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Thermodynamic and acoustical study of zinc oxide-nematic liquid crystals mixtures

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ABSTRACT

Thermodynamical and acoustical studies have been carried out in nematic liquid crystal (8CB) and zinc oxide (ZnO) nanoparticle doped 8CB mixtures. The effect of nanoparticle concentration on the ultrasonic velocity and density has been studied using density and sound velocity analyzer. Adiabatic compressibility, molar compressibility, sound velocity, acoustic impedance and intermolecular free length have been estimated. Density and sound velocity decrease with the increase of the temperature and ZnO concentration, however intermolecular free length increases with increasing the temperature and ZnO concentration. The results have been compared with pure nematic liquid crystal mixture.

1. Introduction

Liquid crystal (LC) materials have attracted both physicist and chemist due to their fundamental point of view and technological applications in displays, optical switches [1,2]. The application of these materials depends on detailed study of its molecular structure and thermodynamical behavior. The liquid crystalline state is characterized by the orientation and transition order between various mesophase. These transitions depend on an important parameter viz. order parameter. The LC order parameter can be obtained by a number of ways. The nature of the phase and its pre-transitional effects across the isotropic–nematic–smectic–crystalline can be studied using various techniques such as polarizing optical microscopy (POM), differential scanning calorimetric (DSC), image processing techniques, transitions and dielectric spectroscopy. One of the precise methods to study the phase transitions, molecular order and molecular interactions [3–6] in liquid crystal is density measurements. The study of density measurements helps to understand the nature of phase transitions in the mesomorphic compounds at the phase transitions. Several researchers have reported that the thermo-acoustic parameters are a versatile tool to study the phase transitions and molecular interactions in liquid, solids, liquid crystals [7–12]. Over the past decade, a great deal of work was extended in the evaluation of thermo-acoustical parameters, which are useful qualities to study the structure–property correlation ship, molecular arrangement and interactions. The ultrasonic velocity as a function of temperature determines the overall response of the medium and the nature of interaction between the molecules of the liquids. Successful attempts have been made by several workers for the measurements of adiabatic compressibility, molar compressibility, molar sound velocity, expansion coefficients, Huggins parameters, Gruneisen parameters, Sharma parameter, internal parameters molecular radius and specific volume in liquid crystals [4]. Recently, doping of various types of nanomaterials into nematic, ferroelectric liquid crystals has attained a considerable interest among researchers due to their improved electrical, optical and mechanical properties. Nanomaterials such as Ag, Cu, Ni, Silica, Al_2O_3, ZrO_2,TiO_2, CdTe, ZnS, ZnO, single wall and multiwall carbon nanotubes, nickel-ferrite, iron-oxide, quantum dots in varying concentration, size, and shape have been studied for electro-optic, electrical and optical parameters [13–16]. Various reports are available on phase transition behavior and thermodynamical parameters measured by density measurements in liquid crystals but fewer reports were seen in nanomaterials–liquid crystal mixtures. The aim of present work is to study the effect of ZnO concentration on phase transitions, molecular interactions, energy and related thermo-acoustical parameters in nematic liquid crystal mixture.

2. Theory

The procedure for the estimation of various parameters using the density data in conjunction with sound velocity data is described

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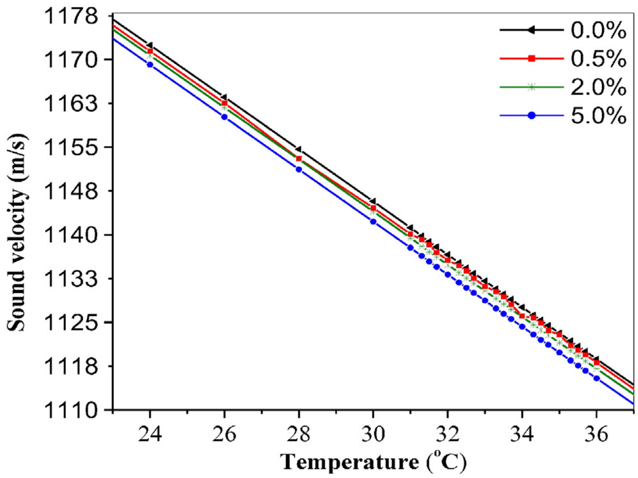

Fig. 1. Temperature dependence of sound velocity for pure and ZnO doped NLC mixture.

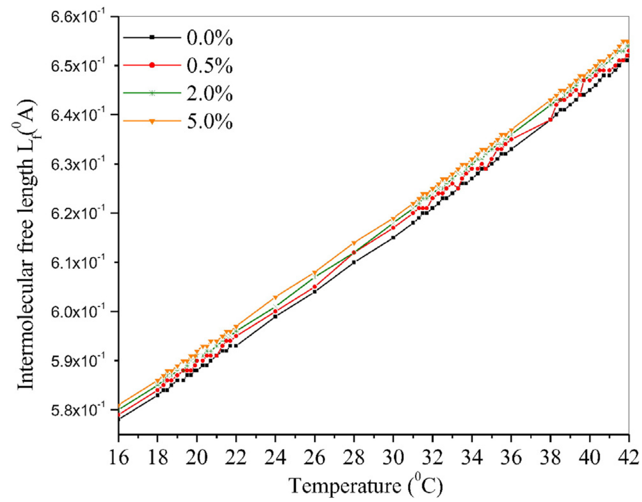

Fig. 3. Temperature dependence of intermolecular free length for pure and ZnO doped NLC mixture.

below [12]. Rao [9] reported a relationship between thermal co-efficient of velocity and density and can be written as

$$\left(\frac{1}{v}\right)\frac{dv}{dT} = \left(\frac{1}{p}\right)\frac{dp}{dT} \quad (1)$$

where v, ρ are the ultrasonic velocity and density of liquid. On integrating and simplifying the Eq. (1) becomes:

$$\frac{v^{1/3}}{\rho} = k \quad (2)$$

where k is constant and independent of temperature.

In terms of molecular weight of mixture (M), the Eq. (2) can be rewritten as;

$$\frac{Mv^{1/3}}{\rho} = R \quad (3)$$

where R is known as Rao's constant. For a particular liquid, Rao suggested that $M\,(v)^{1/3}$ is constant. From the velocity v and density ρ, the values of adiabatic compressibility (K_{ad}), molar sound velocity (R), molar compressibility (B), acoustic impedance (Z) and intermolecular free length (L_f) have been calculated using the following relations:

$$K_{ad} = 1/p\,v^2 \quad (4)$$

$$R = \left(\frac{M}{p}\right) v^{1}/_{3} \quad (5)$$

$$B = \left(\frac{M}{p}\right) K_{ad}{}^{1}/_{7} \quad (6)$$

$$Z = v \cdot p \quad (7)$$

$$L_f = k\,(K_{ad})^{1}/_{2} \quad (8)$$

where, M is given by

$$M = \frac{n_1 M_1 + n_2 M_2}{(n_1 + n_2)} \quad (9)$$

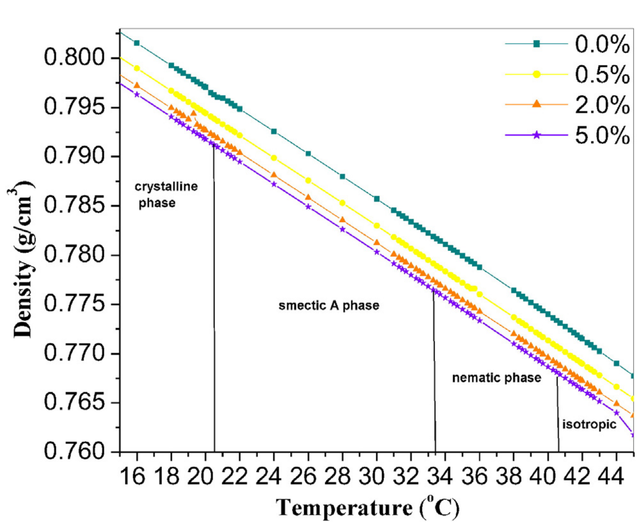

Fig. 2. Temperature dependence of density for pure and ZnO doped NLC mixtures.

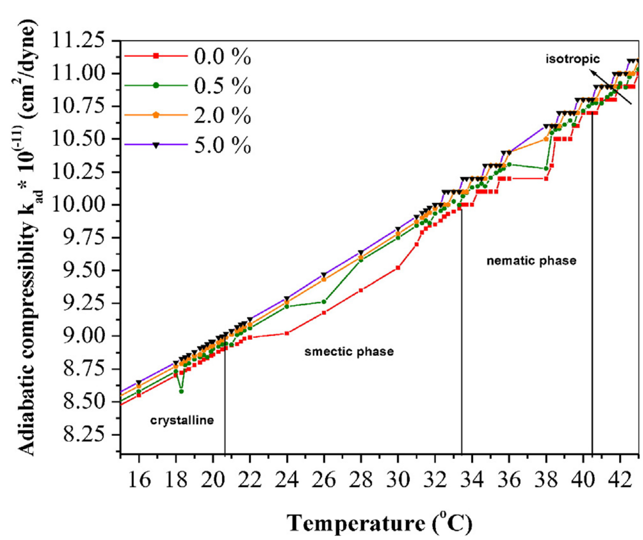

Fig. 4. Temperature dependence of adiabatic compressibility for pure and ZnO doped NLC mixture.