

# Contents

<i>Preface</i>	<b>xiii</b>
<i>Acknowledgements</i>	<b>xv</b>
<b>1 Introduction</b>	<b>1</b>
1.1 A Sustainable Energy Supply	1
1.2 The Greenhouse Effect and Climate Change	3
1.3 Light Absorption in Nature as a Source of Energy	4
1.4 The Contribution of Science: Understanding, Modelling and Monitoring	5
Exercises	6
References	6
<b>2 Light and Matter</b>	<b>7</b>
2.1 The Solar Spectrum	7
2.1.1 Radiation from a Black Body	7
2.1.2 Emission Spectrum of the Sun	9
2.2 Interaction of Light with Matter	12
2.2.1 Electric Dipole Moments of Transitions	12
2.2.2 Einstein Coefficients	14
2.2.3 Absorption of a Beam of Light: Lambert-Beer's Law	16
2.3 Ultraviolet Light and Biomolecules	19
2.3.1 Spectroscopy of Biomolecules	20
2.3.2 Damage to Life from Solar UV	21
2.3.3 The Ozone Filter as Protection	22
Exercises	28
References	28
<b>3 Climate and Climate Change</b>	<b>31</b>
3.1 The Vertical Structure of the Atmosphere	32
3.2 The Radiation Balance and the Greenhouse Effect	36
3.2.1 Simple Changes in the Radiation Balance	39
3.2.2 Radiation Transfer	41
3.2.3 A Simple Analytical Model	44
3.2.4 Radiative Forcing and Global Warming	45
3.2.5 The Greenhouse Gases	48

3.3	Dynamics in the Climate System	51	4.5.4	Aerosols	127
3.3.1	Horizontal Motion of Air	53	4.5.5	Volatile Organic Compounds VOC	128
3.3.2	Vertical Motion of Ocean Waters	58	4.5.6	Thermal Pollution	129
3.3.3	Horizontal Motion of Ocean Waters	59	4.5.7	Regulations	129
3.4	Natural Climate Variability	59	4.6	The Private Car	129
3.5	Modelling Human-Induced Climate Change	62	4.6.1	Power Needs	130
3.5.1	The Carbon Cycle	63	4.6.2	Automobile Fuels	131
3.5.2	Structure of Climate Modelling	66	4.6.3	Three-Way Catalytic Converter	132
3.5.3	Modelling the Atmosphere	67	4.6.4	Electric Car	133
3.5.4	A Hierarchy of Models	70	4.6.5	Hybrid Car	134
3.6	Analyses of IPCC, the Intergovernmental Panel on Climate Change	70	4.7	Economics of Energy Conversion	134
3.7	Forecasts of Climate Change	70	4.7.1	Capital Costs	134
	Exercises	74	4.7.2	Learning Curve	138
	References	76		Exercises	138
				References	142
<b>4</b>	<b>Heat Engines</b>	<b>77</b>	<b>5</b>	<b>Renewable Energy</b>	<b>145</b>
4.1	Heat Transfer and Storage	78	5.1	Electricity from the Sun	146
4.1.1	Conduction	79	5.1.1	Varying Solar Input	146
4.1.2	Convection	82	5.1.2	Electricity from Solar Heat: Concentrating Solar Power CSP	150
4.1.3	Radiation	82	5.1.3	Direct Conversion of Light into Electricity: Photovoltaics PV	152
4.1.4	Phase Change	83	5.2	Energy from the Wind	159
4.1.5	The Solar Collector	84	5.2.1	Betz Limit	160
4.1.6	The Heat Diffusion Equation	87	5.2.2	Aerodynamics	162
4.1.7	Heat Storage	90	5.2.3	Wind Farms	165
4.2	Principles of Thermodynamics	91	5.2.4	Vertical Wind Profile	165
4.2.1	First and Second Laws	91	5.2.5	Wind Statistics	167
4.2.2	Heat and Work; Carnot Efficiency	95	5.2.6	State of the Art and Outlook	168
4.2.3	Efficiency of a 'Real' Heat Engine	97	5.3	Energy from the Water	169
4.2.4	Second Law Efficiency	98	5.3.1	Power from Dams	169
4.2.5	Loss of Exergy in Combustion	101	5.3.2	Power from Flowing Rivers	170
4.3	Idealized Cycles	103	5.3.3	Power from Waves	170
4.3.1	Carnot Cycle	103	5.3.4	Power from the Tides	174
4.3.2	Stirling Engine	104	5.4	Bio Energy	175
4.3.3	Steam Engine	105	5.4.1	Thermodynamics of Bio Energy	175
4.3.4	Internal Combustion	107	5.4.2	Stability	180
4.3.5	Refrigeration	110	5.4.3	Solar Efficiency	180
4.4	Electricity as Energy Carrier	113	5.4.4	Energy from Biomass	182
4.4.1	Varying Grid Load	114	5.5	Physics of Photosynthesis	183
4.4.2	Co-Generation of Heat and Electricity	115	5.5.1	Basics of Photosynthesis	184
4.4.3	Storage of Electric Energy	117	5.5.2	Light-Harvesting Antennas	185
4.4.4	Transmission of Electric Power	123	5.5.3	Energy Transfer Mechanism	187
4.5	Pollution from Heat Engines	125	5.5.4	Charge Separation	190
4.5.1	Nitrogen Oxides NO <sub>x</sub>	125	5.5.5	Flexibility and Disorder	193
4.5.2	SO <sub>2</sub>	126	5.5.6	Photoprotection	193
4.5.3	CO and CO <sub>2</sub>	126	5.5.7	Research Directions	195

5.6	Organic Photocells: the Grätzel Cell	196	7.2	Dispersion in Rivers	270
5.6.1	The Principle	196	7.2.1	One-Dimensional Approximation	271
5.6.2	Efficiency	199	7.2.2	Influence of Turbulence	275
5.6.3	New Developments and the Future	202	7.2.3	Example: A Calamity Model for the Rhine River	277
5.6.4	Applications	203	7.2.4	Continuous Point Emission	278
5.7	Bio Solar Energy	203	7.2.5	Two Numerical Examples	280
5.7.1	Comparison of Biology and Technology	204	7.2.6	Improvements	281
5.7.2	Legacy Biochemistry	207	7.2.7	Conclusion	282
5.7.3	Artificial Photosynthesis	209	7.3	Dispersion in Groundwater	282
5.7.4	Solar Fuels with Photosynthetic Microorganisms: Two Research Questions	213	7.3.1	Basic Definitions	283
5.7.5	Conclusion	213	7.3.2	Darcy's Equations	286
	Exercises	215	7.3.3	Stationary Applications	290
	References	217	7.3.4	Dupuit Approximation	295
<b>6</b>	<b>Nuclear Power</b>	<b>221</b>	7.3.5	Simple Flow in a Confined Aquifer	298
6.1	Nuclear Fission	222	7.3.6	Time Dependence in a Confined Aquifer	301
6.1.1	Principles	222	7.3.7	Adsorption and Desorption of Pollutants	302
6.1.2	Four Factor Formula	226	7.4	Mathematics of Fluid Dynamics	304
6.1.3	Reactor Equations	229	7.4.1	Stress Tensor	304
6.1.4	Stationary Reactor	231	7.4.2	Equations of Motion	308
6.1.5	Time Dependence of a Reactor	233	7.4.3	Newtonian Fluids	309
6.1.6	Reactor Safety	234	7.4.4	Navier-Stokes Equation	310
6.1.7	Nuclear Explosives	237	7.4.5	Reynolds Number	311
6.2	Nuclear Fusion	238	7.4.6	Turbulence	313
6.3	Radiation and Health	244	7.5	Gaussian Plumes in the Air	317
6.3.1	Definitions	244	7.5.1	Statistical Analysis	319
6.3.2	Norms on Exposure to Radiation	245	7.5.2	Continuous Point Source	321
6.3.3	Normal Use of Nuclear Power	247	7.5.3	Gaussian Plume from a High Chimney	322
6.3.4	Radiation from Nuclear Accidents	247	7.5.4	Empirical Determination of the Dispersion Coefficients	323
6.3.5	Health Aspects of Fusion	247	7.5.5	Semi-Empirical Determination of the Dispersion Parameters	324
6.4	Managing the Fuel Cycle	248	7.5.6	Building a Chimney	325
6.4.1	Uranium Mines	249	7.6	Turbulent Jets and Plumes	326
6.4.2	Enrichment	249	7.6.1	Dimensional Analysis	328
6.4.3	Fuel Burnup	252	7.6.2	Simple Jet	329
6.4.4	Reprocessing	252	7.6.3	Simple Plume	331
6.4.5	Waste Management	253		Exercises	333
6.4.6	Nonproliferation	256		References	334
6.5	Fourth Generation Nuclear Reactors	257	<b>8</b>	<b>Monitoring with Light</b>	<b>337</b>
	Exercises	258	8.1	Overview of Spectroscopy	337
	References	259	8.1.1	Population of Energy Levels and Intensity of Absorption Lines	341
<b>7</b>	<b>Dispersion of Pollutants</b>	<b>261</b>	8.1.2	Transition Dipole Moment: Selection Rules	341
7.1	Diffusion	262	8.1.3	Linewidths	342
7.1.1	Diffusion Equation	262	8.2	Atomic Spectra	345
7.1.2	Point Source in Three Dimensions in Uniform Wind	267	8.2.1	One-Electron Atoms	345
7.1.3	Effect of Boundaries	269	8.2.2	Many-Electron Atoms	346

8.3	Molecular Spectra	347		
8.3.1	Rotational Transitions	347		
8.3.2	Vibrational Transitions	349		
8.3.3	Electronic Transitions	353		
8.4	Scattering	359		
8.4.1	Raman Scattering	359		
8.4.2	Resonance Raman Scattering	360		
8.4.3	Rayleigh Scattering	361		
8.4.4	Mie Scattering	362		
8.4.5	Scattering in the Atmosphere	362		
8.5	Remote Sensing by Satellites	362		
8.5.1	ENVISAT Satellite	362		
8.5.2	SCIAMACHY's Operation	362		
8.5.3	Analysis	364		
8.5.4	Ozone Results	368		
8.6	Remote Sensing by Lidar	368		
8.6.1	Lidar Equation and DIAL	369		
8.6.2	Range-Resolved Cloud and Aerosol Optical Properties	371		
	Exercises	376		
	References	377		
<b>9</b>	<b>The Context of Society</b>	<b>379</b>		
9.1	Using Energy Resources	380		
9.1.1	Energy Consumption	380		
9.1.2	Energy Consumption and Resources	382		
9.1.3	Energy Efficiency	383		
9.1.4	Comparing Energy Resources	384		
9.1.5	Energy Options	387		
9.1.6	Conclusion	388		
9.2	Fresh Water	389		
9.3	Risks	389		
9.3.1	Small Concentrations of Harmful Chemicals	390		
9.3.2	Acceptable Risks	392		
9.3.3	Small Probability for a Large Harm	393		
9.3.4	Dealing with Uncertainties	394		
9.4	International Efforts	396		
9.4.1	Protection of the Ozone Layer	396		
9.4.2	Protection of Climate	396		
9.5	Global Environmental Management	398		
9.5.1	Self-Organized Criticality	398		
9.5.2	Conclusion	401		
9.6	Science and Society	401		
9.6.1	Nature of Science	401		
9.6.2	Control of Science	402		
9.6.3	Aims of Science	402		
9.6.4	A New Social Contract between Science and Society	404		
	Exercises and social questions		405	
	Social questions		405	
	References		406	
	<i>Appendix A: Physical and Numerical Constants</i>		409	
	<i>Appendix B: Vector Algebra</i>		411	
	<i>Appendix C: Gauss, Delta and Error Functions</i>		419	
	<i>Appendix D: Experiments in a Student's Lab</i>		423	
	<i>Appendix E: Web Sites</i>		425	
	<i>Appendix F: Omitted Parts of the Second Edition</i>		427	
	<i>Index</i>		<b>429</b>	