

Contents

Foreword	xv
Introduction	xvii
A. THE FOUNDATIONS OF THE PHYSICS OF LIQUID CRYSTALS	
CHAPTER 1. Properties of liquid crystals	3
1.1 Classification and structure	3
1.1.1 General considerations	3
1.1.2 Classification of smectic phases	6
1.1.3 The structure of individual phases	7
1.1.4 Columnar mesophases	12
1.2 Chemical aspects	12
1.2.1 Chemical classes	12
1.2.2 Structure and transition temperatures	16
1.3 The director. The degree of orientational order	18
1.3.1 The director	18
1.3.2 Degree of order	19
1.3.3 The experimental determination of S	20
1.3.4 The S tensor	21
1.4 A molecular-statistical description of the liquid crystalline state	22
1.4.1 General method of approach	22
1.4.2 Born's theory	24
1.4.3 Tsvetkov's semi-empirical model	25
1.4.4 Maier-Saupe theory	26
1.4.5 Cholesteric liquid crystals	28
1.4.6 Smectic liquid crystals	28
CHAPTER 2. The anisotropy of a liquid crystalline medium	31
2.1 Optical and dielectric properties of isotropic liquids	31
2.1.1 Dielectric permittivity	31
2.1.2 Debye's equation for the angular distribution of dipoles	33
2.1.3 Dipole relaxation time (Debye relaxation)	35
2.2 Magnetic anisotropy	36

2.3	Optical anisotropy	39
2.3.1	Absorption anisotropy (dichroism)	39
2.3.2	Absorption by impurities	41
2.3.3	Refractive indices	43
2.3.4	Anisotropy of a local field	45
2.3.5	The components of the molecular polarizability	49
2.4	Dielectric permittivity (static field case)	49
2.4.1	Maier and Meier's theory of static dielectric permittivities of nematic liquid crystals	50
2.4.2	A generalization of the Maier–Meier theory	52
2.4.3	Smectic mesophases	54
2.5	Frequency dependence of dielectric permittivities	56
2.5.1	Low-frequency dispersion in ϵ_{\parallel}	56
2.5.2	Low-frequency dispersion in ϵ_{\perp}	60
2.5.3	Dielectric losses and Cole–Cole diagrams	61
2.6	Properties of mixtures	64
2.6.1	Phase diagrams	64
2.6.2	Optical properties of mixtures	65
2.6.3	Dielectric anisotropy	66
2.6.4	Relaxation times	67
CHAPTER 3. Visco-elastic properties		69
3.1	Elasticity theory	69
3.1.1	Frank's equation for the elastic free energy density	69
3.1.2	Numerical calculations	73
3.1.3	Defects in the structure	74
3.1.4	Other examples of the application of elasticity theory ..	74
3.1.5	Molecular theories of the elastic constants	75
3.2	Principal equations for the dynamics of nematic liquid crystals	78
3.2.1	Hydrodynamics of an isotropic liquid	78
3.2.2	The dynamics of nematic liquid crystals	80
3.2.3	Some specific cases	82
3.2.4	Orientation of the director by the flow of a nematic liquid crystal	84
3.2.5	Diffusion coefficients	87
3.3	Fluctuations of the director and light scattering in nematic liquid crystals	88
3.3.1	Results of early investigations	88
3.3.2	The scattering wave vector	89
3.3.3	Chatelain's experiment	90
3.3.4	Fluctuations of the director	91
3.3.5	Correlation length of director fluctuations	93
3.3.6	Scattering cross-section	94
3.3.7	Dynamics of the fluctuations and quasi-elastic scattering of light	96

B. ELECTRO-OPTICAL AND MAGNETO-OPTICAL EFFECTS IN LIQUID CRYSTALS

CHAPTER 4. Orientational effects in nematic liquid crystals	101
4.1 Experimental procedures: methods of orientation	101
4.1.1 Cells	101
4.1.2 The electrodes	101
4.1.3 Orientation of the molecules	102
4.1.4 Planar orientation methods	103
4.1.5 Homeotropic orientation methods	104
4.1.6 Berreman's model	104
4.1.7 Tilted orientation	106
4.1.8 Weak anchoring of the molecules to a surface	106
4.2 Frederiks transition: theory	107
4.2.1 The simplest case	108
4.2.2 Generalization to include the anisotropy of the elastic properties	110
4.2.3 A field oriented at an angle to the director	112
4.2.4 Weak anchoring of nematic liquid crystal molecules to the restricting surface	113
4.2.5 Electrical conductivity	114
4.2.6 Crossed magnetic and electric fields	115
4.2.7 Dynamics of the Frederiks transition	116
4.2.8 Back-flow effect	118
4.3 Experimental investigation of the Frederiks transition: S and B effects	120
4.3.1 General considerations	120
4.3.2 The S effect	121
4.3.3 The B effect	123
4.3.4 Some special cases	124
4.4 The twist effect	125
4.4.1 Optical properties of a twist cell	125
4.4.2 Behaviour in an external field: the steady-state condi- tion	127
4.4.3 The dynamics of the twist effect	128
4.4.4 Reverse twist effect	130
4.5 The guest-host effect in doped nematic liquid crystals	130
4.5.1 Change in intensity of the colouring	130
4.5.2 Colour switching	132
4.5.3 Change in fluorescence	134
4.6 The flexo-electric effect	134
4.6.1 Meyer's approach	134
4.6.2 Experimental determination of the flexo-coefficients ...	137
4.6.3 Dynamics of the flexo-electric effect	139
4.6.4 Microscopic approach to determining the flexo-electric coefficients	141

4.6.5	Other configurations	142
4.6.6	Non-uniform fields in Meyer's model	143
4.6.7	Flexo-electric domains	143
4.6.8	Some other consequences of the flexo-electric effect ...	145
4.7	The Kerr effect in the isotropic phase	145
4.7.1	The Kerr effect	145
4.7.2	Pretransition phenomena in the isotropic phase of nematic liquid crystals	146
4.7.3	Laser-induced Kerr effect	148
CHAPTER 5. Electrohydrodynamic effects in nematic liquid crystals ...		150
5.1	Electrical conduction	150
5.1.1	Ionic electrical conductivity of organic liquids	150
5.1.2	Concentration dependences of electrical conductivity in large samples	151
5.1.3	Thin cells	153
5.1.4	Frequency dependence of the electrical conductivity: ion mobility	156
5.1.5	Anisotropy of the electrical conductivity	157
5.1.6	Processes occurring near the electrodes	159
5.2	Anomalous alignment of nematic liquid crystals in an electrical field	162
5.2.1	Experimental data	162
5.2.2	Conductivity-induced torque	164
5.2.3	Balance of the torques	168
5.3	Mechanism of electrohydrodynamic instabilities in nematic liquid crystals when either $\Delta\epsilon < 0$ or small $\Delta\epsilon > 0$	170
5.3.1	Domains and the diffraction of light	170
5.3.2	Threshold for the onset of Kapustin-Williams domains: steady-state case	171
5.3.3	Calculation including boundary conditions	173
5.3.4	Frequency characteristics of the threshold for an insta- bility in a nematic liquid crystal with $\Delta\epsilon < 0$	179
5.3.5	Experimental results	186
5.3.6	Thin cells	192
5.4	Behaviour of nematic liquid crystals with $\Delta\epsilon < 0$ above the instability threshold: dynamic scattering of light	195
5.4.1	Field dependence of the angle of deviation of the director	195
5.4.2	Velocity of the liquid and the focal length of domain lenses	196
5.4.3	Transition to turbulent motion of the liquid and dynamic scattering of light	197
5.4.4	Rise and decay times of an instability	199
5.4.5	Dynamic scattering of light	200

5.5	Some special cases when $\Delta\epsilon < 0$	201
5.5.1	Finite anchoring energy of molecules to the surface and tilted director orientation	201
5.5.2	Influence of the sign of the α_3 coefficient	202
5.5.3	Different configurations	202
5.5.4	Periodic oscillations	203
5.5.5	Allowance for the flexo-electric effect	203
5.5.6	The influence of Poiseuille flow on an electrohydrodynamic instability	203
5.5.7	The influence of a magnetic field	203
5.5.8	Other theoretical approaches	204
5.6	Electrohydrodynamic instability in an isotropic liquid and in a nematic liquid crystal when $\Delta\epsilon \gg 0$	204
5.6.1	The isotropic phase in a direct current	204
5.6.2	The isotropic phase in an alternating current	209
5.6.3	Instabilities in nematic liquid crystals with $\Delta\epsilon > 0$	209
CHAPTER 6. Cholesteric liquid crystals		212
6.1	The pitch of a cholesteric helix	212
6.1.1	Textures	212
6.1.2	Methods of measuring the pitch	215
6.1.3	Cholesteric mixtures	217
6.2	Optical properties	218
6.2.1	Experimental data	218
6.2.2	The simplest model	219
6.2.3	General case of normal incidence of light on a planar texture	220
6.2.4	Oblique incidence of light on a semi-infinite planar texture	223
6.2.5	Thin cells	224
6.2.6	Non-ideal helix	224
6.2.7	Focal-conic texture	225
6.3	Features of the theory of elasticity and the dynamics of cholesteric liquid crystals	225
6.3.1	Equation for the free energy	225
6.3.2	Fluctuations in cholesteric liquid crystals	226
6.3.3	The permeation effect	227
6.3.4	Couette flow in a planar texture	228
6.4	Texture changes in cholesteric liquid crystals in external fields	229
6.4.1	Anisotropy of the properties	229
6.4.2	Orientation effects in the absence of a current	230
6.4.3	Effects related to the flow of a current	236
6.4.4	Behaviour above the threshold when electrical conductivity is present	238

6.5	Field untwisting of a cholesteric helix	240
6.5.1	The model	240
6.5.2	Field dependence of the pitch	241
6.5.3	A different geometry	244
6.5.4	The dynamics of the process	245
6.5.5	Experimental data	249
6.6	Characteristics of thin cells	250
6.6.1	The influence of the walls in the absence of a field	250
6.6.2	Features of field untwisting of a helix	251
6.6.3	Periodic instabilities	253
CHAPTER 7. Smectic liquid crystals		257
7.1	Characteristic elastic and viscous properties of the smectic phase	257
7.1.1	Smectic A elasticity theory	257
7.1.2	The divergence of K_{33} and K_{22} in the pretransition regions of the nematic phase	259
7.1.3	The scattering of light by smectic A	261
7.1.4	The dynamics of smectic A	263
7.1.5	Elastic properties of smectic C	266
7.2	Field effects	267
7.2.1	The Frederiks transition in smectic A	267
7.2.2	Experimental data	269
7.2.3	Parodi's model	270
7.2.4	A wave-like instability in smectic A	273
7.2.5	The flexo-electric effect in smectic A	274
7.2.6	The Frederiks transition in smectic C	275
7.2.7	The influence of a field on the smectic A to smectic C phase transition	277
7.3	Electrohydrodynamic instabilities in a smectic and in the pretransition region of the nematic phase	278
7.3.1	Electrical conductivity	278
7.3.2	Anomalous alignment	281
7.3.3	The electrohydrodynamic instability in smectic A	281
7.3.4	The electrohydrodynamic instability in smectic C	284
7.4	Properties of the chiral smectics C and H	284
7.4.1	Symmetry	284
7.4.2	Optical properties	285
7.4.3	Electro-optical behaviour	286
7.4.4	Other effects	289
CHAPTER 8. Problems and perspectives for the practical application of electro-optical effects in liquid crystals		290
8.1	Information displays	291
8.1.1	Alpha-numeric displays	291
8.1.2	Mosaics	294

8.1.3	Multiplexing	295
8.1.4	Matrix screens	297
8.1.5	Image converters	300
8.2	Devices for optical information processing	304
8.2.1	Modulators and deflectors of radiation	304
8.2.2	Integrated optical devices	306
8.2.3	Controllable transparencies	307
8.2.4	Liquid crystal logic elements	309
8.2.5	Optical filtration	309
8.3	Other examples	310
8.3.1	Light shutters	310
8.3.2	Storage devices	310
8.3.3	Non-destructive testing	310
Bibliography		312
Index		339