This should prove to be the definitive work explaining van der Waals forces, how to calculate them and to take account of their impact under any circumstances and conditions. These weak intermolecular forces are of truly pervasive impact, and biologists, chemists, physicists, and engineers will profit greatly from the thorough grounding in these fundamental forces that this book offers. Parsegian has organized his book at three successive levels of sophistication to satisfy the needs and interests of readers at all levels of preparation. The Prelude and Level 1 are intended to give everyone an overview in words and pictures of the modern theory of van der Waals forces. Level 2 gives the formulae and a wide range of algorithms to let readers compute the van der Waals forces under virtually any physical or physiological conditions. Level 3 offers a rigorous basic formulation of the theory.

V. Adrian Parsegian is chief of the Laboratory of Physical and Structural Biology in the National Institute of Child Health and Human Development. He has served as Editor of the Biophysical Journal and President of the Biophysical Society. He is happiest when graduate students come up to him after a lecture and ask hard questions.
CONTENTS

List of tables page vii
Preface xiii

PRELUDE 1
Pr.1. The dance of the charges 4
Pr.2. How do we convert absorption spectra to charge-fluctuation forces? 24
Pr.3. How good are measurements? Do they really confirm theory? 30
Pr.4. What can I expect to get from this book? 37

LEVEL 1: INTRODUCTION 39
L1.1. The simplest case: Material A versus material B across medium m 41
L1.2. The van der Waals interaction spectrum 61
L1.3. Layered planar bodies 65
L1.4. Spherical geometries 75
L1.5. Cylindrical geometries 95

LEVEL 2: PRACTICE 99
L2.1. Notation and symbols 101
L2.1.A. Geometric quantities 101
L2.1.B. Force and energy 102
L2.1.C. Spherical and cylindrical bodies 102
L2.1.D. Material properties 102
L2.1.E. Variables to specify point positions 104
L2.1.F. Variables used for integration and summation 104
L2.1.G. Differences-over-sums for material properties 105
L2.1.H. Hamaker coefficients 105
L2.1.I. Comparison of cgs and mks notation 106
L2.1.J. Unit conversions, mks-cgs 107
L2.2. Tables of formulae 109
L2.2.A. Tables of formulae in planar geometry 110
L2.2.B. Tables of formulae in spherical geometry 149
L2.2.C. Tables of formulae in cylindrical geometry 169
L2.3. Essays on formulae
  L2.3.A. Interactions between two semi-infinite media 182
  L2.3.B. Layered systems 190
  L2.3.C. The Derjaguin transform for interactions between oppositely curved surfaces 204
  L2.3.D. Hamaker approximation: Hybridization to modern theory 208
  L2.3.E. Point particles in dilute gases and suspensions 214
  L2.3.F. Point particles and a planar substrate 228
  L2.3.G. Line particles in dilute suspension 232

L2.4. Computation
  L2.4.A. Properties of dielectric response 241
  L2.4.B. Integration algorithms 261
  L2.4.C. Numerical conversion of full spectra into forces 263
  L2.4.D. Sample spectral parameters 266
  L2.4.E. Department of tricks, shortcuts, and desperate necessities 270
  L2.4.F. Sample programs, approximate procedures 271

LEVEL 3: FOUNDATIONS

L3.1. Story, stance, strategy 278
L3.2. Notation used in level 3 derivations
  L3.2.A. Lifshitz result 280
  L3.2.B. Layered systems 281
  L3.2.C. Ionic-fluctuation forces 281
  L3.2.D. Anisotropic media 282
  L3.2.E. Anisotropic ionic media 282
L3.3. A heuristic derivation of Lifshitz' general result for the interaction between two semi-infinite media across a planar gap 283
L3.4. Derivation of van der Waals interactions in layered planar systems 292
L3.5. Inhomogeneous media 303
L3.6. Ionic-charge fluctuations 313
L3.7. Anisotropic media 318

Problem sets
  Problem sets for Prelude 325
  Problem sets for level 1 332
  Problem sets for level 2 337

Notes 349

Index 375
TABLES

Prelude

Pr. 1. Idealized power-law forms of interaction free energy in various geometries

Pr. 2. Typical estimates of Hamaker coefficients in the limit of small separation

Level 1

I.1.1. Language, units, and constants

I.1.2. The frequency spectrum

I.1.3. Typical Hamaker coefficients, symmetric systems, retardation screening neglected

Level 2

Tables of formulae in planar geometry

P.1.a. Forms of the van der Waals interaction between two semi-infinite media

P.1.a.1. Exact, Lifshitz

P.1.a.2. Hamaker form

P.1.a.3. Nonretarded, separations approaching contact, \( l \to 0, r_n \to 0 \)

P.1.a.4. Nonretarded, small differences in permittivity

P.1.a.5. Infinitely large separations, \( l \to \infty \)

P.1.b. Two half-spaces across a planar slab, separation \( l \), zero-temperature limit

P.1.b.1. With retardation

P.1.b.2. Small-separation limit (no retardation)

P.1.b.3. Large-separation limit

P.1.c. Ideal conductors

P.1.c.1. Finite temperature

P.1.c.2. Finite temperature, long distance

P.1.c.3. Zero temperature

P.1.c.4. Corrugated–flat conducting surfaces, across vacuum at zero temperature

P.1.c.5. Corrugated–corrugated conducting surfaces, across vacuum at zero temperature
<table>
<thead>
<tr>
<th>TABLES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P.1.d. Ionic solutions, zero-frequency fluctuations, two half-spaces across layer m</td>
<td>114</td>
</tr>
<tr>
<td>P.1.d.1. Variable of integration $\beta_m$</td>
<td></td>
</tr>
<tr>
<td>P.1.d.2. Variable of integration $p$</td>
<td></td>
</tr>
<tr>
<td>P.1.d.3. Variable of integration $x$</td>
<td></td>
</tr>
<tr>
<td>P.1.d.4. Uniform ionic strength $\kappa_A = \kappa_m = \kappa_B = \kappa$</td>
<td>115</td>
</tr>
<tr>
<td>P.1.d.5. Salt solution m; pure-dielectric A, B, $\varepsilon_m \gg \varepsilon_A, \varepsilon_B, \kappa_A = \kappa_B = 0$</td>
<td></td>
</tr>
<tr>
<td>P.1.d.6. Salt solution A, B; pure-dielectric m, $\varepsilon_m \ll \varepsilon_A, \varepsilon_B, \kappa_A = \kappa_B = \kappa$</td>
<td></td>
</tr>
<tr>
<td>P.2.a. One surface singly layered</td>
<td>116</td>
</tr>
<tr>
<td>P.2.a.1. Exact, Lifshitz</td>
<td></td>
</tr>
<tr>
<td>P.2.b. One surface singly layered: Limiting forms</td>
<td>117</td>
</tr>
<tr>
<td>P.2.b.1. High dielectric-permittivity layer</td>
<td></td>
</tr>
<tr>
<td>P.2.b.2. Small differences in $\varepsilon$’s and $\mu$’s, with retardation</td>
<td></td>
</tr>
<tr>
<td>P.2.b.3. Small differences in $\varepsilon$’s and $\mu$’s, without retardation</td>
<td></td>
</tr>
<tr>
<td>P.2.c. Finite planar slab with semi-infinite medium</td>
<td>118</td>
</tr>
<tr>
<td>P.2.c.1. Exact, Lifshitz</td>
<td></td>
</tr>
<tr>
<td>P.2.c.2. Small differences in $\varepsilon$’s and $\mu$’s</td>
<td></td>
</tr>
<tr>
<td>P.2.c.3. Small differences in $\varepsilon$’s and $\mu$’s, nonretarded limit</td>
<td></td>
</tr>
<tr>
<td>P.3.a. Two surfaces, each singly layered</td>
<td>119</td>
</tr>
<tr>
<td>P.3.a.1. Exact, Lifshitz</td>
<td></td>
</tr>
<tr>
<td>P.3.b. Two surfaces, each singly layered: Limiting forms</td>
<td>120</td>
</tr>
<tr>
<td>P.3.b.1. High dielectric-permittivity layer</td>
<td></td>
</tr>
<tr>
<td>P.3.b.2. Small differences in $\varepsilon$’s and $\mu$’s, with retardation</td>
<td></td>
</tr>
<tr>
<td>P.3.b.3. Small differences in $\varepsilon$’s and $\mu$’s, without retardation</td>
<td></td>
</tr>
<tr>
<td>P.3.c. Two finite slabs in medium m</td>
<td>121</td>
</tr>
<tr>
<td>P.3.c.1. Exact, Lifshitz</td>
<td></td>
</tr>
<tr>
<td>P.3.c.2. Small differences in $\varepsilon$’s and $\mu$’s</td>
<td></td>
</tr>
<tr>
<td>P.3.c.3. Small differences in $\varepsilon$’s and $\mu$’s, nonretarded limit</td>
<td></td>
</tr>
<tr>
<td>P.4.a. Half-spaces, each coated with an arbitrary number of layers</td>
<td>122</td>
</tr>
<tr>
<td>P.4.b. Addition of a layer, iteration procedure</td>
<td>123</td>
</tr>
<tr>
<td>P.4.c. Addition of a layer, iteration procedure for small differences in susceptibilities</td>
<td>124</td>
</tr>
<tr>
<td>P.5. Multiply coated semi-infinite bodies A and B, small differences in $\varepsilon$’s and $\mu$’s Hamaker form</td>
<td>125</td>
</tr>
<tr>
<td>P.6.a. Multilayer-coated semi-infinite media</td>
<td>126</td>
</tr>
<tr>
<td>P.6.b. Limit of a large number of layers</td>
<td>127</td>
</tr>
<tr>
<td>P.6.c. Layer of finite thickness adding onto a multilayer stack</td>
<td></td>
</tr>
<tr>
<td>P.6.c.1. Finite number of layers</td>
<td></td>
</tr>
<tr>
<td>P.6.c.2. Limit of a large number of layers</td>
<td></td>
</tr>
<tr>
<td>P.7.a. Spatially varying dielectric responses</td>
<td>128</td>
</tr>
<tr>
<td>P.7.a.1. Spatially varying dielectric response in a finite layer, asymmetric, $\varepsilon(z)$ discontinuous at interfaces, with retardation</td>
<td></td>
</tr>
<tr>
<td>P.7.a.2. Spatially varying dielectric response in a finite layer, asymmetric, $\varepsilon(z)$ discontinuous at inner and outer interfaces, no retardation</td>
<td>129</td>
</tr>
<tr>
<td>P.7.b. Inhomogeneous, $\varepsilon(z)$ in finite layer, small range in $\varepsilon$, retardation neglected</td>
<td></td>
</tr>
<tr>
<td>P.7.c. Exponential $\varepsilon(z)$ infinite layer, symmetric systems</td>
<td>130</td>
</tr>
</tbody>
</table>
P.7.c.1. Two semi-infinite media A symmetrically coated with a finite layers a of thickness D with exponential variation $\varepsilon_a(z)$ perpendicular to the interface, retardation neglected

P.7.c.2. Exponential variation in a finite layer of thickness D, symmetric structures, no discontinuities in $\varepsilon$, retardation neglected

P.7.c.3. Exponential variation of dielectric response in an infinitely thick layer, no discontinuities in $\varepsilon$, discontinuity in $d\varepsilon/dz$ at interface, retardation neglected

P.7.d. Power-law $\varepsilon(z)$ in a finite layer, symmetric systems

P.7.d.1. Power-law variation in a finite layer of thickness D, symmetric structures, no discontinuities in $\varepsilon$ but discontinuity in $d\varepsilon/dz$ at interfaces, retardation neglected

P.7.d.2. Continuously changing $\varepsilon(z)$, continuous $d\varepsilon/dz$ at inner interface; quadratic variation over finite layers, retardation neglected

P.7.e. Gaussian variation of dielectric response in an infinitely thick layer, no discontinuities in $\varepsilon$ or in $d\varepsilon/dz$, symmetric profile, retardation neglected

P.8.a. Edge-to-edge interaction between two thin rectangles, length a, width b, separation $l \gg$ thickness c, Hamaker limit

P.8.b. Face-to-face interaction between two thin rectangles, length a, width b, separation $l \gg$ thickness c, Hamaker limit

P.8.c. Two rectangular solids, length a, width b, height c, parallel, separated by a distance $l$ normal to the a,b plane, Hamaker limit

P.8.d. Rectangular solids, length = width = a, height c, corners are separated by the diagonal of a square of side d, Hamaker limit

P.9.a. Interactions between and across anisotropic media

P.9.b. Interactions between anisotropic media A and B across isotropic medium m ($\varepsilon_m^x = \varepsilon_m^y = \varepsilon_m^z$)

P.9.c. Low-frequency ionic-fluctuation interactions between and across anisotropic media (magnetic terms neglected)

P.9.d. Birefringent media A and B across isotropic medium m, principal axes perpendicular to interface

P.9.e. Birefringent media A and B across isotropic medium m, principal axes parallel to interface and at a mutual angle $\theta$

P.10.a. Sphere in a sphere, Lifshitz form, retardation neglected and magnetic terms omitted

P.10.b. Small sphere in a concentric large sphere, special case $R_1 \ll R_2$

P.10.c. Concentric parallel surfaces, special case $R_1 \approx R_2 \gg R_1 - R_2 = l$, slightly bent planes; retardation and magnetic terms neglected

P.10.c.1. Sphere in a sphere

P.10.c.2. Cylinder in a cylinder

P.10.c.3. Thin cylinder in a concentric large cylinder, special case $R_1 \ll R_2$

Tables of formulae in spherical geometry

S.1. Spheres at separations small compared with radius, Derjaguin transform from Lifshitz planar result, including retardation and all higher-order interactions
<table>
<thead>
<tr>
<th>TABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.1.a. Force</td>
</tr>
<tr>
<td>S.1.b. Free energy of interaction</td>
</tr>
<tr>
<td>S.1.c. Nonretarded limit</td>
</tr>
<tr>
<td>S.1.c.1. Spheres of equal radii</td>
</tr>
<tr>
<td>S.1.c.2. Sphere-with-a-plane, ( R_2 \to \infty )</td>
</tr>
<tr>
<td>S.2. Sphere–sphere interactions, limiting forms</td>
</tr>
<tr>
<td>S.2.a. Many-body expansion to all orders, at all separations, no retardation</td>
</tr>
<tr>
<td>S.2.b. Sphere–sphere interaction expanded about long-distance limit, retardation neglected</td>
</tr>
<tr>
<td>S.2.c. Sphere–sphere interaction, easily calculated accurate approximations to the exact, many-body form, no retardation</td>
</tr>
<tr>
<td>S.2.d. Twin spheres, easily calculated approximations to the exact, many-body form, no retardation</td>
</tr>
<tr>
<td>S.3. Sphere–sphere interaction, Hamaker hybrid form</td>
</tr>
<tr>
<td>S.3.a. Hamaker summation</td>
</tr>
<tr>
<td>S.3.b.1. Point-particle limit</td>
</tr>
<tr>
<td>S.3.b.2. Close-approach limit</td>
</tr>
<tr>
<td>S.3.b.3. Equal-size spheres</td>
</tr>
<tr>
<td>S.3.b.4. Equal-size spheres, large separation</td>
</tr>
<tr>
<td>S.4. Fuzzy spheres, radially varying dielectric response</td>
</tr>
<tr>
<td>S.4.a. Small differences in ( \varepsilon ), no retardation</td>
</tr>
<tr>
<td>S.4.b. Two like spheres, small differences in ( \varepsilon ), no retardation</td>
</tr>
<tr>
<td>S.4.c. Two like spheres with coatings of exponentially varying ( \varepsilon_f(\theta) ): small differences in ( \varepsilon ), no retardation</td>
</tr>
<tr>
<td>S.5. Sphere–plane interactions</td>
</tr>
<tr>
<td>S.5.a. Accurate approximations to the exact, many-body form, no retardation</td>
</tr>
<tr>
<td>S.5.b. Sphere–plane interaction, Hamaker hybrid form</td>
</tr>
<tr>
<td>S.5.b.1. Sphere plane, all separations</td>
</tr>
<tr>
<td>S.5.b.2. Large-separation limit</td>
</tr>
<tr>
<td>S.5.b.3. Near contact</td>
</tr>
<tr>
<td>S.6. Point particles (without ionic fluctuations or ionic screening)</td>
</tr>
<tr>
<td>S.6.a. General form</td>
</tr>
<tr>
<td>S.6.b. Nonretarded limit</td>
</tr>
<tr>
<td>S.6.c. Zero-temperature retarded limit</td>
</tr>
<tr>
<td>S.6.d. Fully retarded finite-temperature low-frequency limit</td>
</tr>
<tr>
<td>S.7. Small spheres (without ionic fluctuations or ionic screening)</td>
</tr>
<tr>
<td>S.7.a. General form</td>
</tr>
<tr>
<td>S.7.b. Nonretarded limit</td>
</tr>
<tr>
<td>S.7.c. Zero-temperature retarded limit, ( T = 0 )</td>
</tr>
<tr>
<td>S.7.d. Fully retarded finite-temperature low-frequency limit</td>
</tr>
<tr>
<td>S.8. Point–particle interaction in vapor, like particles without retardation screening</td>
</tr>
<tr>
<td>S.8.a. “Keesom” energy, mutual alignment of permanent dipoles</td>
</tr>
<tr>
<td>S.8.b. “Debye” interaction, permanent dipole and inducible dipole</td>
</tr>
<tr>
<td>S.8.c. “London” energy between mutually induced dipoles</td>
</tr>
<tr>
<td>S.9. Small charged particles in saltwater, zero-frequency fluctuations only, ionic screening</td>
</tr>
</tbody>
</table>
### TABLES

S.9.a. Induced-dipole–induced-dipole fluctuation correlation  
S.9.b. Induced-dipole–monopole fluctuation correlation  
S.9.c. Monopole–monopole fluctuation correlation  
S.10. Small charged spheres in saltwater, “zero-frequency” fluctuations only, ionic screening  
S.10.a. Induced-dipole–induced-dipole fluctuation correlation  
S.10.b. Induced-dipole–monopole fluctuation correlation  
S.10.c. Monopole–monopole fluctuation correlation  
S.11. Point-particle substrate interactions  
S.11.a.1. General case  
S.11.a.2. Small-$\Delta_{1}$ limit  
S.11.b.1. Nonretarded limit, finite temperature  
S.11.b.2. Nonretarded limit, $T \to 0$  
S.11.c. Fully retarded limit  
S.12. Small-sphere substrate interactions  
S.12.a. Spherical point particle of radius $b$ in the limit of small differences in $\varepsilon$  
S.12.b. Hamaker form for large separations  
S.12.c. Small sphere of radius $b$ concentric within a large sphere of radius $R_2 \approx z$  
S.13. Two point particles in a vapor, near or touching a substrate (nonretarded limit)  
S.13.a. Near  
S.13.b. Touching  

### Tables of formulae in cylindrical geometry

C.1. Parallel cylinders at separations small compared with radius, Derjaugin transform from full Lifshitz result, including retardation  
C.1.a. Force per unit length  
C.1.b. Free energy of interaction per unit length  
C.1.c.1. Nonretarded (infinite light velocity) limit  
C.1.c.2. Cylinders of equal radii  
C.1.c.3. Cylinder with a plane  
C.2. Perpendicular cylinders, $R_1 = R_2 = R$, Derjaugin transform from full Lifshitz planar result, including retardation  
C.2.a. Force  
C.2.b. Free energy per interaction  
C.2.c. Nonretarded (infinite light velocity) limit  
C.2.d. Light velocities taken everywhere equal to that in the medium, small $\Delta_{1}, \Delta_{2}, q = 1$  
C.2.e. Hamaker–Lifshitz hybrid form  
C.3. Two parallel cylinders  
C.3.a. Two parallel cylinders, retardation screening neglected, solved by multiple reflection  
C.3.b. Two parallel cylinders, pairwise summation approximation, Hamaker–Lifshitz hybrid, retardation screening neglected  
C.3.b.1. All separations  
C.3.b.2. Large separations  
C.3.b.3. Small separations
C.4. “Thin” dielectric cylinders, parallel and at all angles, interaxial separation $z \ll$ radius $R$; Lifshitz form; retardation, magnetic, and ionic-fluctuation terms not included 173
C.4.a. Parallel, interaxial separation $z$
C.4.b.1. At an angle $\theta$, minimal interaxial separation $z$
C.4.b.2. Torque $\tau(z, \theta)$
C.4.c. Hamaker hybrid form (small-delta limit with $\epsilon_{\perp} = \epsilon_{\parallel}$)
C.5.a. Thin dielectric cylinders in saltwater, parallel and at an angle, low-frequency ($n = 0$) dipolar and ionic fluctuations 175
C.5.a.1. Parallel, center-to-center separation $z$
C.5.a.2. At an angle $\theta$ with minimum center-to-center separation $z$
C.5.b. Thin cylinders in saltwater, parallel and at an angle, ionic fluctuations, at separations $\gg$ Debye length 176
C.5.b.1. Parallel
C.5.b.2. At an angle, minimum separation $z$
C.6. Parallel, coterminous thin rods, length $a$, interaxial separation $z$, Hamaker form 177
C.6.a. Cross-sectional areas $A_1$, $A_2$
C.6.b. Circular rods of radii $R_1$, $R_2$
C.7. Coaxial thin rods, minimum separation $l$, length $a$, Hamaker form 178
C.7.a. Cross-sectional areas $A_1$, $A_2$
C.7.b. Circular cylinders, $A_1 = \pi R_1^2$, $A_2 = \pi R_2^2$
C.8. Circular disks and rods 179
C.8.a. Circular disk or rod of finite length, with axis parallel to infinitely long cylinder, pairwise-summation form
C.8.b. Circular disk with axis perpendicular to axis of infinite cylinder, pairwise-summation form 180
C.8.c. Sphere with infinite cylinder, pairwise-summation form

Sample spectral parameters
L2.1. Pure water 266
L2.2. Tetradecane 267
L2.3. Polystyrene 268
L2.4. Gold
L2.5. Silver
L2.6. Copper 269
L2.7. Mica
"What is this about entropy really decreasing?" I didn’t know how to answer my family, worried by some preposterous news report. My best try was, “I don’t know the words that you and I can use in the same way. I tell you what. Let me give you examples of where you see entropy changing, as when you put cream and sugar in coffee. You think a while about these examples. Then we can answer your question together.”

That was part of the dream to which I woke the morning I was to write this welcome to readers. I connected the dream with the way my friend David Gingell came to learn about van der Waals forces 30 years ago. He began immediately by computing with previously written programs, then improved these programs to ask better questions, and finally worked back to foundations otherwise inaccessible to a zoologist.

Written using the “Gingell method,” this book is an experiment in what another friend called “quantum electrodynamics for the people.” First the main ideas and the general picture (Level 1); after that, practice (Level 2); then, finally, the bedrock science (Level 3), culled and rephrased from abstruse sources. This is a strategy intended to defeat the fear that stops many who need to use the theory of van der Waals forces from taking advantage of progress over the past 50 or 60 years.

Many excellent physically sophisticated texts already exist, but they remain inaccessible to too many potential users. Many popular texts simplify beyond all justification and thus deprive their readers of an exciting peek into the universe.

Although intended to be popular, the present text is not sound-bite science. There are no skimmable captions, side boxes, or section headings intended to spare the reader careful thinking. See this text as a set of conversations-at-the-blackboard to support the tables of collected or derived formulae suitable for knowing application. Peter Rand, with whom I have done more science than with any other person, says I rely heavily on the intelligence of my readers. Yes, I accept that. I hope that I can also rely on readers’ motivation and pleasure in learning about a subject that reaches into all the basic sciences and into several branches of engineering.

As the book grew, I wondered if there could be more examples of applications, more details on the mechanics of computation, more exhaustive review of works in progress.
Regarding applications: I have found that many people are already eager to learn about van der Waals forces because of prior need or interest. I prefer to devote space to satisfy those needs.

Regarding computation: Spectroscopy and data processing are finally catching up with possibilities revealed by basic physical theory; any detailed How-To given here would soon be obsolete.

Regarding works in progress: “Perfection can be achieved if a limit is accepted; without such a boundary, the end is never in sight.” These painful phrases from Mary McCarthy’s *The Stones of Florence* can burden any author who is worrying about what not to include, where to stop. The “maybe-include” list—excited states, ions in solution, atomic beams, weird geometries, etc.—grew faster than I could rationally consider. The only option was to reassure myself that, after absorbing what has been written, readers would be newly able to learn on their own. In that spirit of learning to learn, this book is designed. Through this design, I hope now to learn from my readers.

The *Prelude* gives the kind of too-brief summary and overview students might get from their pressured professors—history, principles, forms, magnitudes, examples, and measurements.

*Level 1*, a word-and-picture essay, tells the more motivated readers what there is for them in the modern theory. After the Prelude, it is the only part of the book best read through consecutively.

*Level 2* is the doing.

Its first part, *Formulae*, examines the basic forms in a set of tables and essays that explain their versions, approximations, and elaborations. The formulae themselves are tabulated by geometry and physical properties of the interacting materials. (Take a look now. Pictures on the left; formulae on the right; occasional comments at the bottom.)

The second part, *Computation*, advises the user on algorithms as well as ways to convert experimental data into grist for the computational mill. It includes an essay on the physics of dielectric response, the aspect of van der Waals force theory that needlessly daunts potential users.

*Level 3*, the basic formulation, was the easiest part to write but is probably the most difficult to read. I put it last because people have a right to know what they are doing, though they need not be pushed through derivations before learning to use the theory. It is, as I imagined in the dream with my family, better to stir the coffee and have a few sips before getting into the principles of coffee making.

This brings me to think of a far more learned group of friends and fellow coffee drinkers with whom I have been lucky to study this subject (none of whom is responsible for inevitable errors or shortcomings in this text). Among them:

Barry Ninham, my original collaborator; our high moment together set our paths of learning over the next decades and founded lifelong friendship; Aharon Katzir-Katchalsky and Shneior Lifson, wise, shrewd, inspiring teachers who introduced me to this subject and who guided my early scientific life; George Weiss, my one-time “boss” who made sure that I always had complete freedom, whose corny jokes and mathematical wit have nourished me for decades; Ralph Nossal, steady friend of forty years, who has reliably provided wise advice on book writing, bike riding, and much else; Rudi Podgornik, whose “you’re the one to do it” kept me doing it, and whose fertile
PREFACE

This page contains a preface acknowledging various individuals and entities who contributed to the creation of a book. The text expresses gratitude to numerous individuals for their support, encouragement, and assistance throughout the process. The preface also contains a personal reflection and a dedication to someone, possibly a late colleague or friend, who passed away in 1995. The page ends with a dedication to David Gingell, who died in 1995, expressing a wish to have another fruitful conversation with him.