

Contents

1 Introduction	1
1.1 The importance of ice	1
1.2 The physics of ice and the structure of the book	2
1.3 The water molecule	4
1.4 The hydrogen bond	6
2 Ice Ih	10
2.1 Introduction	10
2.2 Crystal structure	15
2.3 Zero-point entropy	25
2.4 Lattice energy and hydrogen bonding	29
2.5 The actual structure	31
2.6 Summary	35
3 Elastic, thermal, and lattice dynamical properties	36
3.1 Introduction	36
3.2 Elasticity	36
3.3 Thermal properties	40
3.4 Spectroscopy of lattice vibrations	45
3.5 Modelling	55
4 Electrical properties-theory	60
4.1 Basics	60
4.2 Frequency dependence of the Debye relaxation	64
4.3 The static susceptibility χ_s	68
4.4 Protonic point defects	73
4.5 Jaccard theory	78
4.6 Ice with blocking electrodes	84
4.7 Time constants	88
4.8 Summary	89
5 Electrical properties-experimental	91
5.1 Introduction	91
5.2 Techniques	91
5.3 Pure ice	94

5.4 Doped ice	98
5.5 Charge exchange at ice-metal electrodes	112
5.6 Space charge effects	114
5.7 Injection and extraction of charge carriers	119
5.8 Thermally stimulated depolarization	123
6 Point defects	126
6.1 Introduction	126
6.2 Thermal equilibrium concentrations	127
6.3 Diffusion and mobility	129
6.4 Molecular defects	131
6.5 Protonic point defects	136
6.6 Nuclear magnetic resonance	146
6.7 Muon spin rotation, relaxation, and resonance	147
6.8 Chemical impurities	149
6.9 Electronic defects	151
6.10 Photoconductivity	152
6.11 Review	153
7 Dislocations and planar defects	156
7.1 Introduction to dislocations	156
7.2 Dislocations in the ice structure	157
7.3 Direct observation of dislocations	161
7.4 Dislocation mobility	168
7.5 Electrical effects	175
7.6 Stacking faults	176
7.7 Grain boundaries	180
8 Mechanical properties	184
8.1 Introduction	184
8.2 Plastic deformation of single crystals	186
8.3 Plastic deformation of polycrystalline ice	193
8.4 Brittle fracture of polycrystalline ice	206
8.5 Summary	212
9 Optical and electronic properties	214
9.1 Introduction	214
9.2 Propagation of electromagnetic waves in ice	215
9.3 Infrared range	219
9.4 Visible optical range-birefringence	219
9.5 Ultraviolet range	223
9.6 Electronic structure	224

10 The surface of ice	227
10.1 Introduction	227
10.2 Surface structure	228
10.3 Optical ellipsometry and microscopy	231
10.4 Electrical properties of the surface	233
10.5 Nuclear magnetic resonance	240
10.6 Scanning force microscopy	242
10.7 Surface energy	243
10.8 Review of experimental evidence	245
10.9 Theoretical models	247
10.10 Conclusions	250
11 The other phases of ice	252
11.1 Introduction	252
11.2 Ice XI-The ordered form of ice Ih	257
11.3 Ices VII and VIII	262
11.4 Ice VI	266
11.5 Ice II	267
11.6 Ices III, IV, V, IX, and XII	269
11.7 Ice X and beyond	273
11.8 Cubic ice (Ice Ic)	276
11.9 Amorphous ices	277
11.10 Clathrate hydrates	281
11.11 Lattice vibrations and the hydrogen bond	283
12 Ice in nature	287
12.1 Lake and river ice	287
12.2 Sea ice	290
12.3 Ice in the atmosphere	292
12.4 Snow	296
12.5 Glacier and polar ice	299
12.6 Frozen ground	305
12.7 Ice in the Solar System	307
13 Adhesion and friction	314
13.1 Experiments on adhesion	314
13.2 Physical mechanisms of adhesion	317
13.3 Friction	318
Bibliography	322
References	324
Index	367