

Contents

1	The Continuity Equation	1
1.1	Introduction	1
1.2	The Continuum Hypothesis	2
1.2.1	Example: Glass of Water	2
1.2.2	Example: Grains in a Stellar Envelope	3
1.3	The Continuity Equation	3
1.3.1	Example: Incompressible Fluids	5
1.3.2	Example: Steady State	5
1.4	The Mass Flux	6
1.5	Spherical Coordinates	6
1.6	Cylindrical Coordinates	8
1.7	The Mass Loss Rate	9
1.7.1	Example: The Solar Wind	10
1.7.2	Example: Mass loss in Red Giants	11
1.7.3	Example: Mass Loss in Hot Stars	11
	Exercises	12
	Bibliography	12
2	The Euler Equation	15
2.1	The Euler Equation	15
2.1.1	Example: Static Star	18
2.2	Euler Equation in the Presence of a Magnetic Field	19
2.2.1	Example: Solar Atmosphere	20
2.3	Spherical Coordinates	21
2.3.1	Example: Azyuthal Symmetry	25
2.3.2	Example: Spherical Symmetry	25
2.3.3	Example: Spherical Symmetry and Steady State	25
2.3.4	Example: Hydrostatic Equilibrium	26
2.4	Cylindrical Coordinates	26
2.4.1	Example: Azyuthal Symmetry	28
2.4.2	Example: The Unidimensional Case	28

2.5	Euler Equation in a Stellar Envelope	28
2.5.1	Example: Envelope in Hydrostatic Equilibrium.....	30
2.5.2	Example: Hydrostatic Solar Corona	30
2.5.3	Example: Free-Falling Stellar Envelope	31
2.5.4	Example: Accelerated Envelope	33
2.5.5	Example: The Escape Velocity.....	34
2.5.6	Example: The Γ Parameter in Hot Stars	35
2.5.7	Example: The Γ Parameter in Cool Stars	36
2.5.8	Example: Expanding Planetary Nebula.....	37
	Exercises	37
	Bibliography	38
3	The Equation of State	39
3.1	Introduction.....	39
3.2	The Equation of State of a Perfect Gas.....	40
3.3	The Mean Molecular Weight	41
3.3.1	Example: Neutral H Gas	41
3.3.2	Example: Neutral H Gas with 10 % of Neutral He.....	42
3.3.3	Example: Completely Ionized H Gas	42
3.3.4	Example: Ionized H Gas with 10 % Neutral He.....	42
3.3.5	Example: Molecular Hydrogen Gas	42
3.3.6	Example: The Solar Photosphere	43
3.4	Validity of the Perfect Gas Hypothesis	44
3.4.1	Example: Neutral Gas Envelope	44
3.4.2	Example: Ionized Gas Envelope	45
	Exercises	45
	Bibliography	46
4	The Energy Equation	47
4.1	Introduction.....	47
4.2	Adiabatic Motion.....	48
4.2.1	Example: Adiabatic Solar Corona	51
4.2.2	Example: Entropy Flux Density	52
4.2.3	Example: Euler Equation in Isentropic Motion	53
4.3	Energy Conservation in a Fluid.....	54
4.3.1	Example: Energy Deposition in the Interstellar Medium	55
4.4	The Energy Equation in the Lagrangian Form	56
4.5	The Energy Equation in the Eulerian Form	59
4.5.1	Example: Bernoulli Equation	59
4.6	Fluid in a Conservative Force Field	60
4.7	The Energy Flux.....	61
4.7.1	Example: Spherically Symmetric Conductive Flux	61
4.7.2	Example: Conductive Flux and Radiative Force	62
	Exercises	63
	Bibliography	63

5	Cartesian Tensor Notation	65
5.1	Introduction	65
5.2	Vectors	65
5.2.1	Example: Rotation Around the z Axis	66
5.2.2	Example: Rotation Around the x Axis	67
5.3	Cartesian Tensors	68
5.4	Vector Operations	70
5.4.1	Example: Scalar Product	70
5.4.2	Example: Gradient	70
5.4.3	Example: Divergence	71
5.4.4	Example: Vector Product	71
5.4.5	Example: Rotational	72
5.4.6	Example: Stokes Theorem	72
5.4.7	Example: Gradient Theorem	73
5.4.8	Example: Divergence Theorem	73
5.4.9	Example: Laplacian	73
5.4.10	Example: Total Derivative	74
5.5	The Divergence Theorem	74
5.5.1	Example: Outer Product	74
5.5.2	Example: Inner Product	75
	Exercises	76
	Bibliography	76
6	Fluid Equations in Tensor Form	79
6.1	Introduction	79
6.2	The Continuity Equation	79
6.3	Euler Equation in the Absence of External Forces	80
6.4	The Momentum Flux Tensor	81
6.5	Euler Equation with External Forces	83
6.6	The Energy Equation	83
	Exercises	84
	Bibliography	85
7	The Navier-Stokes Equation	87
7.1	Viscous Fluids	87
7.2	The Viscosity Tensor	88
7.3	The Navier-Stokes Equation: Incompressible Fluids	93
7.4	The Navier-Stokes Equation: Compressible Fluids	94
	Exercises	95
	Bibliography	96
8	Sound Waves	97
8.1	Propagation of Sound Waves	97
8.2	The Speed of Sound in the Isothermal Case	99
8.3	The Speed of Sound in the Adiabatic Case	100

8.4	The Critical Point in Stellar Winds	101
8.4.1	Example: Radiation Pressure on Molecules	102
8.5	Structure of Isothermal Winds	102
	Exercises	107
	Bibliography	108
9	Shock Waves	109
9.1	Introduction	109
9.2	Shock Waves in the Interstellar Medium	110
9.3	The Rankine-Hugoniot Conditions	112
9.3.1	Example: Pressure in the Interstellar Clouds	114
9.4	The Mach Number	114
9.4.1	Example: The Mach Number in Interstellar Clouds	115
9.5	Physical Conditions in the Shock Zone	116
9.5.1	Example: Diffuse Interstellar Clouds	117
9.6	Fixed Reference System	117
9.6.1	Example: Winds in Hot Stars	119
9.7	Isothermal Shocks	119
9.7.1	Example: Isothermal Winds in Hot Stars	121
9.8	Hydromagnetic Shocks	121
9.8.1	Example: Adiabatic Interstellar Shock	122
9.8.2	Example: Isothermal Interstellar Shock	123
	Exercises	124
	Bibliography	125
10	Stellar Winds: An Overview	127
10.1	Introduction	127
10.2	Observational Evidence	129
10.2.1	Example: P Cygni Profiles	129
10.2.2	Example: Terminal Velocity in the Wind of NGC 7009	130
10.2.3	Example: Terminal Velocity and Model Fitting in CSPN	131
10.2.4	Example: Turbulence in Stellar Atmospheres	132
10.2.5	Example: The H α Emission Line	133
10.2.6	Example: Infrared and Radio Excess	134
10.2.7	Example: Molecular Emission of Cool Stars	134
10.2.8	Example: Grain Infrared and Millimeter Emission	135
10.3	Isothermal and Non-isothermal Winds	136
10.3.1	Example: Isothermal Wind with an External Force Proportional to r^{-2}	137
10.4	Mechanisms Responsible for the Ejection	138
10.4.1	Example: Coronal Winds	138
10.4.2	Example: Winds Driven by Sound Waves	139
10.4.3	Example: Winds Driven by Circumstellar Dust	139

10.4.4	Example: Two-Fluid Hydrodynamics – AGB Stars	142
10.4.5	Example: Winds Driven by Line Radiation	143
10.4.6	Example: The Velocity Law and the Mass Loss Rate with the Finite Disk Correction	145
10.4.7	Example: Winds and Metallicities in Hot Stars	146
10.4.8	Example: Winds and the Metallicity of CSPN	146
10.4.9	Example: Winds and Magnetic Fields – Alfvén Waves...	147
10.5	An Estimate of the Mass Loss Rate in Hot Stars	148
10.6	An Estimate of the Mass Loss Rate in Cool Stars	150
10.7	Interaction with the Interstellar Medium	152
10.8	Mass Loss and Stellar Evolution	153
	Exercises	154
	Bibliography	155
Solutions		157
Index		173

Hydrodynamics and Stellar Winds

An Introduction

Maciel, W.J.

2014, XVII, 178 p. 30 illus., 2 illus. in color., Softcover

ISBN: 978-3-319-04327-2