



# Contents

Preface	ix
Introduction	1
I-1 What Is Screening?	1
I-2 The Fundamental Problem of Screening: Small Fixed Point Charges in a Boltzmann Gas of Free Charged Particles	3
I-3 References	6
<b>Part I: Distributions of Charges at Equilibrium or Near Equilibrium</b>	<b>7</b>
Chapter I: Screening of a Weak Static Charge Distribution	9
I-A Gases of Classical Charged Particles (Maxwell–Boltzmann Statistics)	9
I-A-1 The Basic Tools: The Poisson Equation and Boltzmann Statistics	9
I-A-2 The Dielectric Function $\epsilon(\vec{q})$	10
I-A-3 Screening of a Distribution of External Charges $\rho_e(\vec{r})$	14
I-A-4 Thermodynamics of Point-Charge Screening: Ion Activity in an Electrolyte	16
I-B Anisotropic Medium or Reduced Dimensionality	19
I-B-1 Anisotropic Medium	19
I-B-2 2-D Systems	19
I-B-3 1-D Systems	21
I-C Fermion Gas (Electrons in a Metal)	22
I-C-1 Fermi–Dirac Statistics	22
I-C-2 Screening in the Thomas–Fermi Approximation	25
I-C-3 Quantum Treatment of Screening for a Degenerate Free-Electron Gas	27
I-C-4 A Remarkable Feature of $\epsilon(\vec{q})$ : The Singularity at $2k_F$	30
I-C-5 Screening of a Point Charge: Friedel Oscillations	34
Problems	37
References	43

Chapter II: Screening of a Static Charge Distribution Beyond the Linear Regime	45
II-A General Formalism with Local Constitutive Equation	45
II-B Semiconductor Surfaces and Interfaces	47
II-B-1 Semiconductor Statistics	47
II-B-2 Surface of a Doped Semiconductor: The Space-Charge Layer	48
II-B-3 The Free Semiconductor Surface	52
II-B-4 MOS Structures	59
II-B-5 Schottky Junctions	66
II-B-6 A Correction to Poisson–Boltzmann Approximation: The Image Potential	68
II-C Electrochemical Interfaces: The Double Layer	71
II-C-1 Diffuse and Compact Layer: Interface Capacitance	72
II-C-2 Interfaces of Arbitrary Geometrical Shape	75
II-D Biophysical Systems	79
II-D-1 Screening in Polyelectrolytes	79
II-D-2 The B-Z Transition of DNA	82
II-E Fermion Systems	84
II-E-1 Thomas–Fermi Approximation	84
II-E-2 A Simple View of the Atom: Drawbacks of the Thomas–Fermi Approximation	84
II-E-3 About Rigorous Treatments of Multielectron Systems	87
II-E-4 An Improved Version of Screening Methods: Density-Functional Theory	90
Problems	91
References	99
Chapter III: Time-Dependent Charge Distributions: The Generalized Dielectric Function $\epsilon(\vec{q}, \omega)$	102
III-A Spatially Uniform Time-Dependent Perturbation: $\epsilon(\omega)$	102
III-A-1 A.C. Electrical Conductivity	102
III-A-2 General Properties of $\sigma(\omega)$ and $\epsilon(\omega)$ : Causality Principle	106
III-A-3 Good Conductors Versus Poor Conductors	109
III-A-4 Optical Properties of Metals: Plasma Frequency	116
III-B Spatially Variable Time-Dependent Perturbation: $\epsilon(\vec{q}, \omega)$	120
III-B-1 Good Conductors: Plasmons	120
III-B-2 Poor Conductors	130
III-B-3 General Case: The Transport-Equation Approach	134
III-B-4 Effect of Dimensionality	139
III-C Appendix: A More Elaborate Version of Linear-Response Theory	140
III-C-1 Kubo Formalism	140
III-C-2 Fluctuation-Dissipation Theorem	142

Problems	144
References	149
 Chapter IV: Applications of $\varepsilon(\vec{q}, \omega)$ to Practical Problems	 150
IV-A Motion of an External Charge through the System	150
IV-A-1 General Formalism: Force Experienced by the External Charge	150
IV-A-2 Fast Particle through a Solid: Electronic Stopping Power	155
IV-A-3 Inelastic Electron Scattering	158
IV-A-4 Inelastic Light Scattering (Electronic Raman Effect)	159
IV-A-5 Ion in an Electrolyte: Mobility	162
IV-A-6 An Example of Breakdown of the Linear Approach: Core-Level Photoemission in Metals	164
IV-B Plasmons in the Solid State	167
IV-B-1 Two-Component Plasmas: Phonons in Metals	167
IV-B-2 Crystal-Related Effects: Local Field and Interband Transitions	172
IV-B-3 Surface Plasmons; Plasmons in 2-D and 1-D Systems	174
IV-B-4 Physics of a Metal in a Magnetic Field: New Resonances and Quasi-Particle Excitations	178
IV-B-5 Concluding Remarks on Systems of Charges near Equilibrium	182
Problems	186
References	195
 <b>Part II: Distributions of Charges Far from Equilibrium</b>	 199
 Chapter V: Screening Survival: The Quasi-Neutrality Approximation	 201
V-A General Formalism	201
V-A-1 Setting up the Problem	201
V-A-2 Three Cases for Getting a Feeling	202
V-A-3 Quasi-Neutrality Approximation	206
V-B Quasi-Neutrality Approximation in Semiconductor Physics	207
V-B-1 Demer Effect	207
V-B-2 Doped Semiconductor in the Presence of Excess Minority Carriers	212
V-B-3 The p-n Junction Diode	214
V-C Quasi-Neutrality Approximation in Electrochemistry and Biology	219
V-C-1 Mass Transport near an Electrode: Effect of a Supporting Electrolyte	219
V-C-2 Junction Potentials and Ion Transport through Membranes	223
V-C-3 Nerve-Impulse Propagation	227

Problems	230
References	238
Chapter VI: Screening Breakdown: Space-Charge-Limited Currents	239
VI-A Electrons in Vacuum: Child's Law	239
VI-B Transport of a Single Type of Charge in a Solid	242
VI-B-1 Ideal Insulator: Child's Law for Solids	243
VI-B-2 Weakly Doped n-Type Semiconductor	245
VI-B-3 Problem of the Boundary Conditions	248
VI-B-4 Injection into a Semiconductor in the Presence of Traps	253
VI-B-5 Systems with Peculiar Transport Properties	258
VI-B-6 Transient Regime	258
VI-C Injection of Two Types of Charges	261
VI-C-1 Injected Plasma	261
VI-C-2 A.C. Transport in a p-i-n Diode	268
VI-D Importance of the Boundary Conditions: Mixed Conductors and Binary Electrolytes	269
VI-D-1 Introduction to Mixed Conductors	270
VI-D-2 Measuring the Electronic Conductivity of a Mixed Conductor	271
VI-D-3 Binary Electrolytes Under Extreme Conditions: Growth of Ramified Metallic Electrodeposits	277
Problems	279
References	287
Conclusion	289
Answers and Solutions to Selected Problems	291
Index of Symbols	339
Index	345