

# Atmospheric POLLUTION

HISTORY, SCIENCE, AND REGULATION

Mark Z. Jacobson



CAMBRIDGE

# CONTENTS

<i>Preface</i>	page ix
<i>Acknowledgments</i>	xi
<b>1. BASICS AND HISTORY OF DISCOVERY OF ATMOSPHERIC CHEMICALS</b>	1
<b>1.1. Basic Definitions</b>	2
<b>1.2. History of Discovery of Elements and Compounds of Atmospheric Importance</b>	4
<b>1.3. Chemical Structure and Reactivity</b>	21
<b>1.4. Chemical Reactions and Photoprocesses</b>	24
<b>1.5. Lifetimes of Chemicals</b>	26
<b>1.6. Summary</b>	26
<b>1.7. Problems</b>	26
<b>2. THE SUN, THE EARTH, AND THE EVOLUTION OF THE EARTH'S ATMOSPHERE</b>	29
<b>2.1. The Sun and Its Origin</b>	30
<b>2.2. Spectra of the Radiation of the Sun and the Earth</b>	33
<b>2.3. Primordial Evolution of the Earth and Its Atmosphere</b>	36
<b>2.4. Summary</b>	47
<b>2.5. Problems</b>	48
<b>3. STRUCTURE AND COMPOSITION OF THE PRESENT-DAY ATMOSPHERE</b>	49
<b>3.1. Air Pressure and Density Structure</b>	50
<b>3.2. Processes Affecting Temperature</b>	52
<b>3.3. Temperature Structure of the Atmosphere</b>	54

3.4.	<i>Equation of State</i>	58
3.5.	<i>Composition of the Present-Day Atmosphere</i>	62
3.6.	<i>Characteristics of Selected Gases and Aerosol Particle Components</i>	63
3.7.	<i>Summary</i>	79
3.8.	<i>Problems</i>	79
4.	<b>URBAN AIR POLLUTION</b>	81
4.1.	<i>History and Early Regulation of Urban Air Pollution</i>	82
4.2.	<i>Chemistry of the Background Troposphere</i>	93
4.3.	<i>Chemistry of Photochemical Smog</i>	99
4.4.	<i>Pollutant Removal</i>	111
4.5.	<i>Summary</i>	111
4.6.	<i>Problems</i>	112
5.	<b>AEROSOL PARTICLES IN SMOG AND THE GLOBAL ENVIRONMENT</b>	115
5.1.	<i>Size Distributions</i>	116
5.2.	<i>Sources and Compositions of New Particles</i>	118
5.3.	<i>Processes Affecting Particle Size</i>	128
5.4.	<i>Summary of the Composition of Aerosol Particles</i>	138
5.5.	<i>Aerosol Particle Morphology and Shape</i>	139
5.6.	<i>Health Effects of Aerosol Particles</i>	140
5.7.	<i>Summary</i>	142
5.8.	<i>Problems</i>	142
6.	<b>EFFECTS OF METEOROLOGY ON AIR POLLUTION</b>	145
6.1.	<i>Forces</i>	146
6.2.	<i>Winds</i>	147
6.3.	<i>Global Circulation of the Atmosphere</i>	150
6.4.	<i>Semipermanent Pressure Systems</i>	154
6.5.	<i>Thermal Pressure Systems</i>	155
6.6.	<i>Effects of Large-Scale Pressure Systems on Air Pollution</i>	156
6.7.	<i>Effects of Local Meteorology on Air Pollution</i>	168
6.8.	<i>Summary</i>	175
6.9.	<i>Problems</i>	176
7.	<b>EFFECTS OF POLLUTION ON VISIBILITY, ULTRAVIOLET RADIATION, AND ATMOSPHERIC OPTICS</b>	179
7.1.	<i>Processes Affecting Solar Radiation in the Atmosphere</i>	180
7.2.	<i>Visibility</i>	197
7.3.	<i>Colors in the Atmosphere</i>	202
7.4.	<i>Summary</i>	205
7.5.	<i>Problems</i>	206
7.6.	<i>Project</i>	207

<b>8. INTERNATIONAL REGULATION OF URBAN SMOG SINCE THE 1940s</b>	209
<b>8.1. Regulation in the United States</b>	210
<b>8.2. Pollution Trends and Regulations Outside the United States</b>	225
<b>8.3. Summary</b>	238
<b>8.4. Problems</b>	239
<b>9. INDOOR AIR POLLUTION</b>	241
<b>9.1. Pollutants in Indoor Air and Their Sources</b>	242
<b>9.2. Sick Building Syndrome</b>	251
<b>9.3. Regulation of Indoor Air Pollution</b>	251
<b>9.4. Summary</b>	252
<b>9.5. Problems</b>	252
<b>10. ACID DEPOSITION</b>	253
<b>10.1. Historical Aspects of Acid Deposition</b>	254
<b>10.2. Causes of Acidity</b>	257
<b>10.3. Sulfuric Acid Deposition</b>	260
<b>10.4. Nitric Acid Deposition</b>	263
<b>10.5. Effects of Acid Deposition</b>	263
<b>10.6. Natural and Artificial Neutralization of Lakes and Soils</b>	266
<b>10.7. Recent Regulatory Control of Acid Deposition</b>	270
<b>10.8. Summary</b>	271
<b>10.9. Problems</b>	272
<b>11. GLOBAL STRATOSPHERIC OZONE REDUCTION</b>	273
<b>11.1. Structure of the Present-Day Ozone Layer</b>	274
<b>11.2. Relationship between the Ozone Layer and UV Radiation</b>	277
<b>11.3. Chemistry of the Natural Ozone Layer</b>	278
<b>11.4. Recent Changes to the Ozone Layer</b>	283
<b>11.5. Effects of Chlorine on Global Ozone Reduction</b>	286
<b>11.6. Effects of Bromine on Global Ozone Reduction</b>	293
<b>11.7. Regeneration Rates of Stratospheric Ozone</b>	294
<b>11.8. Antarctic Ozone Depletion</b>	295
<b>11.9. Effects of Enhanced UV-B Radiation on Life and Ecosystems</b>	301
<b>11.10. Regulation of CFCs</b>	303
<b>11.11. Summary</b>	306
<b>11.12. Problems</b>	307
<b>12. THE GREENHOUSE EFFECT AND GLOBAL WARMING</b>	309
<b>12.1. The Temperature on the Earth in the Absence of a Greenhouse Effect</b>	310
<b>12.2. The Greenhouse Effect and Global Warming</b>	316
<b>12.3. Recent and Historical Temperature Trends</b>	323

<b>12.4. Feedbacks and Other Factors That May Affect Global Temperatures</b>	337
<b>12.5. Possible Consequences of Global Warming</b>	342
<b>12.6. Regulatory Control of Global Warming</b>	345
<b>12.7. Summary</b>	349
<b>12.8. Problems</b>	350
<b>12.9. Essay Questions</b>	351
<i>Appendix: Conversions and Constants</i>	353
<i>References</i>	355
<i>Photograph Sources</i>	371
<i>Index</i>	377