Separation-insensitive attractive interaction between particles mediated by the elastic distortions of a nematic liquid crystal

NRI AIST and JST ERATO/SORST Liquid Crystal Nano-system Project
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ネマチック液晶の弾性変形が媒介する粒子間相互作用を，Landau–de Gennes 理論に基づいて調べる．本研究で考察するのは，2つの球状粒子が表面で強い垂直配向を課し，「第3次元への逃げ」によって特異性を失した環状の転傾が粒子間にあるという状況である．液晶が媒介する粒子間相互作用は引力であり，そのエネルギーは粒子間距離のほぼ線型な関数，つまり粒子間に働く力は距離にほとんど依存しないことが，数値計算により示される．この性質は，Poulin ら [1] によって実験的に観測された「バブルガム構造」の振る舞いと一致している．

Liquid crystal colloidal dispersions constitute a novel attractive class of soft matter. One of the intriguing and important properties of liquid crystal colloidal dispersions is that elastic distortions of the host liquid crystal can mediate an effective long-range interaction between particles immersed in it. Well-known examples of such interactions in a nematic liquid crystal include the dipolar one between particles carrying a hyperbolic hedgehog defect, or the quadrupolar one when the particle surfaces impose tangential anchoring. In Ref. [1] Poulin and co-workers reported a different type of orientational configuration of the host nematic and the resultant interaction. Two particles with strong normal anchoring stick to each other with narrow strings of birefringent regions (they referred to this configuration as "bubble-gum") and surprisingly, the attractive interaction force between the particles is almost independent of the inter-particle distance. There have been virtually no theoretical or numerical attempts to elucidate the structures and properties of this "bubble-gum" configuration, except for a possible director profile suggested in Ref. [2], where an escaped nontopological ring disclination is situated between the particle. The aim of the present study is to account for this unusual interaction by numerical calculations based on the Landau–de Gennes continuum theory starting from the suggested profile in Ref. [2].

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To describe the orientational order of a nematic liquid crystal, we use a second-rank tensor order parameter Q_{ij}. The free energy of the host nematic liquid crystal is given by $F = \int_\Omega dr[\frac{1}{2}A\mathrm{TrQ}^2 - \frac{1}{3}B\mathrm{TrQ}^3 + \frac{1}{4}C\left(\mathrm{TrQ}^2\right)^2 + \frac{1}{2}L_1\partial_k Q_{ij}\partial_k Q_{ij}]$, where Ω is the region outside the two particles occupied by the nematic liquid crystal. We impose rigid normal anchoring at the surfaces of two spherical particles with equal radii. We assume uniform alignment at infinity. The details of the numerical procedures are described in Ref. [3].

We show in Fig. 1 a typical orientational configuration around two particles[4], in close resemblance to the experimentally observed orientation profile reported in Ref. [1]. Figure 2 plots the rescaled free energy of the host liquid crystal as a function of the distance D between the centers of the particles[4]. The free energy almost falls on a straight line with a positive slope. It indicates that the interaction between particles is attractive and the force is almost independent of D. This finding is consistent with the experimental observation of the constant force in the bubble-gum configuration[1].

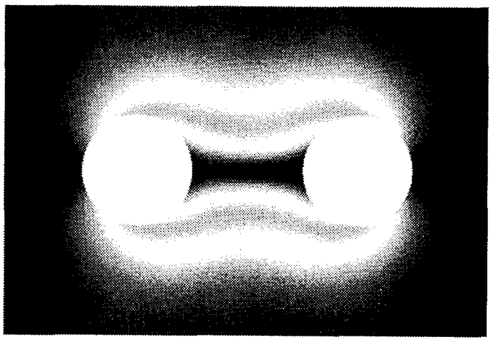

Figure 1: The orientation profile of a nematic liquid crystal shown by a gray-scale plot of Q_{zz}^2 (The z axis is along the horizontal direction).

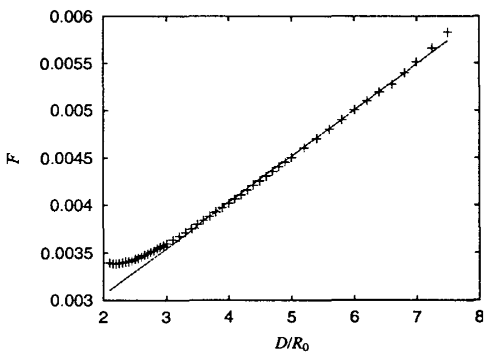

Figure 2: The rescaled free energy as a function of D, distance between the centers of the particles. R_0 is the particle radius.

References

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