



# CONTENTS

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Molecular Diffusion</b>	<b>8</b>
2.0	Scope	8
2.1	Principal Symbols	8
2.2	Molecular Diffusion	10
2.3	Simple Molecular Model of Diffusion in a Gas Mixture	11
2.4	Phenomenological Theory of Molecular Diffusion	16
2.5	Estimation of Diffusion Coefficients in Binary Gas Mixtures	17
2.6	Diffusion in Liquids	25
2.7	Diffusion in Electrolyte Solutions	35
2.8	Diffusion in Porous Materials	39
2.9	Diffusion in Polymers	43
	References	49
	Problems	51

<b>3</b>	<b>Rate Equations for Molecular Diffusion</b>	<b>54</b>
3.0	Scope	54
3.1	Principal Symbols	54
3.2	Introduction	56
3.3	Steady-State Molecular Diffusion	57
3.4	Diffusion in Multicomponent Mixtures	61
3.5	Transient Diffusion—Introduction	67
3.6	Transient Diffusion in Stagnant Media	70
3.7	Mass Transfer in Laminar Flow	77
3.8	Quasi-Steady-State Diffusion	90
	Appendix	92
	References	94
	Problems	95
<b>4</b>	<b>Turbulent Diffusion</b>	<b>101</b>
4.0	Scope	101
4.1	Principal Symbols	101
4.2	Turbulence	103
4.3	The Eddy Viscosity	106
4.4	The Universal Velocity Distribution in Smooth Tubes	109
4.5	The Eddy-Diffusion Coefficient	112
4.6	Turbulent Diffusion	114
4.7	Experimental Studies of Turbulent Diffusion	119
4.8	Interaction of Molecular and Turbulent Diffusion	126
4.9	Turbulent Schmidt and Prandtl Numbers	127
4.10	Mixing and Dispersion in Packed Beds	129
4.11	Axial Dispersion in Pipe Lines	137
	References	141
	Problems	145
<b>5</b>	<b>Mass Transfer at a Phase Boundary</b>	<b>148</b>
5.0	Scope	148
5.1	Principal Symbols	149
5.2	Models	150
5.3	Analogies between Mass, Heat, and Momentum Transfer	159
5.4	Mass Transfer at Large Fluxes and at High Concentration Levels	172
5.5	The Two-Film Theory	178
5.6	Mass Transfer at the Interface between Phases	181
	References	192
	Problems	196

<b>6</b>	<b>Rates of Mass Transfer at Surfaces with Simple Geometry</b>	<b>199</b>
6.0	Scope	199
6.1	Principal Symbols	200
6.2	Flat Surfaces	201
6.3	Falling Liquid Films	203
6.4	Mass Transfer between a Fluid and a Solid Sphere	214
6.5	Solid Particles Suspended in Agitated Vessels	220
6.6	Drops	224
6.7	Bubbles	231
6.8	Cylinders and Disks	236
6.9	Single-Phase Flow in Packed Beds	241
	References	247
	Problems	252
<b>7</b>	<b>Simultaneous Heat and Mass Transfer</b>	<b>255</b>
7.0	Scope	255
7.1	Principal Symbols	255
7.2	The Effect of Mass Transfer on the Rate of Heat Transfer at the Same Surface	257
7.3	The Theory of the Wet-Bulb Thermometer	261
7.4	The Design of Partial Condensers	263
7.5	Condensation from a Superheated Gas	265
7.6	The Formation of Fog in Partial Condensers	267
7.7	Effect of Variations in Interface Temperature	269
7.8	The Condensation of Mixed Vapors	273
7.9	The Mechanism of Vapor-Phase Nucleation in Partial Condensers	276
7.10	Water Cooling Towers	280
7.11	Values of the Mass-Transfer Coefficient for Water Cooling Towers	286
7.12	The Crossflow Cooling Tower	291
	References	296
	Problems	297
<b>8</b>	<b>Mass Transfer and Simultaneous Chemical Reaction</b>	<b>301</b>
8.0	Scope	301
8.1	Principal Symbols	302
8.2	Introduction	303
8.3	Effect of a Chemical Reaction in Gas Absorption	306
8.4	The Theory of Simultaneous Diffusion and Chemical Reaction near an Interface	310

8.5	The Film Theory for a First-Order Irreversible Reaction	312
8.6	The Theory of First-Order Reactions according to the Surface-Replacement Model	313
8.7	First-Order Reactions during Unsteady-State Diffusion into a Semiinfinite Medium: The Penetration Theory	314
8.8	Comparison of the Film, Surface-Replacement, and Penetration Theories for First-Order Reactions	321
8.9	Bimolecular Reactions	322
8.10	Bimolecular Reaction in a Turbulent Fluid near a Solid Interface	334
8.11	The Effect of Reversibility of the Chemical Reaction on the Mass-Transfer Rate	336
8.12	Computations of the Reaction Effect for a Few, More General Chemical Situations	343
8.13	The Reactions of $\text{NO}_x$ with Water and Aqueous Solutions	346
8.14	The Reactions of $\text{CO}_2$ with Alkaline Aqueous Solutions	361
8.15	The Oxidation of Sulfite Ion by Dissolved Oxygen	371
8.16	Carrier-facilitated Mass Transfer through Membranes	376
8.17	Diffusion and Reaction in Porous Catalysts	379
	References	382
	Problems	385
<b>9</b>	<b>Design Principles for Mass-Transfer Equipment</b>	<b>392</b>
9.0	Scope	392
9.1	Principal Symbols	393
9.2	Introduction	395
9.3	Phase Equilibria	396
9.4	Absorption in a Single Equilibrium Stage	398
9.5	Multistage Countercurrent Absorption	399
9.6	Continuous Differential-Contact Packed-Column Design	427
9.7	Relation between Actual and Theoretical Plates; Plate Efficiency	507
9.8	Distillation	518
9.9	Solvent Extraction	524
	Appendix: A Digital Computer Program for a Packed-Column Absorption and Stripping	525
	References	534
	Problems	536
<b>10</b>	<b>Design of Fixed-Bed Sorption and Ion Exchange Devices</b>	<b>548</b>
10.0	Introduction and Scope	548
10.1	Principal Symbols	549
10.2	Fluid-Solid Equilibria	550

10.3	The Equations of Transport	554
10.4	The Local-Equilibrium Theory of Fixed-Bed Devices	555
10.5	The Effects of Mass-Transfer Resistance between Fluid and Solid Phases	561
10.6	The Thomas Solution for Sorption Breakthrough Curves	565
10.7	Breakthrough Curves for Linear Phase Equilibria and Chromatography	571
10.8	The Resistance to Mass Transfer between Phases for Ion Exchange and Sorption	579
10.9	The Design of Fixed-Bed Adsorbers for Repeated, Cyclic Use	586
	References	589
	Problems	591
<b>11</b>	<b>The Performance of Mass-Transfer Equipment</b>	<b>593</b>
11.0	Scope	593
11.1	Principal Symbols	594
11.2	Mass-Transfer Equipment	595
11.3	The Nature of the Available Design Data	598
11.4	Packed Columns	599
11.5	Tray or "Plate" Columns	624
11.6	Agitated Vessels and Bubble Columns	647
	References	656
	Problems	660
	<b>Index</b>	<b>667</b>