

## CONTENTS

## PREFACE

page ix

## CHAPTER I

## Introduction

1.1. The liquefaction of helium, p. 1. 1.2. The  $\lambda$ -transition, p. 2. 1.3. Superfluidity and the two-fluid theory, p. 3. 1.4. The liquid helium film, p. 6. 1.5. Thermal effects, p. 9. 1.6. Second sound, p. 14. 1.7. Helium three, p. 17.

## CHAPTER 2

## Equilibrium Properties

2.1. The phase diagram, p. 19. 2.2. Energy relations near  $0^\circ\text{K}$ ., p. 21. 2.3. Theories of the structure of the liquid near  $0^\circ\text{K}$ ., p. 24. 2.4. X-ray and neutron diffraction experiments, p. 28. 2.5. Some basic thermodynamic quantities, p. 32. 2.5.1. The specific heat, p. 32. 2.5.2. The latent heat of vaporization, p. 35. 2.5.3. The density, coefficient of expansion and equation of state, p. 36. 2.5.4. The dielectric constant and the refractive index, p. 38. 2.5.5. The surface tension, p. 40. 2.6. The nature of the  $\lambda$ -transition, p. 41. 2.6.1. The Ehrenfest relations, p. 41. 2.6.2. Fluctuations near the  $\lambda$ -point, p. 48.

## CHAPTER 3

## Theories

3.1. Bose-Einstein condensation, p. 52. 3.1.1. Bose-Einstein condensation in an ideal gas, p. 52. 3.1.2. Bose-Einstein condensation in a liquid, p. 56. 3.2. Landau's theory, p. 58. 3.2.1. Phonons and rotons, p. 58. 3.2.2. The thermodynamic functions, p. 62. 3.2.3. The density of the normal component,  $\rho_n$ , p. 66. 3.3. The nature of the elementary excitations, p. 70. 3.3.1. Quantum hydrodynamics, p. 70. 3.3.2. Feynman's theories, p. 73. 3.3.3. Quantum hydrodynamics and the excitation curve, p. 80. 3.4. The quantum mechanical many body problem, p. 82.

## CHAPTER 4

## The New Thermohydrodynamics

4.1. The need for a new hydrodynamics, p. 87. 4.2. Superfluidity, p. 88. 4.2.1. Isothermal flow through narrow channels, p. 88. 4.2.2. The flow of the films, p. 91. 4.2.3. Flow through fine pores, p. 94. 4.2.4. Bulk liquid, p. 95.

4.3. Thermal effects, p. 97. 4.3.1. The mechanocaloric effect, p. 97. 4.3.2. The thermomechanical effect, p. 99. 4.3.3. Theory, p. 100. 4.4. The thermohydrodynamical equations, p. 102. 4.5. The viscosity of the normal component,  $\eta_n$ , p. 104. 4.5.1. Experimental determination of  $\eta_n$ , p. 104. 4.5.2. The Landau-Khalatnikov theory of  $\eta_n$ , p. 106. 4.6. Theories of superfluidity, p. 111. 4.6.1. The nature of superfluidity, p. 111. 4.6.2. Interaction of the superfluid component and the walls, p. 112. 4.6.3. Quantized vortex lines, p. 114. 4.6.4. Liquid in a rotating cylindrical vessel, p. 117.

## CHAPTER 5

### First and Second Sound

5.1. The two types of wave propagation, p. 123. 5.1.1. The two wave velocities, p. 123. 5.1.2. Irreversible effects and attenuation, p. 125. 5.2. First sound, p. 128. 5.2.1. The velocity of first sound, p. 128. 5.2.2. The attenuation of first sound near the  $\lambda$ -point, p. 131. 5.2.3. The attenuation of first sound below  $2^\circ\text{K}$ ., p. 136. 5.3. Second sound, p. 141. 5.3.1. The nature of second sound, p. 141. 5.3.2. The velocity of second sound, p. 148. 5.3.3. The attenuation of second sound, p. 155. 5.3.4. Large amplitude effects and shock waves, p. 157. 5.3.5. The Pitot tube, the Rayleigh disk and the radiation balance, p. 161. 5.4. The thermohydrodynamical equations, p. 163.

## CHAPTER 6

### Further Aspects of the Thermohydrodynamics

6.1. Second sound in uniformly rotating liquid, p. 164. 6.1.1. The experiments and their interpretation in terms of vortex lines, p. 164. 6.1.2. Calculation of the magnitude of the extra attenuation, p. 168. 6.2. The breakdown of superfluidity, p. 171. 6.3. Mutual friction, p. 172. 6.3.1. The thermomechanical effect, p. 172. 6.3.2. Thermal conduction, p. 174. 6.3.3. Flow through narrow channels, p. 177. 6.4. Mutual friction and vorticity, p. 181. 6.4.1. Second sound in a heat current, p. 181. 6.4.2. Transient effects, p. 185. 6.5. Further investigations of non-linear dissipative processes, p. 188. 6.5.1. Gravitational flow through wide capillaries, p. 188. 6.5.2. The rotating cylinder viscometer, p. 190. 6.5.3. Accelerating systems, p. 192. 6.6. Critical velocities, p. 198. 6.7. The Kapitza boundary effect, p. 201.

## CHAPTER 7

### Helium Films

7.1. Introduction, p. 205. 7.2. Experimental difficulties, p. 206. 7.3. Measurements of the thickness of the saturated film, p. 208. 7.4. Unsaturated films, p. 211. 7.5. The flow of the saturated film, p. 214. 7.6. The flow of unsaturated films, p. 219. 7.7. Theories of the formation of the film, p. 224.

## CHAPTER 8

## Helium Three

8.1. Introduction, p. 230. 8.2. Some basic properties, p. 231. 8.3. The entropy and specific heat, p. 234. 8.4. Magnetic properties, p. 237. 8.5. Transport properties, p. 239. 8.6. Theories of liquid  $\text{He}^3$ , p. 241. 8.6.1. de Boer's modified law of corresponding states, p. 241. 8.6.2. The ideal Fermi-Dirac gas, p. 244. 8.6.3. The Fermi liquid, p. 245. 8.6.4. Transport properties and zero sound, p. 248. 8.6.5. Cell models and other theories, p. 250. 8.7. The melting curve, p. 252.

## CHAPTER 9

 $\text{He}^3$ - $\text{He}^4$  Mixtures

9.1. Thermodynamic properties, p. 256. 9.1.1. The theory of ideal solutions, p. 256. 9.1.2. The vapour pressure and distribution coefficient, p. 258. 9.1.3. Departures from ideality, p. 262. 9.2. Theories of  $\text{He}^3$ - $\text{He}^4$  mixtures, p. 267. 9.3. Variation of the  $\lambda$ -temperature with concentration, p. 272. 9.4. The thermohydrodynamics of  $\text{He}^3$ - $\text{He}^4$  mixtures, p. 275. 9.4.1. Non-participation of  $\text{He}^3$  in superfluid flow, p. 275. 9.4.2. The thermohydrodynamical equations, p. 279. 9.4.3. Heat conduction in  $\text{He}^3$ - $\text{He}^4$  mixtures, p. 281. 9.5. Second sound in  $\text{He}^3$ - $\text{He}^4$  mixtures, p. 284. 9.6. Normal density,  $\rho_n$ , and viscosity,  $\eta_n$ , p. 288. 9.7. Methods of concentrating  $\text{He}^3$ - $\text{He}^4$  mixtures, p. 291. 9.8. Ions in liquid helium, p. 292.

## REFERENCES

page 294

## INDEX

309