## Principles of Dielectrics

B. K. P. SCAIFE Trinity College, Dublin

REVISED EDITION

## CONTENTS

Lis	of sy	ymbols	xi
1	Elen	nentary considerations	1
	1.1	Introduction	1
	1.2	The dipole moment of a group of charges	1
	1.3		2
	1.4	Lundblad's theorem and the average electric field	5
	1.5	The energy stored in a charged capacitor	7
	1.6	The complex relative permittivity	10
	1.7	Electric circuit analogues	15
	1.8	Electrical noise generated by a capacitor	19
	1.9	The electromagnetic field in matter	20
	1.10	The complex refractive index and the complex relative	
		permittivity	23
2	Diel	ectrics in static fields	26
	2.1	The electrostatic field in free space	26
	2.2	The electrostatic field in the presence of dielectrics	35
	2.3	A dielectric ellipsoid in a uniform field	39
	2.4	•	41
	2.5	The energy of a dielectric body in a static electric field	43
	2.6	The electric field set up in the vicinity of a spontaneously	
		polarized body	44
	2.7	The multipole moments of a uniformly polarized sphere	45
3	Diel	ectrics in time-dependent fields	46
	3.1	Step-function response and the principle of superposition	46
	3.2	The dispersion relations	51
	3.3	Dielectrics with two polarization mechanisms	56
	3.4	Examples of the dispersion relations	57
	3.5	Examples of unit step-function and pulse responses	57
	3.6	A dissipative dielectric body in an alternating electric field	65
	3.7	Analysis of dielectric data	66
	3.8	The signs of $\chi'(\omega) = [\epsilon'(\omega) - 1]$ and $\chi''(\omega) = \epsilon''(\omega)$ .	72
4	Hete	erogeneous dielectrics	75
	4.1	Introduction	75
	4.2	The calculation of the effective, relative permittivity $\epsilon_{\text{eff}}$	78
	4.3	The theory of Landau and Lifshitz	82

x Contents

	4.4	The theory of Maxwell	86
	4.5	The theory of Rayleigh	88
	4.6	The Maxwell-Wagner effect	105
	4.7	Disordered binary mixture	107
	4.8	The effects of double-layers	108
	4.9	The Method of Wu, Zhang, and Wu, for heterogeneous	
		dielectrics with periodic geometry	108
5	Equi	ilibrium polarization fluctuations	113
	5.1	Einstein's theory of fluctuations in macroscopic variables	115
	5.2	Fröhlich's theory of dipolar fluctuations in dielectric	
		bodies	116
	5.3	Dipole-moment fluctuations in a dielectric sphere	118
	5.4	Multipole-moment fluctuations	121
6	The	spectral properties of equilibrium fluctuations	146
	6.1	The spectral density	147
	6.2	The Wiener-Khinchin theorem	148
	6.3	Cross-correlation functions	148
	6.4		150
	6.5		152
	6.6	The frequency dependence of $a(\omega)$	153
		Prediction of stochastic functions	157
	6.8	The spectral analysis of the multipolar fluctuations in a	
		composite dielectric sphere	159
	6.9	Voltage fluctuations in a parallel-plate capacitor	161
		Nyquist's calculation of voltage fluctuations	163
	6.11	Rytov's theory of electromagnetic fluctuations	164
7	Basic	c principles of the calculation of the relative permittivity	167
	7.1	The molecular polarizability	169
	7.2	The local, or internal, field	177
	7.3	The theories of Kirkwood and Fröhlich	200
	7.4	The frequency dependence of $\epsilon(\omega)$	206
8	Elec	tromechanical effects	217
	8.1	The stress and pressure tensors in a fluid	217
	8.2	The stress tensor in a polarized dielectric fluid	219
	8.3	The pressure distribution in a polarized liquid	221
	8.4	The mechanical stress on the boundary between two	
		immiscible dielectric fluids	223
	8.5	A spherical liquid drop in a uniform field	225

χi

	8.6	A spherical bubble in a polarized dielectric fluid	226
	8.7		228
	8.8	•	230
	8.9	The force exerted on a charge immersed in a polarized	
	0.40	liquid	234
		Dielectrophoresis	237
		A dielectric sphere in a rotating electric field Polarization in rotating dielectrics	239 241
	0.12	Folarization in rotating dielectrics	241
9	Diel	ectric saturation in dipolar liquids	243
	9.1	The incremental-permittivity tensor	244
	9.2	The calculation of the potential distribution in non-linear	
		dielectrics	245
	9.3	A non-linear, dielectric sphere in a uniform field	246
	9.4	The application of Fröhlich's general theory The calculation of $\lambda$	248 249
	9.5	The calculation of $\lambda$	249
10	The	electromagnetic field in matter	252
	10.1	Maxwell's equations for space	252
		General solution of Maxwell's equations	258
		Construction of $\tilde{\pi}$ and $\tilde{j}$ for a discrete set of charges	260
		Segregation of a set of charges	261
		Spatial smoothing of physical variables	262
	10.6	The combined effect of spatial smoothing and charge	266
	10.7	segregation  Maxwell's equations for material media	272
		The significance of the scalar potential for material media	273
	10.0	The significance of the section potential for interior interior	213
Ap	pendic	ces	
Α	Nota	tion	276
В	The	solution of some electrostatic problems	280
С	Sphe	rical harmonics	310
D	Lam	's calculation	314
E	Eval	uation of two integrals	320
F	Lund	lblad's theorem	323
G	The	Dirac delta function and related functions	326
H		time-average of the product of two harmonically	220
	varyi	ng quantities	330

xii	Contents
MII.	00

I	Evaluation of averages in § 7.2.1.6.	332
J	Harmonic oscillators in the Onsager model	345
K	Spectral density of a plane rotator	350
L	Polarizability of free plane-rotators	357
M	Transverse and longitudinal relative permittivities	359
N	Difficulties in the generalization of the Onsager model to the frequency-dependent case	361
O P	The method of Wu, Zhang, and Wu The local field generated in a thin slab by a transverse	373
Q	polarization wave travelling in the plane of the slab  Two examples of the use of autocorrelation functions	379
	in dielectric theory	382
Ref	ferences	387
Ge	neral Bibliography	401
Sul	Subject Index	
Author Index		