Contents

Preface *page* ix

1 Introduction to concepts **1**

1.1 Fluids in the Universe 2
1.2 The concept of a 'fluid element' 4
1.3 Formulation of the fluid equations 5
1.4 Relation between the Eulerian and Lagrangian descriptions 7
1.5 Kinematical concepts 8

2 The fluid equations **12**

2.1 Conservation of mass 12
2.2 Pressure 14
2.3 Momentum equations 15
2.4 Momentum equation in conservative form: the stress tensor and concept of ram pressure 17

3 Gravitation **20**

3.1 The gravitational potential 20
3.2 Poisson's equation 22
3.3 Using Poisson's equation 24
3.4 The potential associated with a spherical mass distribution 27
3.5 Gravitational potential energy 28
3.6 The virial theorem 30

4 The energy equation **32**

4.1 Ideal gases 32
4.2 Barotropic equations of state: the isothermal and adiabatic cases 33
4.3 Energy equation 37
4.4 Energy transport 39
4.5 The form of $\dot{Q}_{cool}$ 45

5 Hydrostatic equilibrium **46**

5.1 Basic equations 46
5.2 The isothermal slab 47
5.3 An isothermal atmosphere with constant g 49
5.4 Stars as self-gravitating polytropes 50
5.5 Solutions for the Lane–Emden equation 52
5.6 The case of $n=\infty$ 55
5.7 Scaling relations 56
5.8 Examples of astrophysical interest 60
5.9 Summary: general method for scaling relations 62

6 Propagation of sound waves **63**

6.1 Sound waves in a uniform medium 63
6.2 Propagation of sound waves in a stratified atmosphere 68
6.3 General approach to wave propagation problems 73
6.4 Transmission of sound waves at interfaces 74

7 Supersonic flows **77**

7.1 Shocks 78
7.2 Isothermal shocks 85

8 Blast waves **89**

8.1 Strong explosions in uniform atmospheres 89
8.2 Blast waves in astrophysics and elsewhere 96
8.3 Structure of the blast wave 99
8.4 Breakdown of the similarity solution 102
8.5 The effects of cooling and blow out from galactic discs 104

9 Bernoulli's equation **107**

9.1 Basic equation 107
9.2 De Laval nozzle 113
9.3 Spherical accretion and winds 118
9.4 Stellar winds 123
9.5 General steady state solutions 126

10 Fluid instabilities **128**

10.1 Rayleigh–Taylor instability 128
10.2 Gravitational instability (Jeans instability) 139

10.3 Thermal instability 142
10.4 Method summary 149

11 Viscous flows 150

11.1 Linear shear and viscosity 150
11.2 Navier–Stokes equation 153
11.3 Evolution of vorticity in viscous flows 157
11.4 Energy dissipation in incompressible viscous flows 158
11.5 Viscous flow through a circular pipe and the transition to turbulence 159

12 Accretion discs in astrophysics 163

12.1 Derivation of viscous evolution equations for accretion discs 165
12.2 Viscous evolution equation with constant viscosity 167
12.3 Steady thin discs 173
12.4 Radiation from steady thin discs 176

13 Plasmas 179

13.1 Magnetohydrodynamic equations 180
13.2 Charge neutrality 184
13.3 Ideal hydromagnetic equations 186
13.4 Waves in plasmas 190
13.5 The Rayleigh–Taylor instability revisited 195

Appendix Equations in curvilinear coordinates 200

Exercises 206

Books for background and further reading 222

Index 224