Liquid Crystals and Living Systems

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Abstract

Most lipids do not pass, on heating, directly from a crystalline structure to an isotropic structure. They are often characterized by a number of intermediate phases, ranging from the plastic crystal, where the center of gravity of the molecule may rotate about one or more axes while the three-dimensional order of the crystal remains, to nematic liquid crystals, which have birefrigent properties of crystals and yet are characterized by completely random ordering of the molecular centers. The smectic and cholesteric liquid crystalline structures are most commonly encountered in lipids. The structural characteristics of these systems are discussed.

Of particular interest in living systems are liquid crystals, which are formed by cholesteric esters and many protein materials, and the two-dimensional crystals (smectic structure), which are formed by fatty acid derivatives. The mechanisms of energy transfer and the mechanical alignment in these liquid crystalline systems are unique and require different considerations from those found adaptable to liquids or solids. The properties of liquid crystals which might best be associated with living systems will be discussed, including surface properties and diffusivity.

Introduction

THE IDEA THAT LIQUID crystals are intimately involved in cell structure is not new. This idea was proposed by Lehmann (1), one of the first investigators in this area. The first article published on liquid crystals in the English language dealt with the role of liquid crystals in living systems (2). At that time however people could see no advantage in associating liquid crystals with cell formation. The lack of utility and limited knowledge of the structure and properties of liquid crystals resulted in their disappearance from biological literature until recent years. With the present state of knowledge however, the utility of considering the role of liquid crystals in living systems can be shown.

Solids, liquids, and gases are limited in the types of electrical and mechanical phenomena to which they will respond; liquid crystals have inherent structural characteristics which make then especially responsive to external forces. Observations of living systems make it quite clear that they cannot be composed of isotropic liquid and crystalline solids since their properties do not meet the requirements of living systems, that is, mechanical freedom to move and to take on a multiplicity of shapes while, at the same time, they possess a high degree of ordering at relatively long ranges; these conditions are uniquely met by liquid crystals. They allow for liquid-like diffusion and for the transmission of energy and information in a selective manner over long distances. Also, liquid crystals respond to detection of heat, light, sound, mechanical pressure, and chemical environment with unprecedented sensitivity. Thus they are ideal building blocks for living systems.

At the present time the role of liquid crystals in biological systems has only begun to be realized. In papers by Chapman and Byrne (3), Luzzati and Husson (4), Cope (5), and Dintenfass (6) studies have been made of liquid crystalline materials which are found in biological systems. More recently Stewart (7) has summarized the role of liquid crystals in vivo. These observations are highly significant. They establish the background that permits an expansion of knowledge to the physical processes within the cell. Among the topics in this paper are the general properties of liquid crystals and their role in sensory systems, in cellular shape, and in the transmission of information. Also to be considered is the relationship of the type of liquid crystal to its location in living organisms.

Liquid Crystalline Forms

Liquid crystalline systems are classified as nematic, cholesteric, and smectic. Liquid crystalline structures may be prepared thermally (thermotropic systems) from one component or by treatment of certain compounds with a controlled amount of water or other polar solvent (lyotropic systems). Lyotropic systems can also be prepared from three or more components.

The molecules which are considered in liquid crystalline structures are asymmetric so molecular orientation must be considered in three directions. In the nematic structure the molecules are in a parallel or nearly parallel arrangement of the molecules. The center of gravity of the molecule is mobile in three directions with restricted rotation about at least one axis.
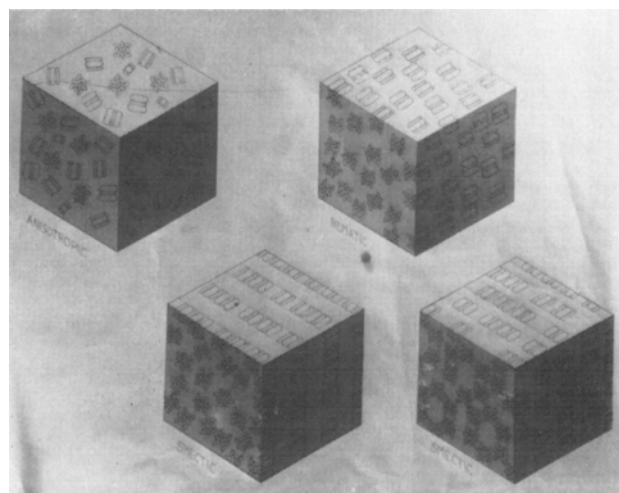

FIG. 1. A three-dimensional schematic representation of the isotropic liquid, the nematic structure, and two possible configurations of the smectic structure.
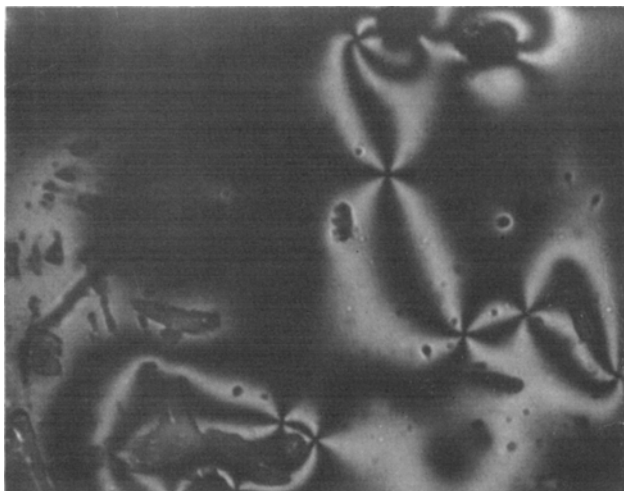
FIG. 2. A photograph of terephthal-bis-p-fluoroaniline in the nematic structure at 227C. Thread-like designs (mag./50×) will be noticed.
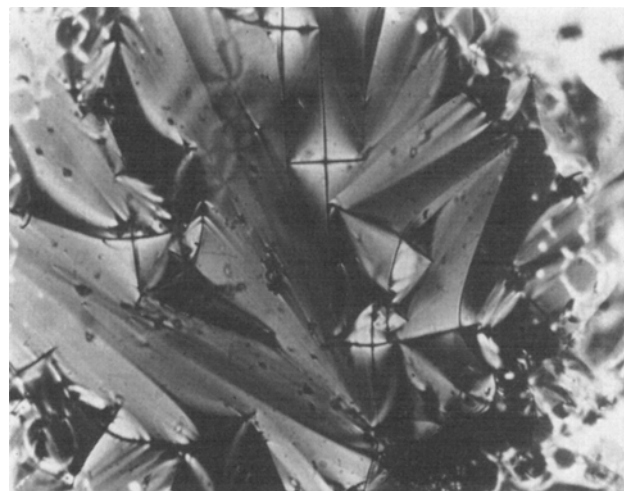

FIG. 3. Photograph of terephthal-p,p'-dibutylaminobenzoate in the smectic structure. The dark lines representing the outline of the ellipse and hyperbola will be noted, also the confocal domains (50×).

This molecular arrangement may be likened to a long box filled with round pencils, which can roll around and slide back and forth but remain parallel to one another in the direction of the long axis of the pencil. A schematic representation of the molecular arrangement in the nematic structure is sketched in Fig. 1. A photograph of a nematic structure is found in Fig. 2.

The smectic structure is stratified; the molecules are arranged in layers with their long axes approximately normal to the plane of the layers. The centers of gravity of the molecules are mobile in two directions (in their plane); they can rotate about one axis. The molecules in the smectic structure may be ordered by arrangement in neat rows within individual layers or the molecules within a layer may be randomly distributed. A schematic representation of the molecular arrangements in the smectic structure is shown in Fig. 1.

The first arrangement in the layers resembles a field of corn planted in rows with the stalks regularly placed within the row whereas the other represents random sowing. The planes can slide without hindrance over similar neighboring layers.

If the strata in the smectic structure are not affected by external forces, they lie parallel to each other. When the smectic structure is attached to a surface or is under the influence of a force, the well-arranged parallel strata take a variety of directions and may fold back on each other. The forms which the strata assume, especially the surfaces of the strata, are a series of Dupin cyclides. In these both sheets of their surface of centers degenerate into curves. Confocal textures are common in the smectic structure and often occur near the transition temperature of the smectic to the isotropic state. Under microscopic observation the outline of the ellipse and hyperbola in the focal conic texture appear as dark lines. The location of the ellipse and hyperbola in the structure represent optical discontinuities in the medium; they are the loci of points at which the strata undergo a sharp change of direction.

Each confocal cluster (domain) has its layers ordered in such a way that their surfaces form a series of cyclides. This arrangement often gives rise to polygonal structures which result in a split into pyramidal and tetrahedral blocks. The dark lines and the blocks can be seen in Fig. 3.

The cholesteric structure has such unique optical properties (8) that it is often considered separate from the nematic and the smectic structures. Its name is derived from cholesterol, most of the derivatives of which exhibit this structure. In actual practice it undoubtedly represents a special condition of the nematic phase. The cholesteric structure has a uniform twist of its optical axis, which gives rise to an appearance of layering and many of the outward textures of the smectic phase. However the repeating layers in the cholesteric structure are greater than 1,000 Å thick. This value may be contrasted with the smectic structure, where the layers are about the length of the molecules, i.e., about 20 Å. Fig. 4 schematically represents the molecules in the cholesteric arrangement by ovals. As can readily be seen, the molecular packing shows a helical pattern which gives rise to the layered arrangement.

Some of the more common properties of and the relationships among the three liquid crystalline states are recorded in Fig. 5 (9,10).
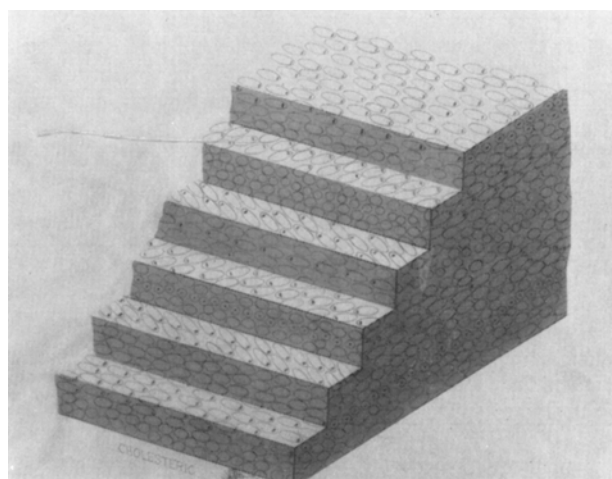

FIG. 4. A three-dimensional schematic diagram of the cholesteric structure. The molecules are represented by the elliptical patterns. The orientation of the long axes of the molecules on the steps will be observed. The molecules have completed a rotation from the bottom step to the top one. This orientation pattern creates a helical design.
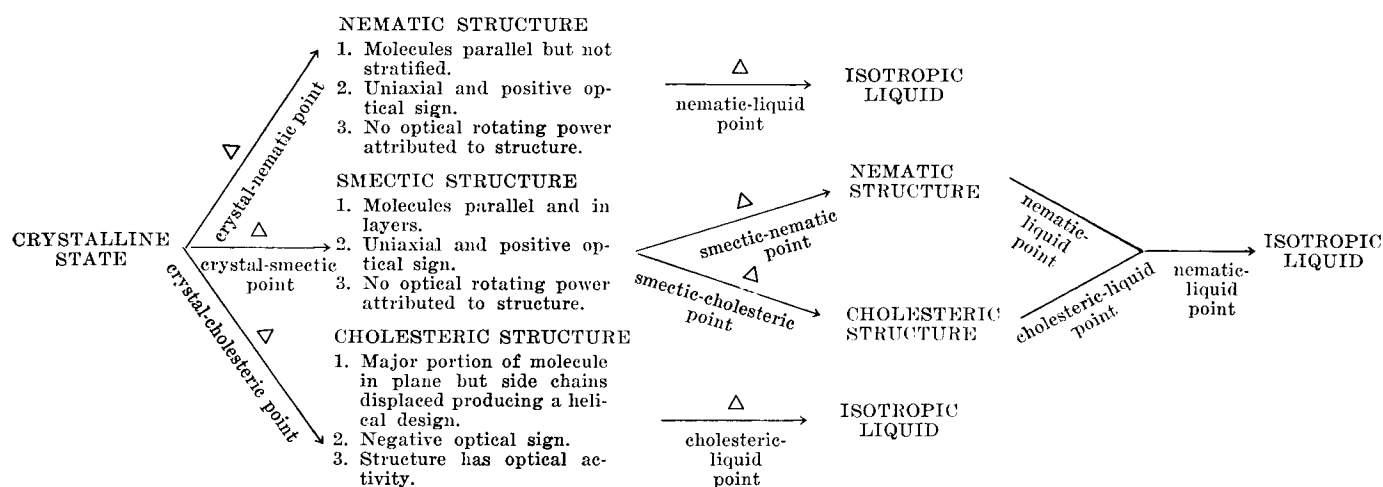
FIG. 5. Relationship among stability ranges of crystalline, liquid crystalline, and liquid states. Nomenclature for transition temperatures is designated on arrows.

A large number of compounds, when treated with a polar solvent, do not form an isotropic system but form one which has the properties of a liquid crystalline structure. Since a solvent is responsible for the formation of the liquid crystal, the phenomenon is described as lyotropic mesomorphism. Lyotropic liquid crystals are strongly birefrigent and may vary in texture from a turbid free-flowing fluid to a waxy substance or a clear gel. Many systems of two or more components can form lyotropic liquid crystalline systems. Amphiphiles and water or amphiphiles, soap, and water are typical examples.

An interesting example of a lyotropic system is that of poly-γ-benzyl-L-glutamate in different solvents. Robinson (11) found that the polyglutamates in certain organic solvents, such as dioxane and methylene chloride, form the cholesteric structure. In dioxane the solution is optically negative, and in methylene chloride it is positive. The sense of the twist in the two solutions must be opposite, and a proper combination of these two solutions will result in an untwisted structure which has the appearance of the nematic structure.

For the purpose of brevity the general properties of a typical lyotropic system have been summarized in Fig. 6. Different systems may have properties different from those described in Fig. 6, but those are illustrative. Some of these properties will be considered as they arise in a consideration of the role of liquid crystals in cell structures.

Specific Molecules in Living Systems

Illustrative of liquid crystalline systems, related to living systems, are the association of cholesterol with lecithin to form a lamellar structure; the association of cholesterol, water, and bile salt to form liquid crystalline structures; and the combination of phospholipids and water to form liquid crystalline structures. Many phospholipids will also form liquid crystalline structures on heating.

A typical example of a phospholipid is the phosphatidylethanolamine molecule. The molecule may be represented:
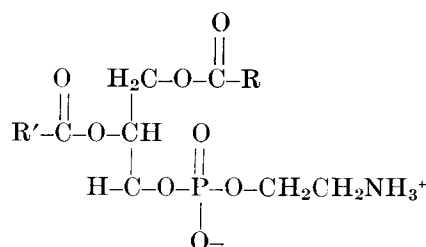
The side chains (i.e., R and R') may contain double-bond character and thus give a kink to one or both of the chains, which results in a looser packing than would result if the chains were saturated. The solubility characteristics of the molecule may be represented schematically, as follows:
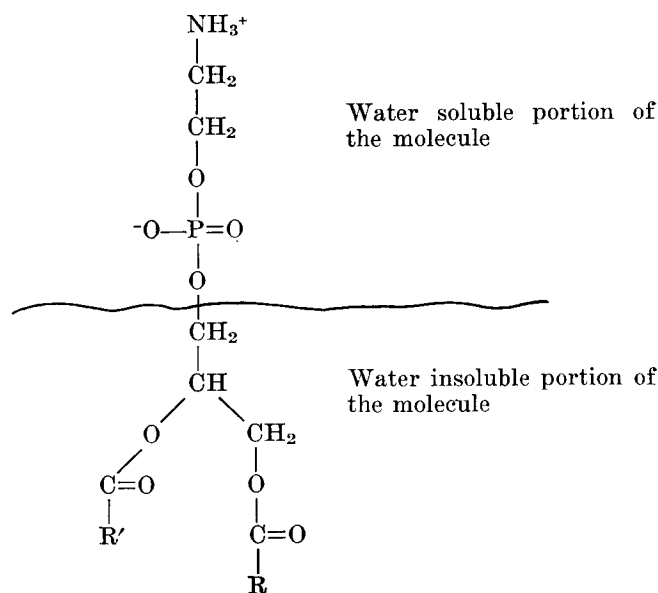
The R and R' chains generally contain 14 to 18 carbon chains. The "head" of this phospholipid molecule is polar and hydrophilic. The hydrocarbon portion of the molecule is nonpolar and is insoluble in water.

Figure 6a

General Outline Describing the Properties of Lyotropic Mesophases (amphiphile and water)

Suggested Structural Arrangement						
% Water[b] (approximate range)	0	5–22—[50]	23–40	34–80	30–99.9	greater than 99.9
Physical State	Crystalline	Liquid crystal-line, lamellar	Liquid crystal-line, face-centered cubic	Liquid crystal-line, hexagonal compact	Micellar solution	solution
Gross Character	opaque solid	clear, fluid moderately viscous	clear, brittle very viscous	clear, viscous	clear, fluid	clear, fluid
Freedom of Movement	none	2 directions	Possibly none	1 direction	no restrictions	no restrictions
Microscopic Properties (crossed nicols)	bireiringeni	neat soap texture	Isotropic with angular bubbles	middle soap texture	Isotropic with round bubbles	Isotropic
X-ray data	ring pattern 3–6 Å	Diffuse halo at about 4.5Å	Diffuse halo at about 4.5Å	Diffuse halo at about 4.5Å		
Structural order	3 dimensions	1 dimension	3 dimensions	2 dimensions	None	None

[a] This figure is comparable to one presented by Small, D. M. and Bourgés Martine, *Molecular Crystals*, *1*, 541 (1966) but the two compilations were prepared independently.
[b] The different percentages of water show that different amphiphiles require different amounts of water. For soaps, the lamellar structure generally occurs between 5–22% water; with some lipophiles the water may be as high as 50%. The cubic structure generally occurs between 23–40%.

In the environment of water and organic compounds present in living systems, phospholipid molecules take on the role of the "building blocks" for cell membranes. The arrangements of these phospholipid molecules follow either the lamellar or hexagonal pattern (4). The lamellar structure is made of alternating clusters of double layers of molecules. The hexagonal structure has water molecules enclosed in the interior of a cylinder; the polar end of the phospholipid molecule is dissolved in the water, and the nonpolar end of the molecule fills the gap between the cylinders. The two structures are represented schematically in Fig. 7.

Mechanics of Living Systems

The mechanical properties of liquid crystals which are applicable to living systems may be illustrated by consideration of a model system (Fig. 8), which has a solid core surrounded by a nematic structure; the nematic structure is, in turn, covered by a smectic membrane. This model has many of the physical characteristics of a living cell and will be capable of sensing light and heat if it has suitable chemical composition.

The nematic structure in this model has a number of important properties which may be utilized. The surface energy in a droplet of nematic material is not a constant but varies as a function of the molecular alignment with the surface. In a nematic material there is a significant direction which will be denoted as l. The surface energy of the system will be denoted as a function of the angle (γ) of the normal of the surface to the direction l (Fig. 9). The cosine of γ is the direction cosine of the surface with respect to l. Thus it may be represented to a first approximation the variation in surface energy by $(\Gamma \pm \Delta\Gamma\cos^2\gamma)$ dA, where Γ is the surface energy in the direction normal to l and $\Delta\Gamma$ is the difference in surface energy

normal to l and parallel to l; $\Delta\Gamma$ for most nematic structures is a few ergs per cm^2 and is a function of temperature and chemical composition. It has been measured (12) in several materials as three ergs per cm^2 at the clearing point. If the nematic surface is placed in contact with a liquid, the surface energy of the interface becomes

$$\text{S.E.} = \int \int [\,(\Gamma \pm \Delta\Gamma\cos\gamma)-\beta\,]\,\mathrm{d}A$$

where β is the surface energy of the liquid. From this expression it may be appreciated that the shape
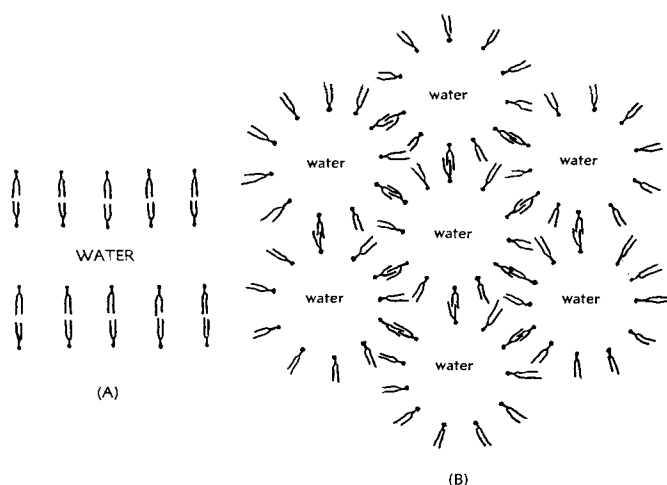

(A)

(B)

Fig. 7. Water with phospholipids can produce at least two molecular arrangements. The lamellar structure is illustrated in part A, where the polar end of the phospholipid molecule is dissolved in water and the hydrocarbon portions of the molecules blend together to form a structure with alternate lipid and water planar sheets. The hexagonal type exhibits a hexagonal arrangement of cylinders; each cylinder serves as a water tunnel. The polar portion of the molecule is oriented around the circumference of the cylinder.
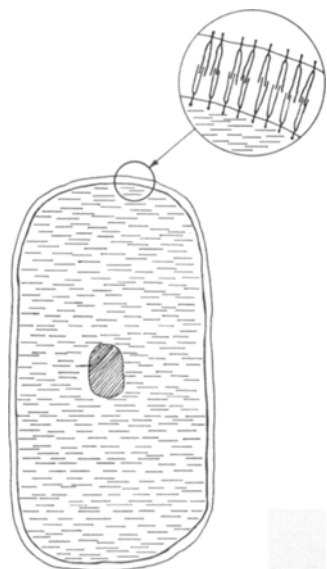
FIG. 8. A schematic of a model cell which shows the location of liquid crystal structures.
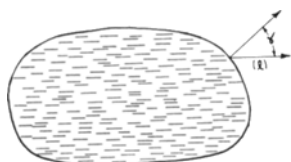
FIG. 9. A nematic droplet with uniform orientation: l represents the significant direction in the liquid crystal, and γ represents the angle formed by l and the normal to the surface.

of liquid crystalline droplets which are uniformly aligned may exhibit a variety of forms varying from an oblate to a prolate spheroid, depending on the properties of the liquid in which they are immersed. If $\Gamma < \beta < \Gamma + \Delta\Gamma$, then the shape of the liquid crystalline droplet will be a tactoid. In no case will the shape of the liquid crystal droplet be a sphere for minimal free energy with uniform alignment.

In that liquid crystalline structures possess varying degrees of self-alignment of their molecules, it follows that the aligned condition represents minimal energy. If there is a change of direction in molecular alignment, an energy is associated with the rate at which it changes direction; stated in a more satisfactory manner, there is a change in the curvature of the medium. A treatment of these concepts is given by Frank (13) in a generalized form. For present purposes it is necessary only to consider some special cases and how they affect the nematic phase in the model.

If the azimuth of the direction of alignment is ϕ, then in any static situation (divorced from discon-

tinuities and interfaces) the orientation will have to satisfy the equation $\nabla^2\phi = 0$. At the interfaces the material will align in a manner that will result in minimal free energy; thus the alignment within the liquid crystal will depend on the boundary conditions. In the most general cases the material will have a uniform curvature for lowest free energy. This occurs in the case of the cholesteric structure, which has a uniform twist.

A release of energy will result in these liquid crystalline materials by a change of chemical species; the energy release, in turn, is converted into mechanical energy in the form of a torque. The mechanical energy will cause a change of shape in the liquid crystal. The information of a local chemical change in these materials will be propagated by a wave obeying the following equation

$$\nabla^2\phi = \frac{1}{V^2}\frac{\partial^2\phi}{\partial t^2}$$

where V = the velocity of propagation
       t = time

The information propagated in this manner is quite different from information transmitted by chemical "messenger." The latter is described by the following equation:

$$\nabla^2 A = \frac{1}{K}\frac{\partial A}{\partial t}$$

It will be noticed that the solutions of the diffusion equation are self-limiting and have considerably less range than solutions of the wave equation (14). In the case of the wave equation a mechanical torque wave is related to a shear sonic wave in a solid.
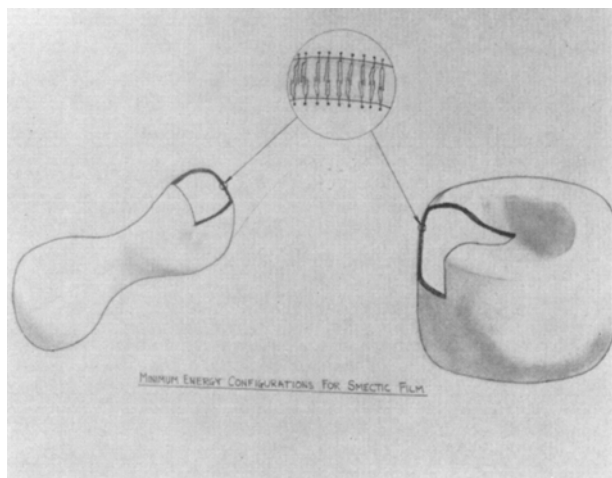

FIG. 10. Two representative shapes of minimal surface energy. The oblate form tends to a torus; the prolate form tends to two spheres.
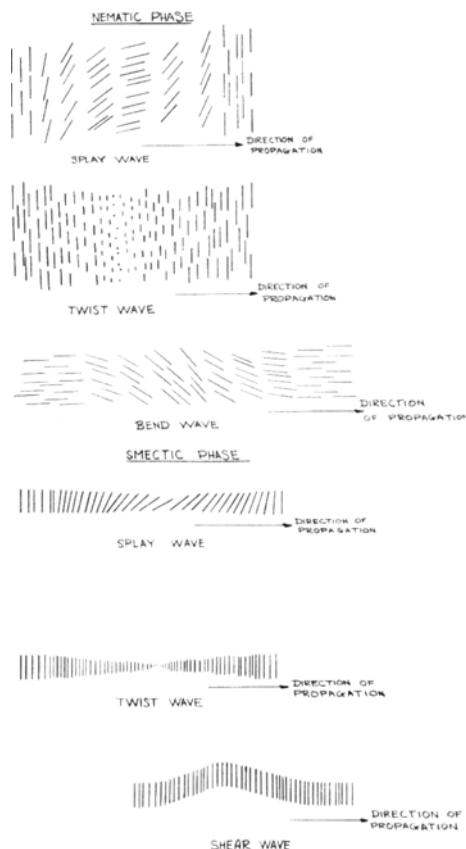

FIG. 11. A comparison of torque waves in nematic and smectic liquid crystals.

The outer layer of the model is a smectic liquid crystal. This material in bulk tends to arrange itself in layers. The surface energy normal to the layer is low compared with the energy in the direction of the layers. In fact, the surface energy may increase when two layers are in contact. This is reflected by the relatively large distance between layers in many smectic phases. Thus a condition exists where no incomplete plane is present. If a disc is formed from a smectic phase, it will tend to cup and thus reduce the edge dimension. In such films, wrinkling will not occur since there is little decrease in surface energy compared with the sharp energy gained because of curvature at the edges of the wrinkles.

The layer will close if the elasticity of the layer is sufficiently low, that is, if

$$\int \alpha \, dl > \int \int g \, ds$$

In this equation α is the free energy per unit length of the edge of the smectic film and g is the energy per unit area. It can easily be appreciated that the energy for film curvature per unit area decreases linearly. There will be a size below which the film will not close. In the size region where it will close, the shape of the closed surface can be varied by changing the elastic constants in the layer as a function of position. Another aspect should be mentioned. If a smectic film contacts a region which lowers its surface energy, it will tend to expand its area of contact; thus a smectic film will engulf other materials that tend to lower its surface energy.

If a smectic film encloses an isotropic liquid, the shape formed will be determined by the minimal surface energy which, in turn, is determined by the curvature. In general, the volume can be less than the volume of a sphere of comparable surface area so the shape assumed will be determined by a consideration of minimal curvature. Further, the shape may be prolate or oblate so that for a single surface there will be two shapes of minimal energy. For a direct dependence on the radius of curvature the shapes will have configurations as shown in Fig. 10.

The smectic phase has many interesting dynamic properties just like the nematic phase. Again there is a unique ability to transmit information by mechanical waves. The wave forms are illustrated in Fig. 11, where they are compared with similar mechanical waves in the nematic phase. The splay wave provides a mechanism for a low-energy pump in that it allows for the inversion of a smectic film with little expenditure of energy.

The mechanical properties of liquid crystals are obviously applicable to living systems. A cell membrane that has as its principal component a smectic liquid crystal would be able to transfer materials and ions either by splay waves or by engulfing larger particles.

To illustrate the transfer of ions the propagation of a splay wave in a smectic film will be considered. This wave can transfer ions through the smectic film by a mechanism shown in Fig. 12. The characteristics of this process can be described by a stable film, which acts as a dielectric in a capacitor when a potential

FIG. 12. A splay wave of sufficient amplitude to cause a reversal of inside to outside. The wave will be reinforced by the capacitative energy released.

difference exists. In a membrane a mechanical wave can trigger the ion-transfer process by which the inside of the smectic layers with its accompanying ionic species can invert, becoming the outside and thus resulting in a net transfer of electric charges across the layer. The information would be carried by the mechanical wave, and the energy supplied by the inversion of the film would be used to reinforce the mechanical wave.

As the interior make-up of the cell is nematic, the effects of chemical changes which result in changes of shape and internal distribution can be accomplished at a much greater rate than would be possible by other states of matter. This concept is supported by a number of experimental studies. Dintenfass (6) has shown that the rheological properties of red blood cells are such that hemoglobin is obviously not a true solution. Perutz (15) has suggested that the arrangement of hemoglobin in cells is intermediate between the order of a solid and the disorder of a dilute solution. The liquid crystalline nature of hemoglobin in cells is augmented by observations by Deaver et al. (16), who observed a nematic phase in hemoglobin gels, and by Hansen (17), who observed that hemoglobin exerts no osmotic effect.

Changes of cellular shape could be created by changes of orientation of the nematic phase at the nucleus interface, thus generating a change of orientation in the nematic phase at the cell wall. This would, in turn, change the shape of the cell. In cases where the cell wall has a stiffness imparted by a protein sheath, the smectic liquid crystal could be triggered by splay waves generated in the nucleus which could, in turn, accommodate a change in ion transmission.

Non-nucleated cells will gain their shape from a total free-energy minimization; the cell wall curvature is considered along with the configuration of the nematic material contained within the cell. This theory would predict both elongated shapes and oblate shapes for this type of cell. If, for some reason, the nematic phase contained within the cell would change from a state of linear alignment to a state of uniform curvature, a drastic change in cell shape could be expected. This is the reason why a normal red cell becomes sickle-shaped upon deoxygenation if the cell contains hemoglobin G.

Liquid Crystal Sensory Systems

Perhaps the most important aspect of liquid crystalline systems is their ability to operate at energy levels limited by thermodynamic noises of the system. Thus kT represents a measurable energy in a liquid crystalline system. In the cholesteric state the complete utilization of small energies is seen more easily. In this case a helical arrangement may vary by small amounts, and the variation may be readily visible. The energy for twisting or untwisting the cholesteric phase is:

$$E = \frac{KV}{2}\left(\frac{1}{P_1} - \frac{1}{P_2}\right)^2$$

$K =$ a force constant 10^{-6} dynes (as determined by electric field measurement)

$V =$ the volume considered

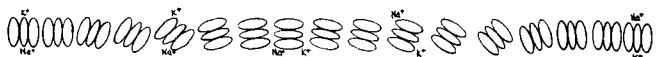$P =$ the pitch where the subscripts represent two states

If visible light is used to observe these materials, a change may be expected in P of one part in a 1,000 or 2×10^{-4} ergs per cm^3 or less than 10^{-16} ergs in a volume compared with a rod in the eye of the vertebrate. The value of $h\nu$ for green light is 3.3×10^{-13} ergs, thus the cholesteric structure has ample sensitivity for detecting the energy of a photon of light. The associated thermal energy is an order of magnitude lower than $h\nu$ so the noise associated with such a detector should be limited by the shot noise of the light.

The mechanism of the light interaction is associated with *cis* to *trans* isomerization of carotenoid pigments. The following description represents one way to make such a transducer by using *cis-trans* isomerization. If a cholesteric liquid crystalline droplet, saturated with the *cis* form of a photoreactive species, is surrounded by a liquid medium which is also saturated with the *cis* form of the same species and if the system is irradiated with light of the proper wavelength, the *cis* form can be changed to the *trans* form with a high degree of efficiency in both phases. The *cis* to *trans* transition changes the molecular arrangement of the chemical which, in turn, is imparted to the environment. The *cis-trans* transformation creates a wave which is transmitted through the cholesteric liquid crystal, changing its twist. The *cis-trans* transformation will also take place in the liquid medium which surrounds the cholesteric phase, but this transformation will not be transmitted through any observable mechanical change in the liquid.

Owing to the difference in solubility of the *cis* and *trans* forms, the partition of the forms between the two media will equilibrate slowly because of dependence on diffusion. The concept to consider carefully is that the response of the cholesteric phase to light is a mechanical one (a wave property), causing a change in curvature in the structure whereas the return to equilibrium is slow because it is a diffusion process.

The concept is applicable to a number of sensory processes. It explains the transfer of information in the form of a torque wave through the nervous system. The *cis* form of retinene is transformed to the *trans* form in the fluid in the retina by light radiation. The liquid crystalline structure in the retina responds to this transformation in a manner outlined above, thus giving the light response which is recorded in the brain.

One of the most dramatic effects observed in liquid crystals is their ability to change their form when exposed to vapors. In this type of response the liquid crystal changes as a function of molecular shape of the intruding vapors, such that the presence of functional groups in the liquid crystalline compound is less important than configuration of the structure. The sensitivity of this effect has been shown to be less than 0.001% impurity by weight in the liquid crystal system (18). This makes possible the detection of 10^{-17} g of a compound by a liquid crystal detector of cellular size.

The response of certain liquid crystalline materials to vapors is both selective and sensitive. It seems quite reasonable to conclude, based on observations in inanimate materials, that the sense of smell can be readily interpreted through the use of liquid crystalline structures. The information transmitted from the sense buds to the brain could be propagated by a torque wave.

Conclusion

The liquid crystalline structure is singularly well-fitted to provide complex forms in which organization and lability may be combined in a unique degree. Stewart (7) has made an interesting statement about the role of liquid crystals in living systems, as follows:

"Liquid crystals are not only present in tissue; they would appear to play a singularly important role in that their structure is part and parcel of biochemical function and reactivity, in normal tissue and in at least one major degenerative disease. Even more important is the possibility that liquid crystal structure exemplifies, in its process of development from relatively organic precursors, the power of elementary physical growth and what might be a self-replicating organization of macromolecules."

The possibility for a broadly expanded view of the physical processes occurring in cells has been shown simply by the recognition of intermediate states of matter and how they apply to living systems. It is believed that liquid crystals will play an increasingly important part in the expanding of an understanding of biological processes.

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Discussion

DR. BURTON: Is this the type of system that is being used for studying variations in skin temperature by producing color changes with temperature sensitive materials?

DR. FERGASON: Yes.

DR. DORITA NORTON (Roswell Park Memorial Institute, Buffalo, New York): Present address: The Medical Foundation of Buffalo, 73 High Street, Buffalo, N.Y. 14203. Toward the end of your lecture you tended to disclaim the biological function of these liquid crystals. Could you elaborate on this point?

DR. FERGASON: I don't mean to disclaim biological function. I mean to disclaim that they are present in the *exact* form that I presented. In other words, it is not clear to me that a sensory system needs to be made up of a cholesteric material. I simply showed that the torque wave (Fig. 11) in the cholesteric material could carry environmental information, such as temperature change, but such information could be carried also in a torque in a smectic phase, which probably would be more adaptable to the body system. If we were to make a model system using the splay wave or the bend wave (Fig. 12) in a single membrane to carry its signal, and we charged this mechanism by depositing an electric charge across it,

we could induce a chemical change which could cause one region of this film to invert. Once this was done, it would be free running. The waves would be propagated through the film and there would be a depletion layer of ions around this film so that any further wave would be blocked, until such time as diffusion would recharge the ionic species. So you would get waves running through a film, carrying information and being helped along by this charge transfer. We can trigger this mechanism by any number of ways such as by other torque waves, chemical reactions, or interactions. Essentially these are sound waves and they must exist,—if we accept the premise that there are such things as liquid crystals and that they tend to align. If this wave exists, then it is an excellent way of carrying information. It can be polarized and it can carry out a great variety of operations.

DR. NORTON: Would you care to speculate on the relationship between order and energy transfer in biological systems?

DR. FERGASON: The smectic film or any type of membrane that we think of in biological systems, even though they have higher and higher degrees of order, will have different means of propagating information through these ordered systems. Now, we have to choose another mechanism besides an electronic-type and solid-state mechanisms are not very good since the mobility of charge-transfer by solid-state mechanisms leaves something to be desired. As we get to higher and higher ordered systems we can use more of these forms of energy transfer such as those I've discussed in my lecture. We can't use them at all in isotropic liquids, and sometimes they are overshadowed in solids. These waves are very intriguing in higher order systems, because the force constant increases and therefore the velocity of propagation increases. I think this mechanism could play a large part in information transfer in biological systems.

It has been questioned whether or not this is an instability wave. This wave is not an instability wave—it is a wave strictly generated for the same reason that a sound wave is generated. Is there any instability associated with sound wave? It is a different kind of sound wave in that it requires a different directional change and it can exchange energy and it can exchange ions.