

Volume 2. Applications to Stars

- 18. *Vogt-Russell Theorem* 569**
 1. "Proof" for Uniform Composition Models, 570. 2. Physical Interpretation, 573. 3. Determination of Chemical Composition in Stellar Interiors, 578. 4. Case of Variable Chemical Composition, 579.
- 19. *Some Special Cases in Stellar Structure* 580**
 1. Pressure a Function only of Density, 581. 2. General Equation of State, 583. 3. Application of *V-R* Theorem to Cowling Model, 585.
- 20. *The Outer Stellar Layers* 587**
 1. Photospheric Conditions, 587. 2. Solution of the Equations of Stellar Structure in the Outer Radiative Layers of a Star, 591. 3. Stellar Envelopes in Radiative Equilibrium, 595. 4. Radiative Transfer in the Photospheric and Sub-Photospheric Regions, 599. 5. Regions on the *H-R* Diagram Where Convection in Stellar Envelopes is Effective, 609. 6. Stellar Envelopes in Convective Equilibrium, 620. 7. Temperature Distribution in the Envelope, 636. 8. Integrated Adiabats in Hydrogen and Helium Ionization Zones, 638.
- 21. *Computation of Stellar Models* 644**
 1. Equations and Mathematical Nature of the Problem, 644. 2. Schwarzschild Dimensionless Variables, 654. 3. Transformations for Integrations from the Center, 660. 4. Invariants and the *U-V* Plane, 663. 5. Developments at Center and Surface, 667. 6. Numerical Integration, 669. 7. "Hydrodynamic" and "Henye" Techniques, 672.
- 22. *Homologous Stars* 680**
 1. Definition of Homologous Stars, 682. 2. Transformation of Temperature Under a Homology Transformation, 685. 3. Alternative Derivation of Homology Relations, 687. 4. Transformation of L_{rad} Under a Homology Transformation, 689. 5. Transformation of L_{gen} Under a Homology Transformation, 691. 6. Permanently Homologous Stars, 692. 7. Transformation of L in Permanently Homologous Stars, 695. 8. Gravitationally Contracting Stars, 699. 9. Case of an Equation of State of the Form $P = P(\rho)$, 701.

- 23. *Stellar Models* 703**
 1. Polytropic Stars, 703. 2. Standard Model, 713. 3. Uniform Energy Source Model, 717. 4. Point-Source (Cowling) Model, 723. 5. Completely Convective Stars, 736. 6. Chemically Inhomogeneous Models, 759.
- 24. *Semi-Degenerate Equations of State* 781**
 1. Meaning of Degeneracy of Electron Gas, 783. 2. Evaluation of η in N.R. and E.R. Regimes, 792. 3. Mean Molecular Weight Per Free Electron, 802. 4. General Expressions for Electron Density, Pressure, Internal Energy, and Entropy, 804. 5. Non-Relativistic (N.R.) and Extreme Relativistic (E.R.) Regimes for Arbitrary Degree of Degeneracy, 812. 6. Completely Degenerate Case ($\eta = \infty$), 816. 7. Expansions of the $F_n(\eta, \beta)$ and of Other Quantities, 825. 8. Criteria for Degeneracy and Regions of Degeneracy on the ρ - T Plane, 842. 9. Effect of Electron-Positron Pairs, 851.
- 25. *Theory of the White Dwarf Stars* 874**
 1. Completely Degenerate Configurations in Hydrostatic Equilibrium, 876. 2. Physical Interpretation, 887. 3. Internal Temperature of White Dwarf Stars, 891. 4. Source of Energy and Internal Chemical Composition of White Dwarf Stars, 926. 5. Secular Stability, 929. 6. Cooling Times for White Dwarf Stars, 939. 7. Evolutionary Significance of White Dwarf Stars, 943.
- 26. *Survey of Stellar Evolution* 944**
 1. Overall Picture and Observational Approach to Stellar Evolution, 947. 2. Star Formation and Pre-Main Sequence Phases, 958. 3. Main Sequence (*MS*) Phase, 977. 4. Evolution Away from the Zero-Age *MS* and in the "Red Giant Regions," 986. 5. Final Stages of Stellar Evolution 1007.
- 27. *Pulsating Stars* 1029**
 1. Time Scales for Pulsating Stars and Brief Survey of Observational Data, 1031. 2. Equations for Spherically Symmetric Radial Motion, 1041. 3. Summary of Results for Linear Adiabatic Radial Oscillations, 1049. 4. Linear, Non-Adiabatic Radial Oscillations and Pulsational Stability, 1064. 5. Mathematical Problem of Linear, Non-Adiabatic Radial Pulsations, 1074. 6. Discussion of Factors Affecting Pulsational Stability, 1085. 7. On Envelope Ionization Mechanisms as a Cause of Pulsational Instability, 1106. 8. Summary of Recent Non-Linear Calculations, 1123.

CONTENTS

APPENDICES

A.1. Physical and Astronomical Constants	1141
A.2. Fermi-Dirac Integrals	1143
A.3. Ideal Fermi-Dirac Equation of State, Electron-Positron Pairs Neglected	1165
A.4. Ideal Fermi-Dirac Equation of State, Electron-Positron Pairs Included	1187
A.5. Emden Functions for $n = 1.5$ and $n = 3$	1203

SUPPLEMENT: Some Recent Developments	1211
--------------------------------------	------

S. 0. Basic Observational Material, 1213. S. 2. Radiation Theory, 1217. S. 6. Solution of the Equation of Transfer, 1218. S. 7. Conditions for LTE, 1218. S. 13. Stability of the Radiative Gradient, 1218. S. 14. Convection Theories, 1219. S. 15. Ionization of Material in Stellar Interiors, 1220. S. 16. Stellar Opacity, 1221. S. 17. Stellar Energy Sources, 1222. S. 20. The Outer Stellar Layers, 1229. S. 21. Construction of Stellar Models, 1230. S. 23. Stellar Models, 1231. S. 24. Semi-Degenerate Equations of State, 1237. S. 25. Theory of the White Dwarf Stars, 1238. S. 26. Stellar Evolution, 1253. S. 27. Pulsating Stars, 1266. *Supplement Reference List*, 1274.

REFERENCE LIST AND AUTHOR INDEX	1287
---------------------------------	------

SUBJECT INDEX	1305
---------------	------

CONTENTS OF VOLUME 1

0.	<i>Introduction and Survey of Observations</i>	1
	1. Luminosities, Masses, and Radii of Stars, 1. 2. Stellar Time Scales, 4. 3. Empirical (L, T_e) Correlation: Hertzsprung-Russell Diagram, 6. 4. Empirical (L, M) Correlation: Empirical Mass-Luminosity Relation, 14.	
1.	<i>Physical Conditions in Stellar Interiors</i>	16
	1. Statement of Condition of Hydrostatic Equilibrium, 16. 2. Estimates of Interior Values of Pressure and Temperature, 17. 3. Effect of Departures from Hydrostatic Equilibrium, 24.	
2.	<i>Radiation Theory</i>	26
	1. Specific Intensity, 28. 2. Net Flux, 33. 3. Energy Density of Radiation, 36. 4. Average Intensity, 38. 5. Radiation Pressure, 38. 6. Mass Emission Coefficient, 46. 7. Mass Absorption Coefficient, 47. 8. Microscopic Picture of Emission and Absorption of Radiation, 49. 9. Equation of Transfer, 64. 10. Elementary Theory of Dispersion, 72. 11. The "Directional Gradient" and Some of Its Properties, 87.	
3.	<i>Thermodynamic Equilibrium</i>	91
	1. General Discussion of Thermodynamic Equilibrium, 91. 2. Basic Distribution Law for a System in Statistical Equilibrium, 97. 3. Statistical Weight, 98. 4. Distribution Laws for Matter, 103. 5. Planck Radiation Law, 108. 6. Relations Among the Einstein Coefficients, 109. 7. Properties of Black Body Radiation, 114.	
4.	<i>Local Thermodynamic Equilibrium (LTE)</i>	117
	1. Equation of Transfer for LTE, 120. 2. Departure of S_ν/μ_ν^2 from $B_\nu(T)$, Assuming LTE, 126.	
5.	<i>Thermal and Radiative Equilibrium</i>	129
	1. Thermal Equilibrium, 129. 2. Radiative Equilibrium, 134.	
6.	<i>Solution of the Equation of Transfer</i>	139
	1. Formal Solutions, 139. 2. Expressions for J'_ν , F'_ν , and $p'_{r,\nu}$ in Terms of S'_ν for an Isotropic Source Function, 144. 3. Power Series Solution of the Equation of Transfer, 146. 4. Convergence, 153.	

7.	<i>Conditions for LTE</i>	158
	1. Equation of Transfer and the Excitation and Kinetic Temperatures, 159. 2. Statistically Steady State for a Two-Level Atom, 163. 3. Simultaneous Solution of the Equation of Transfer and the Statistically Steady State Equations for a Two-Level Atom, 167.	
8.	<i>Radiative Temperature Gradient</i>	171
	1. General Relation Between Radiation Pressure Tensor and Vector Net Flux, 171. 2. Rosseland Mean Mass Absorption Coefficient, 177.	
9.	<i>Some Thermodynamic Relations</i>	183
	1. Definitions, 184. 2. "Zeroth" Law of Thermodynamics, 187. 3. First Law of Thermodynamics, 187. 4. Quantity of Heat, 188. 5. Quasi-Static (or Reversible) Processes, 188. 6. Infinitesimal Changes, 188. 7. Case in Which the Pressure Tensor Does Not Reduce to a Pure Hydrostatic Pressure, 190. 8. Exactness, 192. 9. Second Law of Thermodynamics, 193. 10. Conditions for Thermodynamic Equilibrium, 195. 11. Reciprocity Relation, 197. 12. Chemical Equilibrium, 198. 13. Specific Heats, 206. 14. Quasi-Static Infinitesimal Adiabatic Changes, 210. 15. Gammas and Specific Heats for a Simple Perfect Gas, 214. 16. Gammas and Specific Heats for Black Body Radiation, 215. 17. Gammas and Specific Heats for a Mixture of Black Body Radiation and a Simple Perfect Gas, 217. 18. Gammas and Specific Heats for a Mixture of Perfect Gases Undergoing Ionization, with Radiation Pressure Included, 219.	
10.	<i>Some Results of Kinetic Theory and Statistical Mechanics</i>	232
	1. Pressure in a System of Non-Interacting "Particles," 232. 2. Internal Translational Kinetic Energy per Unit Volume, 234. 3. Statistical Mechanics Approach, 237. 4. Explicit Expressions for N , E , P , and S for Assemblies of Non-Interacting Bosons and Fermions in Statistical Equilibrium, 240. 5. Non-Degenerate (Maxwell-Boltzmann) Systems 243. 6. Principle of the Equipartition of Energy, 247. 7. Application of the Equipartition Principle to Some Simple Systems, 250.	
11.	<i>Importance of Radiation Pressure in Stellar Interiors</i>	253
12.	<i>Polytropic Changes</i>	257
13.	<i>Stability of the Radiative Gradient</i>	262
	1. Case of Uniform Chemical Composition, 265. 2. Estimate of the Degree of Superadiabaticity in the Deep Interior, 270. 3. Case of Non-Uniform Chemical Composition, 272. 4. General Discussion of Stability Against Convection, 277.	

CONTENTS

14.	<i>Mixing Length Theory of Convection</i>	281
	1. The Four Gradients, 283. 2. Convective Flux, 287. 3. Average Speed of Convecting Elements, 289. 4. The Net Flux, 294. 5. Efficiency of Convection, 295. 6. Upper Limits to Values of Various Quantities, 302. 7. Solution of the Equations When the Total Flux is Specified, 311. 8. Solution of the Equations When the Actual Gradient is Specified, 321. 9. Solution of the Equations When Supersonic Convective Velocities Are Indicated, 324.	
15.	<i>Ionization of Material in Stellar Interiors</i>	326
	1. Mean Molecular Weight, 327. 2. Electron Density, 330. 3. Calculation of \bar{n}_e , 331. 4. Excitation and Ionization Energy, 334. 5. Electrostatic Corrections, 335. 6. Numerical Results for a Particular Chemical Composition, 349.	
16.	<i>Stellar Opacity</i>	353
	1. Photo Effect, 355. 2. Free-Free Transitions (Bremsstrahlung), 359. 3. Thomson Scattering (Coherent Compton Effect), 362. 4. Monochromatic Mass Absorption Coefficient, 364. 5. Rosseland Mean Opacity, 371. 6. Approximate Formulae, 372. 7. Electron Thermal Conduction, 384. 8. Other Effects, 390. 9. A.N. Cox Opacity Results, 396.	
17.	<i>Stellar Energy Sources</i>	398
	1. Gravitational Potential Energy of a Star, 400. 2. The Virial Theorem, 402. 3. Internal Energy and Total Energy of a Star, 411. 4. Gravitational Contraction, 412. 5. Some Conditions for Gravitational Contraction, 414. 6. Local Energy Release from Gravitational Contraction, 417. 7. Nuclear Energy Production, 422. 8. Basic Properties of Atomic Nuclei, 423. 9. Bohr Picture of a Nuclear Reaction, 429. 10. Cross Section for Nuclear Reactions, 440. 11. Cross Section for Low Energy Exothermic Nuclear Reactions, 446. 12. Thermonuclear Reaction Rate, 452. 13. Non-Resonant Contribution, 457. 14. Resonant Contribution, 464. 15. Electron Screening, 467. 16. Hydrogen Burning Reactions, 475. 17. Rate of Energy Production by Hydrogen Burning, 483. 18. Helium Burning Reactions, 496. 19. Carbon, Oxygen, and Neon Burning, 508. 20. Neutrino Energy Losses, 512.	

APPENDICES

A.1. Physical and Astronomical Constants	527
--	-----

REFERENCE LIST AND AUTHOR INDEX	528
---------------------------------	-----

SUBJECT INDEX	546
---------------	-----