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Curvature, chirality, and polar symmetry in liquid crystals

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Charles Frank taught us the relationship between curvature and polarity in liquid crystals. He showed that polar ordering of dipolar molecules, with the polar axis parallel to the nematic director, would lead to spontaneous splay deformation of the otherwise uniaxial nematic state. Likewise, he showed that molecular chirality leads to spontaneous twisting of the director field, resulting in the helicoidal textures of chiral nematics. Augmenting Frank's insight on polarity induced splay with the realization that bend induces polarization perpendicular to the director, led to the concept of curvature induced polarization of liquid crystals, or flexoelectricity. The concepts of chirality induced twist and bend induced polarization became intimately combined in the case of chiral smectic C liquid crystals. The chirality induced twisting of the molecular tilt direction from layer to layer in the smectic produces a helical state incorporating both spontaneous twist and bend, and therefore inducing polarization in the smectic layers, normal to the molecular tilt direction. Thus, Frank's original insights led eventually to the discovery of ferroelectric liquid crystals. In fact, spontaneous polarization and helical order are independent consequences of molecular chirality in tilted smectics. The fundamental combination of monoclinic local symmetry in the smectic C phase with molecular chirality leads directly to spontaneous polarization, with no requirement of helical twisting. This realization leads to generalizations of ferroelectricity to include anti-ferroelectric and ferri-electric smectics, among the fascinating array of polar liquid crystal phases. The consequences of these concepts in fundamental science, materials development, and applications will be reviewed.