Pattern Formation in Liquid Crystal

Hiroshi Orihara

Division of Applied Physics, Faculty of Engineering, Hokkaido University, Sapporo, Hokkaido 060-8628, Japan
E-mail address: orihara@eng.hokudai.ac.jp

(Received September 1, 2014; Accepted January 15, 2015)

Key words: Nematic Liquid Crystal, Disclination, Topological Defect, Dynamical Scaling Law

1. Introduction

"Liquid crystals are beautiful and mysterious; I am fond of them for both reasons." Professor Pierre-Gilles de Gennes, who was awarded the Nobel Prize for research on polymers and liquid crystals, began the introduction to his famous work *The Physics of Liquid Crystals* (de Gennes and Prost, 1993) with these words. Because liquid crystals are a liquid formed from long thin molecules that have optical anisotropy, beautiful and mysterious patterns can be observed under a polarizing microscope. The patterns change spatially and sometimes temporally. Like Professor de Gennes, we also find their beauty mesmerizing.

Liquid crystals are generally divided into three types. In the following, however, I will give an introduction to the main patterns formed by nematic liquid crystals, which are the main type of liquid crystal among these groups (Orihara *et al.*, 1993).

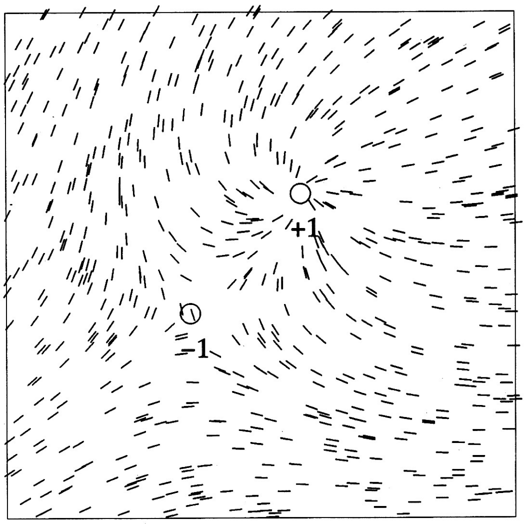

Fig. 1. Top right: $+1$ disclinations. Bottom left: -1 disclinations. Rods indicate liquid crystal molecules.

2. Topological Defect in Liquid Crystal

Figure 1 shows the case where the liquid crystal direction is constrained to lie in a plane. This is an example of the molecular orientation in nematic liquid crystals. Note that the small rods represent a single molecule. Furthermore, the liquid crystal molecules can rotate freely in the plane parallel to the page. One thing that is immediately apparent from this figure is that the orientation state of liquid crystal molecules in the parts indicated by the circles toward the top right and bottom left of the center is changing rapidly. By looking at it carefully, it is clear from tracing a counterclockwise path centered on the circle in the upper right that the liquid crystal molecules rotate counterclockwise by one revolution. In contrast, taking a path counterclockwise around the bottom left circle, the liquid crystal molecules rotate clockwise by one revolution. This kind of phenomenon does not occur at other locations (if you take a path around a point, the orientation of the liquid crystal molecules simply returns to the original orientation), and it is clear that the two points above are special. This kind of point (which is actually a "line", because liquid crystals have depth perpendicular to the plane of the page) is called a disclination. Furthermore, the top right and bottom left disclinations are called the $+1$ and -1 disclinations, respectively, based on the number of rotations and the rotation direction. This kind of defect related to topology is called a topological defect. In addition to defects in liquid crystals, other kinds of topological defects exist, such as crystal dislocations and fluid vortices.

doi:10.5047/forma.2015.s009

3. Patterns Observed by Polarizing Microscopy

The spatial structure of the liquid crystal molecules concerned to their orientations can be viewed under a polarizing microscope. Regions, where the liquid crystal molecules are parallel to the polarizer or analyzer of the microscope, appear dark. Figure 2 shows patterns that were actually observed in nematic liquid crystals. This image shows that many disclinations were created initially (at time 0 s) and then changed with time. There are disclinations at the locations where the four light (or dark) brushes come out. Although the same number of $+1$ and -1 disclinations are present, we cannot distinguish between them from this image alone. An attractive force acts between disclinations of opposite sign and a repulsive force acts between those of the same sign. Furthermore, when pairs of disclinations

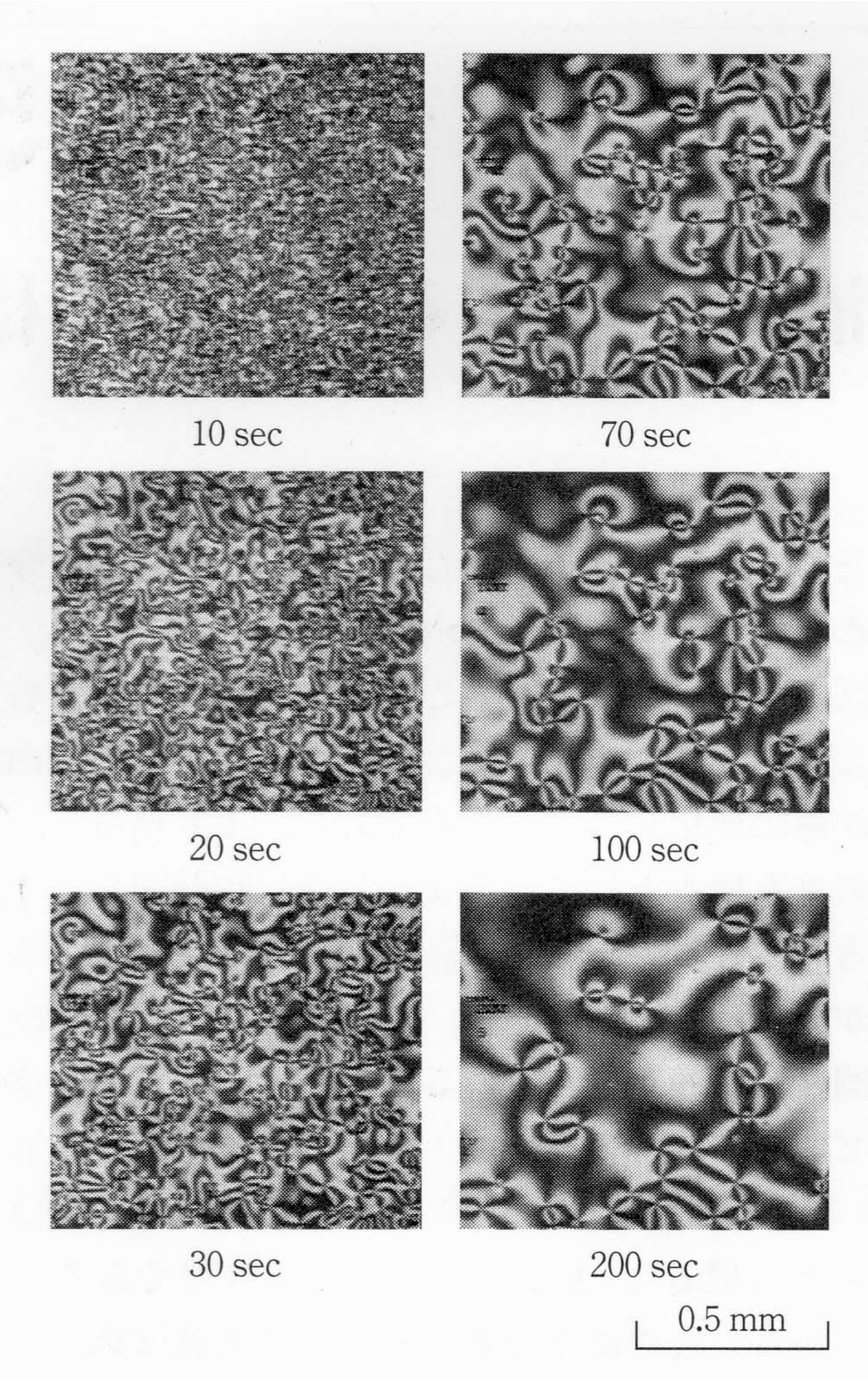

Fig. 2. Time evolution of a system that initially has many +1 and −1 disclinations.

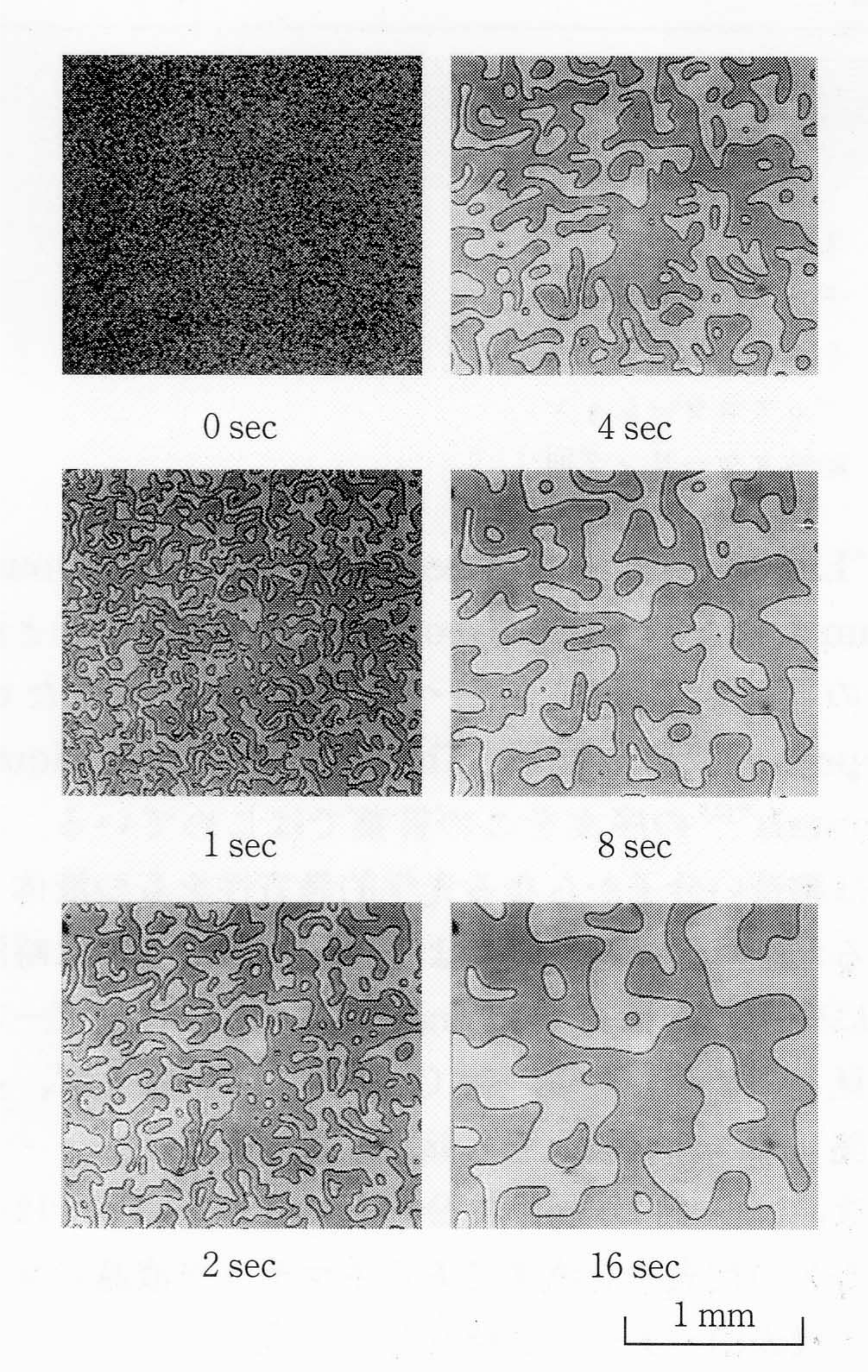

Fig. 3. Time evolution of patterns in a twisted nematic cell.

that have opposite signs approach and touch each other due to the attractive force, they are annihilated. Figure 2 shows the time evolution of the number decreasing due to this annihilation of disclinations. It is clear that if we compare the patterns at each time and magnify or reduce them appropriately, they all appear the same. This is called the dynamical scaling law, which is a general law satisfied by such time evolution of pattern.

Next, Fig. 3 shows a different type of disclination, which is observed in twisted nematic cells used in liquid crystal displays (Orihara *et al.*, 1993). Just like in the previous example, this is the result of observing many disclinations being created initially (at time 0 s) and then changing over time. The black lines are disclinations. Although the disclinations were perpendicular to the plane of the page in the previous example, they are parallel in this example. Like an elastic cord, the disclinations have a tensile force and gradually shrink. Furthermore, if they form a loop, they shrink down toward its center, and finally form a point and disappear. It is clear that the dynamical scaling law also applies in this system. Of course, these threads cannot be seen in liquid crystal displays. This is because mechanisms are used to prevent the occurrence of disclinations. Incidentally, the etymology of nematic liquid crystals is the Greek word *nematos*, which means "thread."

Although I could give only a brief introduction to disclinations in nematic liquid crystals here, beautiful patterns arising from topological defects have been observed in other liquid crystals (de Gennes and Prost, 1993). Although liquid crystals are essential for the modern displays, they are also a deeply interesting research topic full of visual beauty.

References

de Gennes, P. G. and Prost, J. (1993) *The Physics of Liquid Crystal*, Clarendon Press, Oxford.

Orihara, H., Nagaya, T. and Ishibashi, Y. (1993) *Formation, Dynamics and Statistics of Patterns* (eds. K. Kawasaki and M. Suzuki), World Science, Vol. 2.