Universal Scaling of Alpha Relaxation in Complex Liquids

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A plot is given, showing the result of a scaling analysis of dielectric loss curves containing, apart from low molecular glass former data (glycerol, dibutyl phtalate), also loss curves of the following liquid crystalline materials, mostly in the isotropic phase: 4-(2-methylbutyl)-4'cyanobiphenyl (5*CB, supercooled isotropic phase), 4-cyano-4-n-alkyl biphenyls (nematogens 5CB and 8CB, isotropic phase), 4-(4-cyano-4-butylcyclohexyl)-4'-octylbiphenyl (laterally substituted nematogen, isotropic phase), and 4-*n*-alkyl-4'-isothiocyanatobiphenyl (5 and 10 BT, isotropic and SmE phases). The plot applies the scaling formula originally proposed for glassforming, supercooled liquids [Dendzik et al.[7]]. The result supports the recent suggestion that dielectric relaxation in the isotropic phase of nematogens may show some features typical for "*glassy*" materials.

Key words: Complex Liquids Supercooled Liquids; Liquid Crystals; Dielectric Loss Curves; Universality.

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Complex liquids containing a broad class of materials that include associated liquids, polymers, solutions of biomolecules, colloidal liquids, liquid crystal, critical mixtures, supercooled liquids, etc. [1]. It is a most challenging question if there exist universal patterns despite the diversity at microscopic level [2, 3]. Some progress has been reached for supercooled, glassforming liquids. Let us recall here such attempts as the mode-coupling theory (MCT), the concept of fragility [4, 5], and the relaxation time scaling [6, 7]. A unique class of complex liquids is also that of liquids near the critical point with the well-defined universality from the modern theory of critical phenomena [2]. It is noteworthy that its application, within the so-called *fluidlike* description, gave a unified model of so different systems as the homogeneous phase of critical mixtures and the isotropic phase of liquid crystalline materials [8, 9]. Very recently it has been shown that for the isotropic phase of nematogens the behaviour characteristic for supercooled "*glassy*" liquids may appear when considering the relaxation of the dielectric permittivity in a broad range of temperatures [10–12]. In particular, the validity of MCT-based relations was shown [11, 13]:

$$f_p \propto (T - T_C^{MCT})^{\gamma} \ (20\text{ MHz} < f_p < 700\text{ Hz})$$
$$\text{and } \sigma \propto (T - T_C^{MCT})^{\gamma'} \ (10\text{ Hz} < f_p < 1\text{ MHz})$$

where f_p denotes the peak frequency and σ is the electric conductivity. T_C^{MCT} is the MCT-based 'critical' crossover ergodic–nonergodic transition temperature. For 8CB the following parameters were obtained: $T_C^{MCT} \approx 273$ K, $\gamma = 2.4$ and $\gamma' = 2.1$.

For supercooled liquids one of the ideas of exploring '*universality*' is the proposal of Dixon [6] to scale dielectric loss curves for low-molecular-weight glassformers into a single curve. The more general form of such scaling, covering also polymeric materials, was proposed by Dendzik et al. [7].

In this paper we show that the application of the latter make it possible to plot a single scaling curve containing also loss curves of isotropic liquid crystalline materials. They are six liquid crystalline materials: 5*CB [14] (a liquid crystalline material supercooling in the isotropic phase [15], 4-cyano-4-*n*-alkyl biphenyls (nematogens 5CB, 8CB, isotropic phase [11, 12]), 4-(4-cyano-4-butylcyclohexyl)-4'-octylbiphenyl (laterally substituted nematogen, isotropic phase), and 4-*n*-alkyl-4'-isothiocyanatobiphenyl (5BT and 10BT, isotropic and SmE phases). The applied data are for the different pressures and temperatures. The dielectric measurements were made using a BDS dielectric spectrometer (Novocontrol) working in the frequency range 10 MHz to 1 GHz. The scaling plot incorporates four parameters: f_s, ε_s, m, and n. The first two are defined as the frequency and dielectric loss corresponding to the intersection of the two power-law characteristics [4, 5]: $\varepsilon'' \sim \nu^m$ (for $f < f_s$) and $\varepsilon'' \sim \nu^{-n}$ (for $f < f_s$). The parameters m and n are constants for a given temperature (pressure). The scaling relationship formulated in [7] suggests the plot $m^{-1} \log(\varepsilon'' f_s^m / \varepsilon_s f^m)$ versus $(1 + n/m) \log(f/f_s)$. Figure 1 shows such a scaling curve containing superposed dielectric loss curves for glicerol [16], dibutyl phtalate [17] (low-molecular weight glassformers) and the liquid crystalline materials mentioned above. The latter are in the isotropic phase and in the mesophase. Data are also given for pressurized samples. The validity of the Dendzik plot [17] for all tested liquids is evident. The small scatter at the '*bending*' of the scaling curve is characteristic also for '*normal*' glassformers [6, 7].

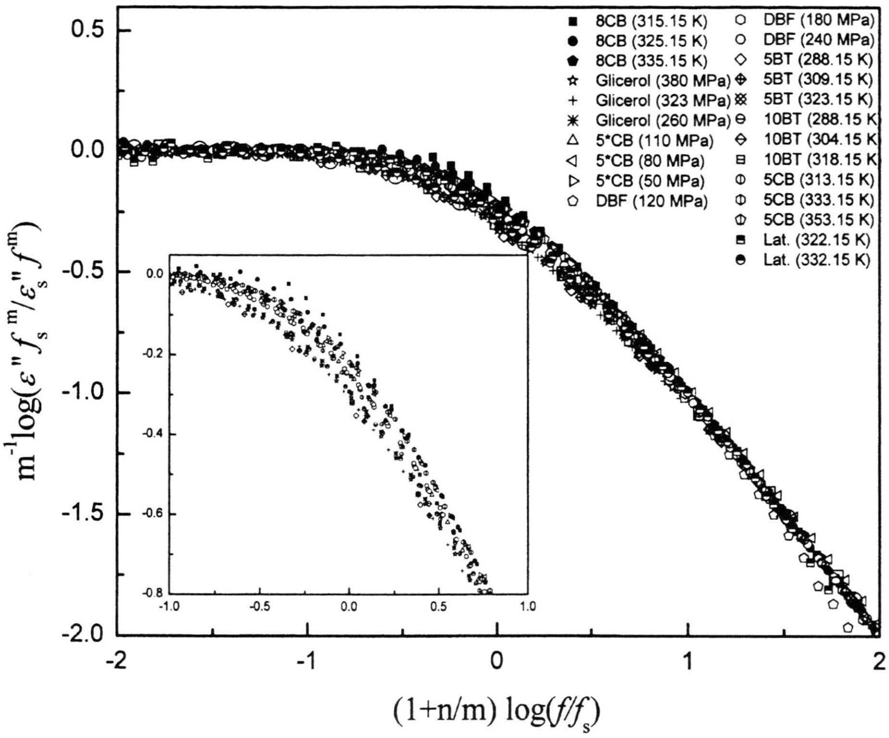

Fig. 1. The Dendzik sacling plot of dielectric loss curves for glycerol, diputyl phtalate (DBF), 4-(2-methylbutyl)-4′cyanobiphenyl (5*CB, supercooled isotropic phase), 4-cyano-4-n-alkyl biphenyls (nematogens 5CB, 8CB, isotropic phase), 4-(4-cyano-4-butylcyclohexyl)-4′-octylbiphenyl (laterally substituted nematogen, isotropic phase), 4-n-alkyl-4′-isothiocyanatobiphenyl (5BT and 10BT, isotropic and SmE phases). Temperatures and pressures of the tested paths are given in the figure.

Concluding, the results obtained suggest that the universal scaling of loss curves originally proposed only for supercooled, glassforming liquid [6, 7] may also be valid for a broader class of so called complex liquids.

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