CONTENTS

Preface Introductio	n	x xii
Part I	Energy	
Chapter 1	Energy Flows and Supplies	3
	1.1 Prologue on Energy and Sustainability	3
	1.2 Natural Energy Flows	4
	1.3 Human Energy Consumption	8
	1.4 Human Energy Sources	14
Chapter 2	Fossil Fuels	19
	2.1 Carbon Cycle	19
	2.2 Origins of Fossil Fuels	21
	2.3 Fuel Energy	25
	2.4 Petroleum	29
	2.4a Composition and Refining	29
	2.4b Advantages	31
	2.4c Disadvantages	31
	2.5 Gas	37
	2.5a Advantages	38
	2.5b Disadvantages	38
	2.6 Coal	38
	2.6a Advantages	39
	2.6b Disadvantages	39
	2.7 Decarbonization	42
	2.7a Separation	42
	2.7b Storage	12

iv	ntents
----	--------

Chapter 3	Nuclear Energy	44
•	3.1 Nuclei, Isotopes, and Radioactivity	44
	3.2 Naturally Occurring Radioisotopes	47
	3.3 Decay Chains: The Radon Problem	49
	3.4 Radioactivity: Biological Effects of Ionizing Radiation	50
	3.4a Alpha Rays	52
	3.4b Beta and Gamma Rays, and Neutrons	52
	3.5 Radiation Exposure	53
	3.6 Fission	54
	3.6a Pressurized Light-Water Reactor	56
	3.6b Isotope Separation	57
	3.6c Breeder Reactor	58
	3.6d Reprocessing	60
	3.7 Hazards of Nuclear Power	60
	3.7a Reactor Safety: Three Mile Island and Chernobyl	60
	3.7b Weapons Proliferation	63
	3.7c Nuclear Waste Disposal	65
	3.8 Is Nuclear Power Part of the Future?	67
	3.9 Fusion	68
	3.9a Fusion Reactions	68
	3.9b Fusion Power Reactors	70
	3.9c Is Fusion the Energy Source of the Future?	73
Chapter 4	Renewable Energy	74
-	4.1 Solar Heating	77
	4.2 Solar Thermal Electricity	79
	4.3 Photovoltaic Electricity	80
	4.3a Principles of the PV Cell	81
	4.3b Photosynthesis and Photoelectrochemistry	85
	4.4 Biomass	87
	4.4a Ethanol from Biomass	88
	4.4b Methane from Biomass	90
	4.5 Hydroelectricity	91
	4.6 Wind Power	92
	4.7 Ocean Energy	95
	4.8 Geothermal Energy	96
Chapter 5	Energy Utilization	98
	5.1 Heat Engine Efficiencies	100
	5.2 Fuel Cells	103
	5.3 Space Heating, Cogeneration	109
	5.4 Electricity Storage: The Hydrogen Economy	109
	5.5 The Materials Connection	112
	5.5a Materials Properties: Paper versus Plastics	113
	5.5b Recycling	113
	5.5c Dematerialization	117

	Contents				v
--	----------	--	--	--	---

	5.6 Systems Efficiency		119
	5.6a Transportation		120
	5.6b Industrial Ecology		125
	5.6c Green Chemistry		128
	5.7 Energy and Society		129
	Summary		133
	Problem Set		134
	Suggested Readings		139
Part II	Atmosphere		143
Chapter 6	Climate		
Chapter 0			145
	6.1 Radiation Balance		145
	6.2 Albedo: Particles and Clouds		150
	6.2a Clouds		150
	6.2b Aerosol Particles		153
	6.2c Sulfur Cycle		156
	6.3 Greenhouse Effect	A BA BA BASA.	160
	6.3a Infrared Absorption and Molecular	vibrations	160
	6.3b Greenhouse Gas Trends 6.4 Climate Modeling		165
	6.5 International Agreements on Greenhouse C		172
Cl		Jases	178
Chapter 7	Oxygen Chemistry		180
	7.1 Nitrogen Oxides: Free Energy		180
	7.1a Free Energy and the Equilibrium Co	onstant	181
	7.1b Free Energy and Temperature		183
	7.2 Nitrogen Oxides: Kinetics		185
	7.3 Free Radical Chain Reactions		186
	7.3a Oxygen Radicals		187
	7.3b Organic Oxygen Radicals		190
	7.3c Hydroxyl Radical		191
	7.3d Transition Metal Activation of O ₂		192
Chapter 8	Stratospheric Ozone		194
	8.1 Atmospheric Structure		196
	8.2 Ultraviolet Protection by Ozone		200
	8.3 Ozone Chemistry		203
	8.3a Formation and Destruction		203
	8.3b Calculating the Ozone Steady State		204
	8.4 Catalytic Destruction of Ozone		207
	8.4a Hydroxyl Radical		207
	8.4b Chlorine and Bromine		207
	8.4c Nitric Oxide		208
	8.5 Polar Ozone Destruction		209

i		Contents

	8.6 Ozone Projections	213
	8.7 CFC Substitutes	213
Chapter 9	Air Pollution	216
	9.1 Pollutants and Their Effects	216
	9.1a Carbon Monoxide	216
	9.1b Sulfur Dioxide	218
	9.1c Toxic Organics	220
	9.1d Particles	222
	9.1e NO _X and Volatile Organics	223
	9.1f Ozone and Other Oxidants	226
	9.2 Photochemical Smog	227
	9.3 Emission Control	232
	9.3a Sulfur Dioxide	232
	9.3b Nitrogen Oxides, Carbon Monoxide, and Hydrocarbons	233
	9.4 Reformulated Gasoline: Oxygenates	237
	9.4a Knocking and Octane	237
	9.4b Diesels and Cetane	238
	9.4c Lead in Gasoline	238
	9.4d Reformulated Gasoline	239
	Summary	241
	Problem Set Suggested Readings	242 247
Part III	Hydrosphere/Lithosphere	251
Chapter 10	Water Resources	253
	10.1 Global Perspective	253
	10.2 Irrigation	256
	10.3 Groundwater	259
	10.4 U.S. Water Resources	260
	10.5 The Oceans	262
	10.6 Water as Solvent and as a Biological Medium	265
Chapter 11	From Clouds to Runoff: Water as Solvent	266
	11.1 Unique Properties of Water	266
	11.1a Hydrogen Bonding	266
	11.1b Clathrates and Water Miscibility	269
	11.2 Acids, Bases, and Salts	272
	11.2a Ions, Autoionization, and pH	272
	11.2b Weak Acids and Bases	274
	11.3 Conjugate Acids and Bases; Buffers	276

Contents		vii

	11.4	Water in the Atmosphere: Acid Rain	277
Chapter 12	Wate	er and the Lithosphere	282
	12.1	Earth as Acid-Base Reactor	282
	12.2	Organic and Inorganic Carbon Cycles	284
		12.2a The Carbonate Control	286
		12.2b Carbonate Sequestration	288
	12.3	Weathering and Solubilization Mechanisms	289
		12.3a Ionic Solids and the Solubility Product	289
		12.3b Solubility and Basicity	290
		12.3c Ion Exchange; Clays and Humic Substances	292
	12.4	Effects of Acidification	297
		12.4a Soil Neutralization	297
		12.4b Hardness and Detergents	298
		12.4c Acid Deposition and Watershed Buffering	300
		12.4d Ecosystem Effects of Acid Rain	303
		12.4e Acid Mine Drainage	305
		12.4f Global Acidification	305
Chapter 13	Oxyo	gen and Life	207
Chapter 15			307
	13.1	Redox Reactions and Energy	307
		13.1a Biological Oxygen Demand	309
•		13.1b Natural Sequence of Biological Reductions	311
	12.2	13.1c Biological Oxidations Aerobic Earth	315
			316
	13.3	Water as Ecological Medium	319
		13.3a The Euphotic Zone and the Biological Pump	319
		13.3b Eutrophication in Freshwater Lakes	319
		13.3c Nitrogen and Phosphorus: The Limiting Nutrients	323
		13.3d Anoxia and its Effects on Coastal Marine Waters	325
		13.3e Wetlands as Chemical Sinks	328
		13.3f Redox Effects on Metals Pollution	330
		13.3g Fertilizing the Ocean with Iron	331
Chapter 14		er Pollution and Water Treatment	333
		Water Use and Water Quality: Point and Nonpoint Sources of Pollution	333
		Regulation of Water Quality	337
		Water and Sewage Treatment	339
	14.4	Health Hazards	341
		14.4a Pathogens and Disinfection	341
		14.4b Organic and Inorganic Contaminants	344
		Summary	346
		Problem Set	347
		Suggested Readings	351

	۰	٠	
1/	E	ï	ı
v	E	ı	B

Contents

Part IV	Biosphere	359
Chapter 15	Nitrogen and Food Production 15.1 Nitrogen Cycle 15.2 Agriculture 15.2a Fertilizer and the Green Revolution 15.2b Environmental Degradation 15.3 Nutrition 15.3a Energy and Calories 15.3b Protein 15.3c Minerals and Vitamins 15.3d Antioxidants	357 357 361 361 365 369 370 374
Chapter 16	Pest Control	382
	 16.1 Insecticides 16.1a Persistent Insecticides: Organochlorines 16.1b Ecosystem Effects; Bioaccumulation 16.1c Nonpersistent Insecticides: Organophosphates and Carbamates 16.1d Natural Insecticides 16.1e Integrated Pest Management 16.2 Herbicides 16.3 Genetically Modified Organisms (GMOs) 16.3a GM Plants: Actualities and Potential 16.3b Resistance to GM Foods 	382 382 386 390 394 397 401 401 402
Chapter 17	Toxic Chemicals	407
	 17.1 Acute and Chronic Toxicity 17.2 Cancer 17.2a Mechanisms 17.2b Cancer Incidence and Testing 17.3 Hormonal Effects 17.4 Persistent Organic Pollutants: Dioxins and PCBs 17.4a Dioxins and Furans 17.4b Polychlorinated Biphenyls 17.4c Global Transport 17.5 Toxic Metals Summary Problem Set Suggested Readings 	407 410 411 415 418 423 423 429 432 432 452 454 458
Appendix	Organic Structures	461
	Hydrocarbons; Alkanes Branched Chains; Isomers Rings	461 462 463

Contents		ix	
	Unsaturated Hydrocarbons	464	
	Molecular Shape	465	
	Carbon Framework Representations	465	
	Aromatic Compounds	466	
	Hetero-Atoms; Functional Groups	467	
Index		471	