

---

# Contents

---

<b>Preface</b> . . . . .	ix
<b>Introduction</b> . . . . .	xiii
<b>Chapter 1. Basic Concepts and Balances</b> . . . . .	1
1.1. Thermal energy and the first law of thermodynamics . . . . .	1
1.2. Thermal energy and the second law of thermodynamics . . . . .	2
1.3. For an energy and mass accounting: balances . . . . .	3
1.3.1. Accounting principles for system inputs and outputs . . . . .	4
1.3.2. Accumulation in the system. . . . .	8
1.3.3. Generation in a system. . . . .	11
1.3.4. Balance equation . . . . .	15
1.4. Fluxes and flux densities . . . . .	20
1.4.1. Energy fluxes . . . . .	20
1.4.2. Mass fluxes . . . . .	20
1.4.3. Flux densities . . . . .	20
1.5. Operating states . . . . .	25
1.5.1. Steady state . . . . .	25
1.5.2. Transient state. . . . .	25
1.6. Transfer area . . . . .	28
1.6.1. What does the transfer area represent? . . . . .	28
1.6.2. Illustration: transfer area in a heat exchanger . . . . .	28
1.6.3. Illustration: transfer area inferred from a technical drawing. . . . .	30
1.7. Driving potential difference . . . . .	31
1.7.1. Heat transfer potential difference . . . . .	32
1.7.2. Mass transfer potential difference . . . . .	34
1.8. Exercises and solutions . . . . .	38
1.9. Reading: seawater desalination . . . . .	75

---

1.9.1. Level of purification . . . . .	75
1.9.2. Water sources used . . . . .	76
1.9.3. Water characteristics according to the source . . . . .	76
1.9.4. Several techniques . . . . .	76
1.9.5. Energy cost: the decisive factor . . . . .	76
1.9.6. A promising outlook . . . . .	77
<b>Chapter 2. Mechanisms and Laws of Heat Transfer . . . . .</b>	<b>79</b>
2.1. Introduction. . . . .	79
2.2. Mechanism and law of conduction . . . . .	79
2.3. Mechanism and law of convection . . . . .	83
2.3.1. Examples. . . . .	83
2.3.2. Law of convection . . . . .	84
2.3.3. Forced convection versus natural convection . . . . .	84
2.4. Radiation transfer mechanism. . . . .	85
2.4.1. Correction to take account of the nature of the surface. . . . .	87
2.4.2. Geometric correction: the view factor. . . . .	87
2.4.3. Radiation transfer between black surfaces under total influence . . . . .	89
2.4.4. Radiation transfer between black surfaces in arbitrary positions . . . . .	90
2.4.5. Radiation transfer between gray surfaces in arbitrary positions. . . . .	91
2.5. Exercises and solutions . . . . .	92
2.6. Reading: Joseph Fourier . . . . .	112
<b>Chapter 3. Mass Transfer Mechanisms and Processes . . . . .</b>	<b>115</b>
3.1. Introduction. . . . .	115
3.2. Classification of mass transfer mechanisms. . . . .	116
3.3. Transfer mechanisms in single-phase systems . . . . .	117
3.3.1. The vacancy mechanism. . . . .	117
3.3.2. The interstitial mechanism . . . . .	118
3.3.3. Random walk . . . . .	118
3.3.4. The kinetic model. . . . .	118
3.3.5. The quantum model . . . . .	120
3.4. Mass transfer processes in single-phase media . . . . .	122
3.4.1. Transfer under the action of a concentration gradient: osmosis . . . . .	122
3.4.2. Transfer under the action of a pressure gradient: ultrafiltration . . . . .	127
3.4.3. Dialysis. . . . .	134
3.4.4. Thermal gradient diffusion . . . . .	139
3.4.5. Diffusion by a gradient of force: centrifugation . . . . .	141
3.4.6. Electromagnetic diffusion. . . . .	143
3.4.7. Laminar flux transfer. . . . .	144
3.4.8. Laser transfer . . . . .	145
3.4.9. Transfer under the action of an electric field: electro dialysis . . . . .	146

---

3.5. Mechanisms and processes in two-phase media . . . . .	154
3.5.1. Distillation . . . . .	154
3.5.2. Absorption mass transfer . . . . .	165
3.6. Exercises and solutions . . . . .	176
3.7. Reading: uranium enrichment . . . . .	217
3.7.1. Uranium as a fuel . . . . .	217
3.7.2. Uranium in nature . . . . .	217
3.7.3. Natural-uranium reactors . . . . .	217
3.7.4. Pressurized-water reactors. . . . .	218
3.7.5. Fast-neutron reactors. . . . .	218
3.7.6. Classification of uranium enrichments . . . . .	218
3.7.7. Uranium enrichment processes . . . . .	219
3.7.8. The uranium enrichment industry . . . . .	219
<b>Chapter 4. Dimensional Analysis . . . . .</b>	<b>221</b>
4.1. Introduction. . . . .	221
4.2. Basic dimensions . . . . .	222
4.3. Dimensions of derived magnitudes . . . . .	222
4.4. Dimensional analysis of an expression. . . . .	225
4.4.1. Illustration: determining the dimensions of $\lambda$ . . . . .	225
4.4.2. Illustration: determining the dimensions of $h$ . . . . .	225
4.5. Unit systems and conversions . . . . .	226
4.5.1. Illustration: dimensions and units of energy . . . . .	227
4.5.2. Illustration: units of heat conductivity $\lambda$ . . . . .	227
4.5.3. Illustration: units of the convective transfer coefficient $h$ . . . . .	228
4.6. Dimensionless numbers . . . . .	229
4.6.1. The Reynolds number . . . . .	230
4.6.2. The Nusselt number . . . . .	231
4.6.3. The Prandtl number . . . . .	231
4.6.4. The Peclet number . . . . .	231
4.6.5. The Grashof number . . . . .	232
4.6.6. The Rayleigh number . . . . .	233
4.6.7. The Stanton number . . . . .	233
4.6.8. The Graetz number . . . . .	234
4.6.9. The Biot number . . . . .	234
4.6.10. The Fourier number. . . . .	234
4.6.11. The Elenbaas number. . . . .	235
4.6.12. The Froude number . . . . .	235
4.6.13. The Euler number . . . . .	236
4.7. Developing correlations through dimensional analysis . . . . .	239
4.8. Rayleigh's method. . . . .	241
4.8.1. Illustration: applying Rayleigh's method . . . . .	242

4.8.2. Illustration: verifying Fourier's law by applying Rayleigh's method . . . . .	245
4.9. Buckingham's method . . . . .	247
4.9.1. Illustration: applying the Buckingham $\pi$ theorem . . . . .	248
4.10. Exercises and solutions . . . . .	251
4.11. Reading: Osborne Reynolds and Ludwig Prandtl. . . . .	294
4.11.1. Osborne Reynolds. . . . .	294
4.11.2. Ludwig Prandtl . . . . .	296
<b>Appendix</b> . . . . .	299
<b>Bibliography</b> . . . . .	315
<b>Index</b> . . . . .	325