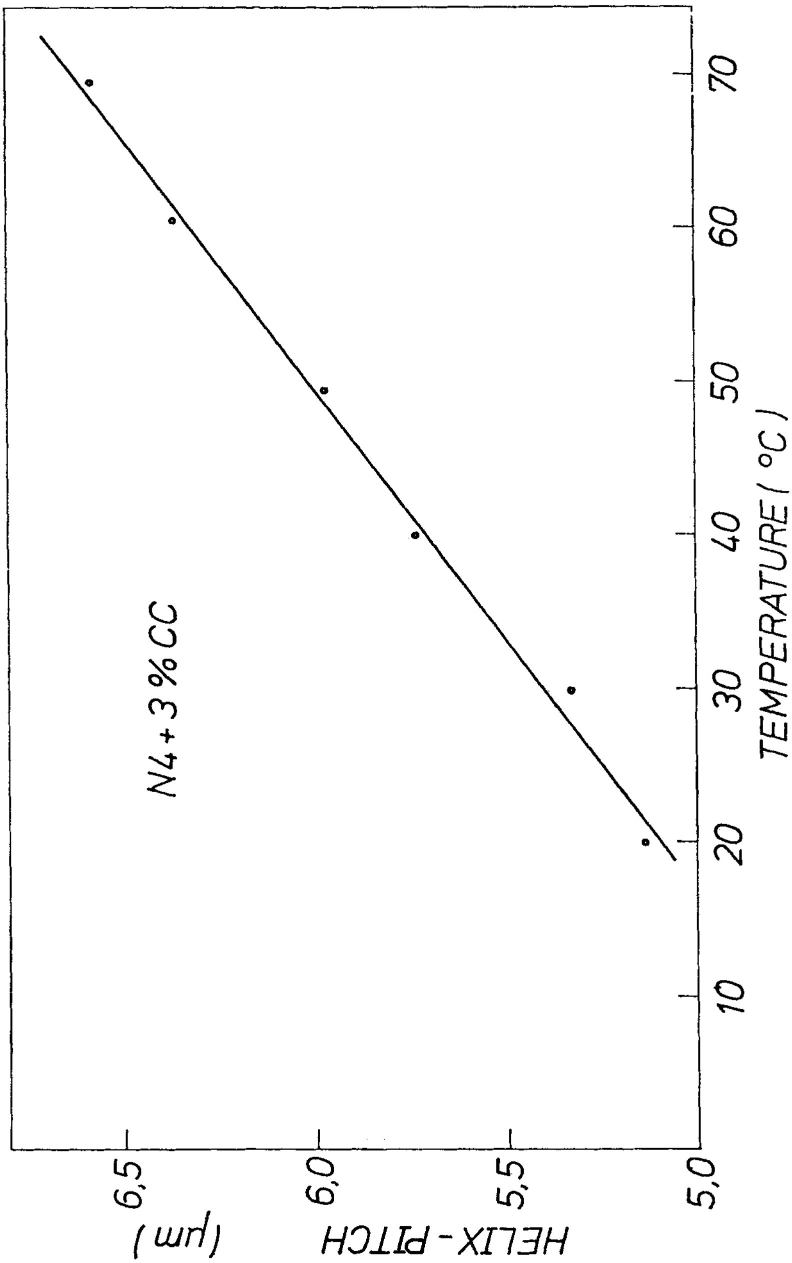

Figure 7. Helix-pitch versus temperature in N4 + 3 % CC.

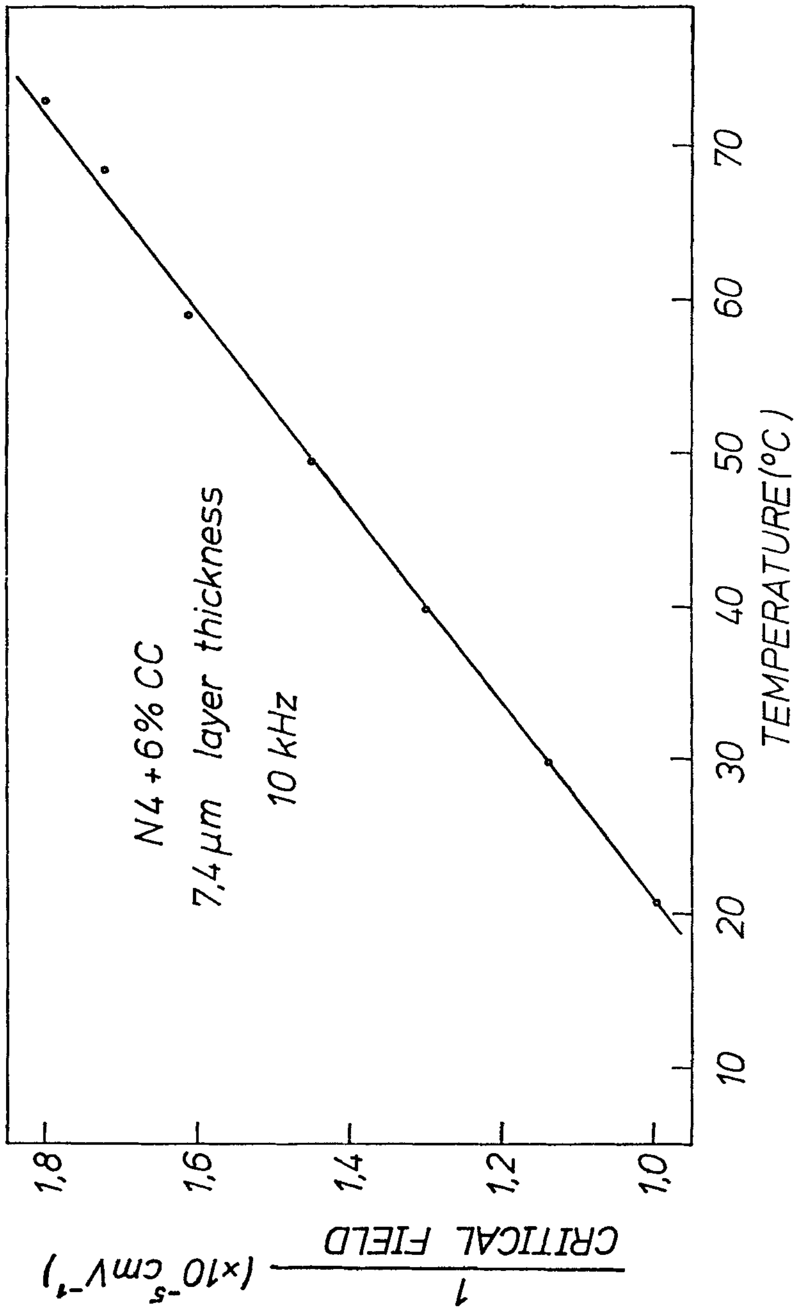

Figure 8. Inverse critical field strength for induced nematic texture versus temperature in N4 + 6 % CC.

The difference in F_c for $\parallel$ and $\perp$ boundary alignment is appreciable showing that the influence of the boundary layers cannot be neglected in calculating the critical field. Contrary to most cholesterics we find a linear increase of pitch with temperature as shown in Fig. 7. Therefore $1/F_c$ should be proportional to the temperature according to equation (1). The result shown in Fig. 8 is in qualitative agreement with this expectation. Furthermore, as for 100% CC the pitch is proportional to the inverse temperature, one can see that for a certain CC-concentration a mixture with temperature insensitive pitch must exist.

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