

## Contents

	Preface	<i>page</i> ix
	Notes on the text	xi
	Acknowledgements	xiii
	Abbreviations	xv
	Standard parameters and symbols	xvi
	Units and their symbols	xviii
	SI prefixes	xix
	Approximate values of commonly used measures	xx
<b>1</b>	<b>Turbulence, heat and waves</b>	<b>1</b>
1.1	Introduction	1
1.2	Reynolds' experiment	3
1.3	Joule's experiment	5
1.4	The surf zone: waves and turbulence	8
1.5	The nature of turbulent flow	13
	1.5.1 Stirring + diffusion = mixing	13
	1.5.2 Entrainment and detrainment	15
1.6	Shear, convergence and strain	18
1.7	Ocean stratification and buoyancy	19
	1.7.1 Density	19
	1.7.2 Buoyancy, and the buoyancy frequency, $N$	22
	1.7.3 The oceanic density profile	23
1.8	Consequences of stratification	25
	1.8.1 Internal waves and turbulent motion	25
	1.8.2 Isopycnal and diapycnal mixing	28
	Suggested further reading	32
	Further study	32
	Problems for Chapter 1	33
<b>2</b>	<b>Measurement of ocean turbulence</b>	<b>37</b>
2.1	Characteristics of turbulence	37
	2.1.1 Structure	37
	2.1.2 Stress and flux	39
	2.1.3 Dissipation	39
2.2	Transport by eddies	39

vi	Contents
2.2.1	Reynolds stress 39
2.2.2	Heat and buoyancy flux 42
2.3	Energetics 43
2.3.1	Turbulent dissipation, $\varepsilon$ , and isotropy 43
2.3.2	The range and observed variation of $\varepsilon$ 45
2.3.3	The rate of loss of temperature variance, $\chi_T$ 47
2.3.4	The Kolmogorov length scale, $l_K$ 48
2.3.5	The turbulence cascade and the structure of turbulence 49
2.3.6	The Taylor hypothesis and the spectrum of turbulent energy 51
2.4	The terms in the energy balance equation 54
2.4.1	The rate of production of turbulent kinetic energy by the mean flow 56
2.4.2	The turbulent potential energy 56
2.4.3	The rate of dissipation 59
2.5	Measurement techniques and instruments 59
2.5.1	The first measurements of turbulence: spectra 60
2.5.2	The air-foil probe: the measurement of $\varepsilon$ 60
2.5.3	First measurements of Reynolds stress, and the related dissipation per unit area 67
2.5.4	Estimates of Reynolds stress and $\varepsilon$ using an ADCP 71
	Suggested further reading 73
	Further study 74
	Problems for Chapter 2 75
<b>3</b>	<b>Turbulence in oceanic boundary layers 77</b>
3.1	Introduction: processes, and types of boundary layers 77
3.2	Convection in the absence of shear 81
3.2.1	Convection below a cooled surface or over a heated seabed 81
3.2.2	Buoyant plumes and entrainment 83
3.3	Stress and no convection; the law of the wall 85
3.4	Stress and buoyancy flux 87
3.4.1	The Monin–Obukov length scale 87
3.4.2	Diurnal and seasonal heat cycling of the mixed layer 89
3.4.3	Other mixing processes in the upper ocean 95
3.4.4	The benthic (or bottom) boundary layer 100
3.4.5	Tidal mixing and straining in shallow seas 102
	Suggested further reading 106
	Further study 107
	Problems for Chapter 3 110

Contents	vii
<b>4 Turbulence in the ocean pycnocline</b>	<b>116</b>
4.1 Introduction	116
4.1.1 Processes of turbulence generation	116
4.1.2 The first observations of turbulence in the thermocline	117
4.2 Shear-flow instability and the transition to turbulence	119
4.3 The Richardson number in the ocean	125
4.4 Further turbulence parameters derived from microstructure measurements	129
4.4.1 Estimation of $\varepsilon$	129
4.4.2 Estimation of eddy diffusion coefficients	131
4.4.3 $R_f$ and the ratio of the eddy coefficients of mass and momentum	133
4.5 Entrainment into the surface mixed layer	135
4.6 Observations of mid-water mixing processes	135
4.7 The rate of diapycnal mixing	139
4.8 Double diffusive convection	144
Suggested further reading	149
Further study	150
Problems for Chapter 4	152
<b>5 Turbulent dispersion</b>	<b>158</b>
5.1 Introduction	158
5.1.1 The properties of dispersants	158
5.1.2 Appropriate measures	163
5.1.3 Effects of relative eddy and patch sizes	164
5.2 The dispersion of particles	168
5.2.1 Autocorrelation and integral scales	168
5.2.2 Richardson's four-thirds power law	170
5.2.3 Dispersion of pairs of particles	171
5.2.4 Effects of closed vertical circulations on buoyant particles	171
5.3 Observations of the dispersion of floats	174
5.3.1 Surface floats	174
5.3.2 Subsurface floats	179
5.4 The dispersion of solutes: methods and observations	180
5.4.1 Dispersion (or horizontal diffusion) of a solute	180
5.4.2 Dye releases in the surface boundary layer	180
5.4.3 Tracer releases in the pycnocline	182
5.4.4 Natural and anthropogenic tracers	187
Suggested further reading	189
Further study	190
Problems for Chapter 5	192

viii		Contents
<b>6</b>	<b>The energetics of ocean mixing</b>	<b>197</b>
6.1	Introduction	197
6.2	How much energy is required to mix the abyssal ocean?	199
6.3	The tides	200
	6.3.1 The surface or barotropic tides	200
	6.3.2 The internal or baroclinic tides	201
6.4	The atmospheric input of energy through the sea surface	204
	6.4.1 The wind stress	204
	6.4.2 Surface waves	205
	6.4.3 Buoyancy flux	207
6.5	The mean circulation and mesoscale eddies	208
6.6	Internal waves	209
6.7	Dissipation produced by bottom stress	210
6.8	Flow through and around abyssal topography	210
6.9	Geothermal heat flux	216
6.10	Discussion	217
	Suggested further reading	218
	Further study	219
	Problems for Chapter 6	220
	References	225
	Index	235