

Mechanisms for the Effects of Electric and
Magnetic Fields on Biological Systems

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Mechanisms for the Effects of Electric and Magnetic Fields on Biological Systems

Introduction

Weak electrical and magnetic fields have been reported to influence a wide variety of biological phenomena. Biomagnetic effects, for example, have been attributed to magnetic field gradients as small as 10^{-6} oersteds, and the literature contains many purported effects on growth rates of animals and plants, germination of seeds, tumor growth, etc. at modest magnetic fields of the order of 1000 oersteds. These reports, in general, are controversial and have been greeted with a considerable amount of skepticism. The absence of explanations at a molecular level of how a weak magnetic or electric field can influence molecular behaviors has hindered the development of any reasonable understanding or approach to the controversy.

It is the purpose of this study to examine molecular level explanations of such phenomena. During the initial period we have focused attention on the possibility that the liquid crystalline phase may well be a suitable model for the structure of many biological organelles¹. The principal investigator has

(1) See for example, C. Robinson, Trans. Farad. Soc. 62, 571 (1956); G. T. Stewart, Nature, 183, 873(1959); Intern. Liquid Crystal Conf., Kent State Univ., Kent, Ohio, August 15-20, 1965, Part I, Molecular Crystals, 1, 201(1966).

presented arguments which suggest that the purported effects of modest magnetic fields (1000-5000 oersteds) on living systems may well be explained on a molecular level by the response of the transport properties of liquid crystalline materials to these modest magnetic fields². To examine this hypothesis, we have

(2) M. M. Labes, Nature, 211, 5052(1966).

decided to examine charge transport, viscosity, and diffusion in the liquid crystalline phase under the influence of a magnetic field.

Charge Carrier Transport in Liquid Crystals

In order to study charge transport in an organic material, it is now clearly established that the most effective studies involve photoconductivity and drift mobility measurements³. Dark

(3) See O. H. LeBlanc in "Physics and Chemistry of the Organic Solid State", Ed. by D. Fox, M. M. Labes and A. Weissberger, Interscience Division, John Wiley & Sons, Inc., New York, 1967.

conductivity measurements are difficult, if not impossible, to interpret on insulating solids, and it seemed most appropriate to attempt to find a liquid crystalline material in which a reasonable photoconductive gain could be observed. It is then possible to probe the transitions from anisotropic solid to liquid crystal to isotropic liquid by measuring firstly steady state photoconductivity and secondly drift mobility via a light pulse excitation technique.

There is no literature on the photoconductive properties of liquid crystals, and consequently we undertook a screening program in which a representative group of liquid crystals were chosen because their structures incorporated aromatic moieties. The dark and photoconductivity of these materials at room temperature (solid phase) was studied. We were pleasantly surprised to find many compounds with high photoconductive response. A few compounds also appear to undergo some interesting photoreactions in the solid phase, and photovoltaic effects were also observed.

The values of dark and photoconductivity on representative liquid crystals are given in Table I. We will not discuss these results in detail at this time, since it is our intention to do detailed work on the system or systems which show the highest photoconductive response. However, three of these materials appear to be very good photoconductors, demonstrating photoconductive responses as high as have typically been observed for organic materials. These are p-p'-dimethoxystilbene(K), p-anisylidene-p-biphenylamine(H) and p-anisylideneaminophenyl acetate(G). The maximum photoresponse observed was a factor of 1000. Diethyl p-p'-azoxydicinnamate(D) also shows a large photoresponse, which appears to be accompanied by some photochemical dimerization. In some cases, very large photovoltaic effects were observed which must be studied further.

These measurements were carried out by illuminating

Table I. Dark-and Photo-conductivity of Liquid Crystals in Solid Form at Room Temperature

Code	Compounds	Applied Voltage (V)	Dark Current (A)	Photo Current (A)	*1 Illuminated Electrode
A	p,p'-Azoxyanisole	1	1.6×10^{-12}	6.6×10^{-11} (-3.0×10^{-11})*2	SnO ₂
B	p,p'-Azoxyphenetole	1	3.5×10^{-13}	1.0×10^{-12} (-2.1×10^{-11})*2	SnO ₂
C	Diethyl p,p'-azoxydibenzoate	1	1.2×10^{-8}	$4.9 \times 10^{-8*3}$	Au
D	Diethyl p,p'-Azoxycinnamate	3	2.5×10^{-14}	$2.9 \times 10^{-11*4}$	Au
		1	3.0×10^{-14}	$5.5 \times 10^{-12*4}$	SnO ₂
E	p-Acetoxycinnamic acid	1	2.5×10^{-9}	1.2×10^{-8}	SnO ₂
F	p-Anisylideneaminocinnamic acid	5	6.7×10^{-14}	-6.0×10^{-14} (7.6×10^{-11})*2	SnO ₂
G	p-Anisylidenaminophenylacetate	1	1.3×10^{-10}	3.6×10^{-8}	SnO ₂
H	p-Anisylidene-p-biphenylamine	1	8.5×10^{-14}	$6.5 \times 10^{-11*3,4}$	Au
		2	2.5×10^{-14}	7.5×10^{-12}	SnO ₂
I	p-Anisalazine	1	2.7×10^{-15}	$3.8 \times 10^{-14*3,4}$	Au
		1	7.1×10^{-13}	1.2×10^{-11}	SnO ₂
J	N-p-Anisylidene-p-phenyl- azoaniline	1	1.5×10^{-15}	$3.5 \times 10^{-14*4}$	Au
K	Dimethoxystilbene	1	1.6×10^{-14}	2.8×10^{-12} (2.6×10^{-12})*2	SnO ₂

L	Cholesteryl-3,5-dinitro- benzoate	5	9.0×10^{-14}	2.9×10^{-11} (2.6×10^{-11})*2	SnO ₂
		1	5.2×10^{-14}	1.5×10^{-12} (7.7×10^{-12})*2	Au Surface cell Quartz slide
		1	1.0×10^{-14}	(4×10^{-12})*2	SnO ₂
		1	6.0×10^{-14}	5.5×10^{-13} (-1.2×10^{-12})*2	Au

Remarks:

- *1 value 10 min. after illumination
- *2 transient current
- *3 maximum value
- *4 without water filter

sandwich cells made by melting the liquid crystals between two conducting glass or quartz plates. Either tin oxide or gold electrodes were used. Conductivity was measured with a Cary 401 Vibrating Reed Electrometer. Illumination was supplied by a 150 watt xenon lamp whose beam was passed through a water filter. The light source was ~25 cm total distance from the sample. The applied voltage (from a Keithley Model 241 power supply) was negative on the illuminated side of the sample.

Viscosity of and Diffusion in Liquid Crystals

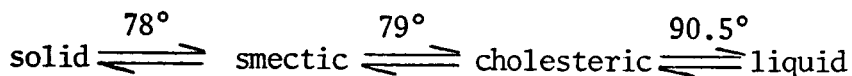
In order to judge the effect of a magnetic field on mass transport in liquid crystals, we have decided to perform viscosity and diffusion measurements. The literature indicates that diffusion rates in nematic liquid crystalline materials can be influenced by modest magnetic fields (1000 to 5000 oersteds). Svedberg in the early 1900's⁴ reported diffusion rates in a mixed liquid crystal system of p-azoxyanisole and p-azoxyphenetole and finds a 40% difference in rates of impurity diffusion when a 3500 oersted magnetic field is held perpendicular or parallel to the diffusional direction. The viscosity of nematic materials responds
(4) T. Svedberg, Kolloid Z. 18, 54, 101(1916); 21, 19(1917); 22, 68(1918).

dramatically to magnetic fields. For example, p-azoxyanisole can show a 2-3 fold increase in its viscosity when a 4000 oersted magnetic field is applied.⁵

(5) M. Miesowicz, Bull. Acad. Pol. A 228(1936).

We are studying the effect of a magnetic field on cholesteric materials, but will also verify the reports on nematic materials. Our critical experiments have not as yet been performed because we have experienced several delays in the delivery of a specially constructed 6" electromagnet. This magnet can be rotated in the horizontal plane and also be tilted into a vertical plane to vary the applied field direction on the liquid crystal.

The literature is devoid of data for cholesteric liquid crystals. Our primary study is being performed on cholesteryl pelargonate which shows the following phase transitions:



In our work thus far, we have designed a miniature falling ball viscometer which can be thermostated between the pole pieces of a magnet. The field can be held either perpendicular or parallel to the motion of the ball.

For the diffusion studies, we have decided that self-diffusion should be performed with liquid crystalline materials prior to the study of ionic diffusion. The primary reason for this is simply that complex diffusion may partially destroy the molecular orientation of the liquid crystalline phase thus complicating the interpretation of results. We have obtained C¹⁴

cholesterol and have prepared C^{14} cholesteryl pelargonate. The diffusion of this material through C^{12} cholesteryl pelargonate will be investigated using two techniques:

- (1) Microdensitometry of autoradiographs
- (2) Liquid scintillation counting of dissolved thin sections.

Diffusion cells have been built for the autoradiographic experiments and similar equipment is being built for the thin sectioning experiments. The autoradiographic equipment is so designed that we are able to study the diffusion of both a point and a line source of the radioactive component through the non-radioactive bulk. A comparison of data using both techniques will provide an estimation of accuracy plus a method for separating bulk diffusion from surface anomalies.

All equipment may be used in a magnetic field. We believe that the diffusion experiments will enable us to work at higher field strengths than those used for the viscosity experiments because of the smaller apparatus size. This will permit the determination of threshold values for magnetic field orientation effects over a wider range of field strengths than could be obtained solely with viscometric measurements.

Personnel

The work on the behavior of liquid crystals in an electric field is being conducted by Dr. S. Kusabayashi. Mr. T. Laronge is performing the work on diffusion and viscosity in liquid crystals. The principal investigator for this study is Dr. M. M. Labes.