Theory and Modeling 5: 1:55 - 2:30 p.m.

Cubic Invariant for Artificial Muscles

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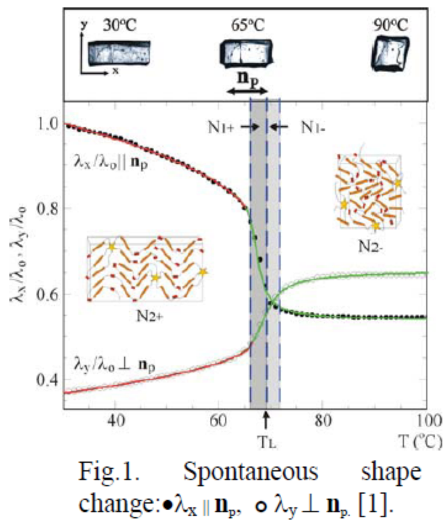

Fig.1. Spontaneous shape change:•λx || np, λy ⊥ np. [1].

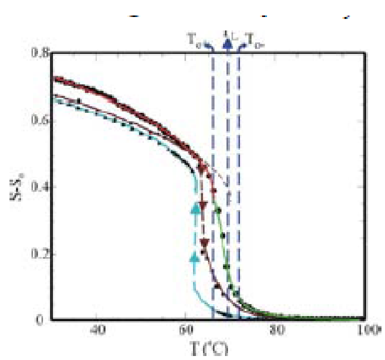

Fig. 2. S-So from [1] and independent birefringence measurements increasing T, t decreasing T [2].

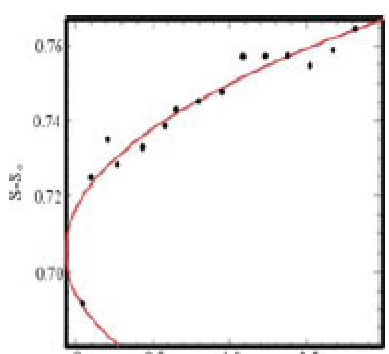

Fig. 3. S-So *vs*. strain [2]

Liquid crystals are characterized by an axis of orientational order, np, where ||np**||=**1. Liquid crystalline elastomers support shear while low molecular weight liquid crystals flow. In monodomain elastomers, supercritical phase transitions with small latent heats result in dramatic muscle action because spontaneous shape changes are in a narrow temperature range. Supercritical first order shape change transitions unfold beautifully in the polarizing microscope (Fig. 1) [1]. The muscle transition for this main chain elastomer [2] occurs in a 5K temperature interval around the temperature, TL≈ 70^{o}C where the cubic invariant, I3, changes sign at a continuous uniaxial positive nematic (N1+) to uniaxial negative nematic (N1-) transition. A single Lorentzian connects the constant volume positive biaxial nematic, N2+ to the constant volume negative biaxial nematic, N2-. The two Lorentzians of dI3/dT, one for N2+ ↔ N1+ and the other for N1- ↔ N2- merge at TL, which is approximately the cross-linking temperature, T_{CL}. Siloxane cross-linking at T_{CL} ≈ 60^{o}C, integrates quadratic uniaxial orientational order, I2, of the liquid crystalline units into one np for the elastomer. Uniaxiality for np is guaranteed in the vicinity of T ≈ TCL. Far from TCL, np is biaxial. Consequently, LCEs require the general description for nematics that includes quadratic, I2, and cubic, I3, invariants [3]. This introduces a new transition at temperature TL ~ TCL≠ TNI where I3 changes from positive to negative. The "L" in TL is for Larkin. The free energy is ΦLCE = - ½(qL/qNI)((TL-TNI)^2/(TL-TNI))(S-So)^2 where qL/qNI is the ratio of the heats of transition at TL ≈70oC and TNI ≈125^{o}C. So is the Lorentzian base line and (S-So)^2 = I3 2/3= 0.55 I2. Fig. 2 shows S-So for the spontaneous shape change in Fig. 1 and for independent birefringence measurement [2]. Fig. 3 shows S-So for relative strain, λ|| || np at T ≈ 25^{o}C: (S-√2/2)^2 = (λ|| -0.957)/Λ [2]. Thus, S=So = √2/2 when λ|| = 0.957 (not 1) because of spontaneous shape change.

1. Y. Yusuf, S.Hashimoto, P.E. Cladis, H.R. Brand, S. Krause, H. Finkelmann,
S. Kai, *Elastic Strain Limited Swelling (ESLS)* (in preparation).
2. Simon Krause, *Nematische Hauptkettenelastomere Synthese und Untersuchung der mechanischen Eigenschaften und der Ordnungszustandes,* Albert-Ludwigs-Universität Freiburg, Juli (2008).
3. P.B. Vigman, A.I. Larkin and V.M. Filev, Sov.Phys. JETP **41**, 944 (1976).