

CONTENTS

| CHAPTER | PAGE |
|---|-------|
| PREFACE | vii |
| ON THE USE OF THIS BOOK | xi |
| INTRODUCTION | xiii |
| THE NATURE AND SCOPE OF OUR SUBJECT | xiii |
| DEVELOPMENT OF MACROSCOPIC THERMODYNAMICS | xiv |
| GENESIS OF FIRST LAW OF THERMODYNAMICS AS AN EMPIRICAL OBSERVATION | xv |
| THE CALORIC THEORY | xvi |
| HISTORY OF SECOND LAW AS AN EMPIRICAL OBSERVATION | xviii |
| DEVELOPMENT OF STATISTICAL METHODS | xix |
| SYMBOLS AND NOMENCLATURE | xxi |
| 1 ENERGY METHODS AND CONSERVATIVE SYSTEMS | 1 |
| 1.1 PLAN OF ATTACK | 1 |
| 1.2 THE LEVER | 1 |
| 1.3 VIRTUAL WORK | 2 |
| 1.4 CONCEPTS OF MOMENTUM AND ENERGY IN DYNAMICAL SYSTEMS | 3 |
| 1.5 POTENTIALS | 4 |
| 1.6 APPLICATION TO GRAVITATIONAL FIELDS | 5 |
| 1.7 ELASTIC FIELDS | 6 |
| 1.8 A LIMITATION OF ENERGY METHODS | 7 |
| 1.9 OSCILLATORS | 7 |
| 1.10 GENERAL CONCEPT OF WORK | 9 |
| 1.10.1 Work of Expansion | 10 |
| 1.10.2 Work Creating a Surface | 11 |
| 1.10.3 Work Associated with a Change in State of Electrical Charge | 11 |
| 1.10.4 Energy Associated with a Magnetic Field | 11 |
| 1.10.5 Work Done Polarizing a Dielectric | 18 |
| 1.11 SUMMARY OF WORK EFFECTS | 20 |
| 1.12 WORK AND POWER | 20 |
| 1.13 THE ROLE OF FRICTION | 23 |
| 1.14 A BARRIER TO THE STUDY OF DETAILED MOTION | 24 |
| 1.15 THE HEISENBERG UNCERTAINTY PRINCIPLE | 24 |
| 1.16 SUMMARY | 26 |
| REVIEW PROBLEMS | 26 |

| CHAPTER | PAGE |
|---|------|
| 2 METHODS OF STATISTICAL INFERENCE | 29 |
| 2.1 ROLE OF INDETERMINACY IN SCIENCE AND ENGINEERING | 29 |
| 2.2 NATURE OF STATISTICAL INFERENCE | 30 |
| 2.3 SYMBOLS AND NOMENCLATURE | 32 |
| 2.3.1 Principle of Insufficient Reason | 38 |
| 2.3.2 A Simple Example: An Urn Problem | 39 |
| 2.3.3 Another Example | 39 |
| 2.3.4 An Example: Bertrand's Box Paradox | 40 |
| 2.3.5 Another Example | 40 |
| 2.3.6 Another Example | 41 |
| 2.3.7 The Curious Prisoner and the Warden | 41 |
| 2.4 PROBABILITY AND FREQUENCY | 43 |
| 2.4.1 Combinations of n Things of Which Some Are Alike | 47 |
| 2.4.2 Stirling's Approximation for $n!$ and $\ln n!$ | 47 |
| 2.4.3 Coin Tossing when the Number of Tosses Is Large | 48 |
| 2.5 CONCEPT OF EXPECTED VALUE | 51 |
| 2.5.1 The Expected Value Operator | 52 |
| 2.6 THE VARIANCE | 53 |
| 2.7 COEFFICIENT OF VARIATION | 54 |
| 2.8 A RATIONAL SCALE OF UNCERTAINTY | 56 |
| 2.9 SHANNON'S FORMULA | 61 |
| 2.9.1 The Surprisal | 64 |
| 2.9.2 Use of Shannon's Formula when G is Small | 66 |
| REVIEW PROBLEMS | 67 |
| 3 THE FORMALISM OF STATISTICAL MECHANICS | 69 |
| 3.1 GUARDING AGAINST BIAS | 69 |
| 3.2 LAGRANGE'S METHOD OF UNDETERMINED MULTIPLIERS | 69 |
| 3.2.1 An Example | 72 |
| 3.3 THE JAYNES FORMALISM | 75 |
| 3.4 AN EXAMPLE: TOSSING OF COINS | 79 |
| 3.5 A COMMENT ON THE ROLE OF λ_1 | 83 |
| 3.6 THE SIGNIFICANCE OF JAYNES FORMALISM | 84 |
| 3.7 SUMMARY | 85 |
| REVIEW PROBLEMS | 86 |
| 4 THE PERFECT MONATOMIC GAS | 89 |
| 4.1 THE IDEALIZATIONS | 89 |
| 4.2 QUANTUM MECHANICAL CONSIDERATIONS | 89 |
| 4.3 THE STATISTICAL TREATMENT | 92 |
| 4.4 THE N PARTICLE PROBLEM | 97 |
| 4.4.1 Uncertainty Associated with the Indistinguishable Nature of Particles | 98 |

| CHAPTER | PAGE |
|--|------|
| 4.5 THE PRESSURE | 100 |
| 4.6 A DIGRESSION ON UNITS | 101 |
| 4.7 PROOF THAT IT WAS LEGITIMATE TO REPLACE SUMS BY INTEGRALS | 102 |
| 4.8 THE MAXWELL DISTRIBUTION | 102 |
| 4.9 CONTINUOUS AND DISCRETE DISTRIBUTIONS | 105 |
| 4.10 EXPERIMENTAL COMPARISONS | 107 |
| 4.11 THERMAL TRANSPIRATION AND DIFFUSION | 109 |
| 4.12 A COMMENT ON JAYNES' FORMALISM | 110 |
| REVIEW PROBLEMS | 110 |
| APPENDIX TO CHAPTER 4. REMARKS CONCERNING QUANTUM MECHANICS | 111 |
| 5 THE GENERAL CONCEPT OF TEMPERATURE | 115 |
| 5.1 THE MACROSCOPIC CONCEPT OF TEMPERATURE | 115 |
| 5.2 THE CASE IN WHICH PARTICLES ARE NOT INDEPENDENT | 116 |
| 5.3 PHYSICAL INTERPRETATION OF PARAMETER β . CONCEPT OF THERMAL EQUILIBRIUM | 117 |
| 5.4 CONCEPT OF A THERMOMETER | 120 |
| 5.5 CONCEPT OF NEGATIVE ABSOLUTE TEMPERATURE | 121 |
| REVIEW PROBLEM | 123 |
| 6 MACROSCOPIC PROPERTIES OF CLOSED SYSTEMS | 124 |
| 6.1 THE CLOSED SYSTEM | 124 |
| 6.2 THE MACROSCOPIC CONCEPT OF "HEAT" | 124 |
| 6.2.1 Secondary Standards for Measurement of Heat | 128 |
| 6.3 THE "EXPECTED" OR "EQUILIBRIUM" FORCE | 129 |
| 6.3.1 An Example | 130 |
| 6.3.2 Concept of Reversible Work | 130 |
| 6.3.3 Difference Between F and $\langle F \rangle$ | 132 |
| 6.3.4 Difference Between dW_r and dW . (Reversible vs. Measured Work) | 134 |
| 6.4 JOULE'S EXPERIMENTS AND THE FIRST LAW OF THERMO- DYNAMICS | 134 |
| 6.4.1 Simple Examples of Use of the First Law | 138 |
| 6.5 DIFFERENCE BETWEEN "HEAT" AND "ENERGY" | 139 |
| 6.6 PHYSICAL MEASUREMENT OF ENTROPY (S) | 140 |
| 6.7 THIRD LAW OF THERMOSTATICS | 143 |
| 6.7.1 An Oversimplified Analogy | 145 |
| 6.8 SECOND LAW OF THERMOSTATICS | 145 |
| 6.8.1 Entropy Change during Cyclic Processes | 147 |
| 6.8.2 Perpetual Motion Machines of the Second Kind | 148 |
| 6.9 CARNOT'S THEOREM | 149 |

| CHAPTER | PAGE |
|--|------|
| 6.10 GENERAL CONCEPT OF FRICTION | 152 |
| 6.11 CONCEPT OF HEAT CAPACITY | 153 |
| 6.11.1 Using Heat Capacity Data to Compute Entropy Changes | 155 |
| 6.12 THE ENTHALPY | 156 |
| 6.13 THE MEANING OF THE PARAMETER ψ | 157 |
| 6.14 SUMMARY | 157 |
| REVIEW PROBLEMS | 160 |
| 7 THE PERFECT DIATOMIC GAS AND THE PERFECT CRYSTALLINE SOLID | 164 |
| 7.1 THE IDEALIZATIONS | 164 |
| 7.2 DEGREES OF FREEDOM | 165 |
| 7.3 TRANSLATIONAL CONTRIBUTION | 167 |
| 7.4 VIBRATIONAL CONTRIBUTION | 168 |
| 7.5 ROTATIONAL CONTRIBUTIONS | 170 |
| 7.5.1 "Degeneracy" | 171 |
| 7.5.2 "Degeneracy" in Rotation | 171 |
| 7.6 EXPERIMENTAL DETERMINATION OF ENERGY LEVELS VIA SPECTROSCOPY | 171 |
| 7.7 PRACTICAL CALCULATIONS | 177 |
| 7.7.1 Rotational Terms, A Simplification | 178 |
| 7.7.2 Working Equations | 179 |
| 7.7.3 Application | 181 |
| 7.7.4 A Second Example | 182 |
| 7.7.5 Practical Working Equations | 183 |
| 7.8 THIRD LAW OF THERMODYNAMICS AND THE SPECTROSCOPIC METHOD | 184 |
| 7.9 SYMMETRICAL AND UNSYMMETRICAL MOLECULES | 185 |
| 7.10 OTHER MORE COMPLEX GASES | 185 |
| 7.11 SOLIDS | 187 |
| 7.11.1 An Example | 188 |
| 7.12 THE EINSTEIN SOLID | 190 |
| 7.12.1 The Debye Solid | 192 |
| 7.13 KOPP'S RULE | 192 |
| 7.14 LIMITING HEAT CAPACITIES AT ELEVATED TEMPERATURES | 194 |
| 7.15 HEAT CAPACITIES OF LIQUIDS | 194 |
| 7.16 COMPLEX ORGANIC GASES | 194 |
| REVIEW PROBLEMS | 195 |
| APPENDIX TO CHAPTER 7 | 195 |
| A7.1 The Oscillator | 195 |
| A7.2 The Rigid Rotator | 198 |

CHAPTER

PAGE

| | | |
|--------|--|-----|
| 8 | EQUATIONS OF STATE. SOME EMPIRICAL AND SEMIEMPIRICAL METHODS | 201 |
| 8.1 | THE CONCEPTS OF PROPERTY AND STATE | 201 |
| 8.2 | THE P - \tilde{V} - T SURFACE | 203 |
| 8.3 | GUIDES TO EMPIRICAL CURVE FITTING | 206 |
| 8.4 | THE VIRIAL EQUATION OF STATE | 213 |
| 8.5 | USE OF REDUCED COORDINATES | 215 |
| 8.6 | INTRODUCTION OF OTHER PARAMETERS | 224 |
| 8.6.1 | Examples of Use of the Tables | 228 |
| 8.7 | EMPIRICAL EQUATIONS | 233 |
| 8.7.1 | Van Der Waals' Equation | 234 |
| 8.8 | LIQUIDS | 238 |
| 8.9 | SOLIDS | 238 |
| | REVIEW PROBLEMS | 241 |
| 9 | GENERALIZING P - \tilde{V} - T DATA | 243 |
| 9.1 | THE FUNDAMENTAL EQUATION | 243 |
| 9.2 | RELATION BETWEEN THE FUNDAMENTAL EQUATION AND THE EQUATION OF STATE | 245 |
| 9.3 | THE PROBLEM OF KEEPING TRACK OF VARIABLES | 245 |
| 9.4 | USE OF JACOBIANS TO KEEP TRACK OF VARIABLES | 246 |
| 9.5 | APPLYING JACOBIANS TO EQUATIONS OF THERMOSTATICS | 248 |
| 9.6 | APPLICATIONS TO PHYSICAL SYSTEMS | 251 |
| 9.6.1 | Compression Process. Water | 251 |
| 9.6.2 | Compression Process. Perfect Gas | 252 |
| 9.7 | ENERGY AS A FUNCTION OF T AND V | 253 |
| 9.8 | RELATION BETWEEN C_P AND C_V | 254 |
| 9.8.1 | $C_P - C_V$ for a Solid | 254 |
| 9.8.2 | Another Example | 255 |
| 9.9 | AN EXAMPLE USING AN EQUATION OF STATE | 256 |
| 9.10 | AN EXAMPLE USING COMPRESSIBILITY CHARTS | 257 |
| 9.10.1 | Generalized Charts for Correcting Enthalpy, Energy and Entropy for Deviations from Perfect Gas Laws | 259 |
| 9.11 | THE CLAUSIUS-CLAPEYRON EQUATION | 270 |
| 9.12 | THE ELASTIC MODULUS OF SOLIDS | 272 |
| 9.12.1 | An Interesting Application to Rubber | 274 |
| 9.13 | MINIMUM AMOUNT OF EXPERIMENTATION REQUIRED TO ESTABLISH ALL THERMOSTATIC PROPERTIES FOR FIXED MASS SYSTEMS | 274 |
| 9.14 | STEAM TABLES | 276 |
| 9.15 | EXAMPLES OF USE OF THE CHARTS | 276 |

| CHAPTER | PAGE |
|--|------|
| REVIEW PROBLEMS | 277 |
| APPENDIX TO CHAPTER 9. MATHEMATICAL PROPERTIES OF JACOBIANS | 296 |
| 10 METHODOLOGY OF MACROSCOPIC THERMOSTATICS APPLIED TO CLOSED SYSTEMS | 299 |
| 10.1 MICROSCOPIC AND MACROSCOPIC VIEWS | 299 |
| 10.2 SOME DEFINITIONS REQUIRED FOR THE METHOD | 300 |
| 10.3 THE LOGICAL STEPS | 301 |
| 10.3.1 An Example | 302 |
| 10.3.2 An Example | 303 |
| 10.4 WORK OF EXPANSION | 303 |
| 10.4.1 An Example | 304 |
| 10.4.2 An Example | 305 |
| 10.5 USE OF P - V AND T - S DIAGRAMS | 305 |
| 10.6 SIGNIFICANCE OF THE ISENTROPIC PROCESS | 305 |
| 10.6.1 An Example | 307 |
| 10.6.2 An Entirely Irreversible Process | 307 |
| 10.7 ESCAPE OF GASES FROM A CONTAINER | 309 |
| 10.8 INFLUX OF GASES TO A CONTAINER | 312 |
| 10.9 A ROUTINE FOR PROBLEM-SOLVING (CLOSED SYSTEMS) | 313 |
| 10.10 AN EXAMPLE. AIR COMPRESSOR | 315 |
| 10.11 RECIPROCATING STEAM ENGINES | 318 |
| 10.12 THE OTTO CYCLE | 318 |
| 10.13 THE DIESEL CYCLE | 319 |
| REVIEW PROBLEMS | 320 |
| APPENDIX TO CHAPTER 10. INFORMATION FLOW DIAGRAMS | 323 |
| 11 STEADY FLOW SYSTEMS | 326 |
| 11.1 BATCH VERSUS FLOW PROCESSES | 326 |
| 11.2 ENERGY BALANCE ON A STEADY FLOW SYSTEM | 326 |
| 11.3 APPLYING THE FORMALISM | 330 |
| 11.4 CLASSIFICATION OF PROCESSES | 332 |
| 11.5 THE GRAVITATIONAL ENERGY TERM | 333 |
| 11.6 THE FLOW WORK TERMS | 335 |
| 11.7 THE KINETIC ENERGY TERMS | 337 |
| 11.7.1 The Role of Entropy | 339 |
| 11.7.2 An Example Using Mollier Diagrams | 340 |
| 11.7.3 An Example: Incompressible Fluid | 341 |
| 11.7.4 An Example: Flow of a Perfect Gas | 341 |
| 11.7.5 Summary of Flow Nozzle Results | 342 |
| 11.8 THROTTLING PROCESSES | 342 |
| 11.8.1 Throttling of Perfect Gases: A Special Case | 343 |

| CHAPTER | PAGE |
|--|------|
| 11.8.2 Throttling of Gases in General | 344 |
| 11.8.3 Liquefaction of Gases | 345 |
| 11.9 WORK PRODUCERS (STEADY FLOW) | 347 |
| 11.9.1 Turbine Efficiency | 349 |
| 11.10 WORK ABSORBERS | 350 |
| 11.11 CYCLE ANALYSIS. A GENERAL TECHNIQUE | 353 |
| REVIEW PROBLEMS | 356 |
| 12 THE GRAND POTENTIAL FUNCTION AND THE GENERAL CRITERIA FOR EQUILIBRIUM | 367 |
| 12.1 CONCEPT OF AN OPEN SYSTEM | 367 |
| 12.2 FORMULATION OF THE OPEN SYSTEM | 369 |
| 12.3 THE UNCERTAINTY | 374 |
| 12.4 PHYSICAL SIGNIFICANCE OF THE LAGRANGIAN MULTIPLIERS | 374 |
| 12.4.1 Macroscopic Interpretation of Ω | 374 |
| 12.4.2 Macroscopic Interpretation of the α 's | 376 |
| 12.5 MACROSCOPIC BEHAVIOR | 376 |
| 12.5.1 The Gibbs Chemical Potential and Free Energy | 377 |
| 12.5.2 Kinds of Equilibrium | 381 |
| 12.5.3 The Difference Between Thermostatistics and Thermodynamics | 383 |
| 12.6 VARIATION OF PLANCK POTENTIAL WITH TEMPERATURE, PRESSURE AND COMPOSITION | 384 |
| 12.7 CALCULATION OF PLANCK POTENTIAL FOR A PERFECT DIATOMIC GAS | 386 |
| 12.7.1 Taking Into Account Deviations for $P\tilde{V} = RT$ | 389 |
| 12.7.2 Practical Calculations for Perfect Gases | 390 |
| 12.8 THE FUGACITY OF GASES | 391 |
| 12.8.1 The Fugacity of Liquids and Solids | 395 |
| 12.9 GRAND POTENTIAL FUNCTION FOR A SYSTEM OF COM- PLETELY INDEPENDENT PARTICLES (BOSONS) | 395 |
| 12.9.1 The Perfect Gas | 397 |
| 12.10 DIFFERENT "KINDS" OF STATISTICS | 398 |
| REVIEW PROBLEMS | 399 |
| 13 SOLUTIONS AND HETEROGENEOUS SYSTEMS | 401 |
| 13.1 PARTIAL MOLAL QUANTITIES | 401 |
| 13.2 DETERMINATION OF PARTIAL MOLAL VOLUMES FROM EXPERIMENTAL DATA | 402 |
| 13.3 DETERMINATION OF PARTIAL MOLAL ENTHALPIES FROM EXPERIMENTAL DATA | 404 |
| 13.4 PARTIAL MOLAL HEAT CAPACITIES | 405 |
| 13.5 USE OF JACOBIANS FOR SYSTEMS OF VARIABLE COM- POSITION | 406 |

| CHAPTER | | PAGE |
|---------|---|------|
| 13.6 | SUMMARY OF JACOBIAN RELATIONS | 409 |
| 13.7 | FINDING ANY GIVEN DERIVATIVE IN TERMS OF MEASURABLE PROPERTIES | 409 |
| 13.7.1 | An Example: Gibbs Chemical Potential as a Function of Temperature, Pressure and Composition | 411 |
| 13.7.2 | Planck Potential as a Function of Temperature, Pressure and Composition | 412 |
| 13.7.3 | The Duhem Equation | 412 |
| 13.8 | NECESSARY MEASUREMENTS TO COMPUTE PLANCK POTENTIAL AT ANY PRESSURE, TEMPERATURE AND COMPOSITION | 413 |
| 13.9 | CONCEPT OF THE PERFECT SOLUTION | 413 |
| 13.9.1 | Some Properties of Perfect Solutions | 416 |
| 13.10 | VAPOR PRESSURE OVER A PERFECT SOLUTION AT LOW TOTAL PRESSURE | 417 |
| 13.11 | BINARY TWO-PHASE SYSTEMS | 417 |
| 13.12 | DISCUSSION OF CONVENTIONS | 419 |
| 13.13 | EXAMPLES OF NONPERFECT SOLUTIONS | 425 |
| 13.13.1 | Constant Boiling Mixtures (Azeotropes) | 425 |
| 13.13.2 | Retrograde Condensation | 427 |
| 13.14 | SOME LAWS ABOUT DILUTE SOLUTIONS | 427 |
| 13.14.1 | Henry's Law | 427 |
| 13.14.2 | Raoult's Law | 428 |
| 13.14.3 | Law of Freezing Point Lowering | 429 |
| 13.14.4 | Boiling Point Elevation | 430 |
| 13.14.5 | Nernst's Distribution Law | 430 |
| 13.15 | FINDING PLANCK POTENTIAL OF ONE COMPONENT GIVEN PLANCK POTENTIAL OF THE OTHER | 431 |
| 13.16 | THE PHASE RULE | 432 |
| 13.16.1 | Phase Diagram for a Binary Three-Phase System | 440 |
| 13.16.2 | An Example: Zinc Cadmium Eutectic | 441 |
| 13.17 | FUNDAMENTAL EQUATION FOR A SINGLE-COMPONENT SYSTEM | 441 |
| 13.18 | ONE-COMPONENT, TWO-PHASE SYSTEMS | 445 |
| 13.19 | MIXTURES OF VAPORS. (PSYCHROMETRY) | 447 |
| | APPENDIX TO CHAPTER 13 | 456 |
| | REVIEW PROBLEMS | 461 |
| 14 | THERMOSTATIC CHARACTERISTICS OF CHEMICALLY REACTIVE SYSTEMS | 463 |
| 14.1 | CONVENTIONS FOR MACROSCOPIC TREATMENT | 463 |
| 14.2 | AN EXAMPLE OF THE USE OF STANDARD ENTHALPIES | 473 |
| 14.3 | EXPERIMENTAL METHODS | 475 |
| 14.4 | CHEMICAL EQUILIBRIUM | 476 |

| CHAPTER | PAGE |
|--|------|
| 14.5 AN EXAMPLE | 491 |
| 14.6 APPLICATION TO SIMULTANEOUS REACTIONS | 492 |
| 14.6.1 An Example | 493 |
| 14.6.2 A Digression on Equation-Solving | 495 |
| 14.7 FLAME TEMPERATURE | 496 |
| 14.7.1 An Example | 497 |
| 14.8 THE OPERATOR Δ | 505 |
| 14.9 CHANGE IN EQUILIBRIUM CONSTANT WITH TEMPERATURE (PERFECT GASES IN PERFECT MIXTURES ONLY) | 506 |
| 14.10 EQUILIBRIUM CONSTANTS AND STANDARD FREE ENERGIES. GENERAL CASE | 507 |
| 14.11 CONVENTIONS: TABLES OF STANDARD FREE ENERGIES | 511 |
| 14.11.1 The Utility of Gibbs Free Energy | 514 |
| 14.12 COMMENT CONCERNING NUCLEAR ENERGY | 514 |
| 14.13 CHEMICAL KINETICS | 515 |
| REVIEW PROBLEMS | 516 |
| 15 THE INTRODUCTION OF VARIABLES OTHER THAN PRESSURE | 519 |
| 15.1 GENERAL REMARKS | 519 |
| 15.2 THE GRAVITATIONAL FIELD | 520 |
| 15.2.1 An Example: Perfect Gas Mixture in a Gravitational Field | 523 |
| 15.2.2 An Example: Solutions in a Gravitational Field | 524 |
| 15.2.3 Perfect Binary Solution in a Gravitational Field | 525 |
| 15.3 FLUCTUATION THEORY | 526 |
| 15.3.1 Brownian Motion | 527 |
| 15.3.2 Generalized Brownian Motion | 528 |
| 15.3.3 Kappler's Experiment | 529 |
| 15.3.4 Electrical Noise | 533 |
| 15.3.5 Noise as a Measure of Temperature | 533 |
| 15.4 OSMOTIC PRESSURE | 534 |
| 15.4.1 An Application: The Hassler Water Purifier | 534 |
| 15.5 SYSTEMS THAT STORE ELECTRICAL CHARGES | 536 |
| 15.6 CAPACITORS AND BATTERIES | 537 |
| 15.7 CHARGING A CAPACITOR | 538 |
| 15.8 THE PERMITTIVITY | 542 |
| 15.9 THE FERROELECTRIC CONVERTER | 543 |
| 15.10 ELECTROCHEMICAL CELLS | 546 |
| 15.11 THERMOSTATIC EQUATIONS OF ELECTROCHEMICAL CELLS | 552 |
| 15.12 SUMMARY OF RESULTS FOR ELECTRICAL CELLS | 553 |
| 15.13 THERMOSTATIC PROPERTIES OF FUEL CELLS | 555 |
| 15.14 THERMODYNAMIC PROPERTIES OF FUEL CELLS | 557 |

| CHAPTER | PAGE |
|--|------|
| 15.15 STATISTICAL TREATMENT OF PARAMAGNETIC MATERIALS | 559 |
| 15.16 MACROSCOPIC TREATMENT OF MAGNETIC SYSTEMS | 562 |
| 15.17 MAGNETIC TEMPERATURE | 565 |
| 15.18 SURFACE TENSION | 567 |
| 15.19 CHANGE OF COMPOSITION WITH SURFACE | 569 |
| 15.20 THERMODYNAMIC PROPERTIES OF ELECTRONS IN METALS | 571 |
| 15.21 A SIMPLIFIED "ELECTRON GAS" THEORY | 576 |
| 15.21.1 Contact Potentials. Volta Effect | 579 |
| 15.21.2 Photoelectric Emission | 581 |
| 15.22 THERMIONIC EMISSION AND RICHARDSON'S EQUATION | 582 |
| 15.23 BLACK BODY RADIATION | 584 |
| APPENDIX | 592 |
| 16 THE THERMODYNAMICS OF INHERENTLY IRREVERSIBLE PROCESSES | 594 |
| 16.1 STEADY STATE COUPLED FLOWS | 594 |
| 16.2 CONCEPT OF A FLUX. ONSAGER'S RULE | 597 |
| 16.3 THERMAL TRANSPIRATION | 600 |
| 16.4 THERMAL TRANSPIRATION AS A SOURCE OF MOTIVE POWER | 603 |
| 16.5 INAPPROPRIATENESS OF THE WORDS "CAUSE" AND "EFFECT" | 604 |
| 16.6 SPECIAL ROLE OF THE MEMBRANE OR SEPARATING SURFACE | 605 |
| 16.7 CAUTION IN THE USE OF THE WORDS "HEAT" AND "WORK" | 606 |
| 16.8 LINEARIZED TREATMENT OF COUPLED FLOWS | 607 |
| 16.8.1 "Heat of Transport" | 609 |
| 16.9 APPLICATION TO THE THERMOCOUPLE | 610 |
| 16.10 CONCLUSIONS ABOUT THERMOCOUPLES USED FOR POWER PRODUCTION OR REFRIGERATION | 617 |
| 16.11 GENERALIZED TREATMENT OF LINEAR SYSTEMS USED FOR POWER PRODUCTION | 619 |
| 16.12 THE THERMOELECTRON ENGINE | 622 |
| 16.13 ONSAGER'S RULE AND THE THERMOELECTRON ENGINE | 625 |
| APPENDIX TO CHAPTER 16 | 627 |
| A16.1 Derivation of Eq. (16.3-7) and (16.3-8) | 627 |
| A16.2 Interactions among Many Fluxes | 630 |
| A16.3 Selective Effect of an Energy Barrier | 631 |
| REFERENCES | 632 |
| CONVERSION OF UNITS OF MEASURE | 633 |
| INDEX | 641 |