

# Contents

**Foreword** *xiii*

**Preface** *xv*

<b>1</b>	<b>Infrared Spectroscopy and Its Application in Atmospheric Research</b>	<b>1</b>
1.1	Basic Theories	1
1.1.1	Energy Level	3
1.1.2	Vibrational Mode	5
1.2	Infrared Spectroscopic Techniques and Principles	7
1.2.1	Interaction Between a Molecule and an Electromagnetic Field in Infrared Spectroscopy	7
1.2.2	Infrared Spectra	9
1.2.3	Intensities in Infrared Spectra	10
1.2.4	Infrared Reflectance Spectroscopy	10
1.2.5	Specular Reflection (Smooth Surfaces)	11
1.2.6	Diffuse Reflection (Rough Surfaces)	12
1.2.7	Attenuated Total Reflection Fourier Transform Infrared Spectroscopy	12
1.2.8	Fourier Transform Infrared Spectroscopy	13
1.2.9	Sample Preparation Requirements of ATR-FTIR	16
1.2.10	Characteristics of ATR-FTIR	16
1.3	Experimental Facility	17
1.3.1	Structural Overview of an Infrared Spectrometer	18
1.3.1.1	Dispersive Infrared Spectrometer	18
1.3.1.2	Interferometric Infrared Spectrometer	19
1.3.1.3	Light Source	19
1.3.1.4	Monochromator	22
1.3.1.5	Interferometer	22
1.3.1.6	Detector	22
1.3.2	Sample Preparation Techniques in Infrared Spectroscopy	24
1.3.2.1	Gas Sample	24
1.3.2.2	Liquid Sample	24
1.3.2.3	Solid Sample	26
1.3.3	Maintenance of an Infrared Spectrometer	27
1.4	Applications of Infrared Spectroscopy in Atmospheric Research	28

1.4.1	Qualitative and Quantitative Analysis	28
1.4.1.1	Verification of Known Substances	28
1.4.1.2	Infrared Spectroscopic Analysis of Unknown Substances	29
1.4.2	Application in Atmospheric Processes	30
1.4.3	Application in Extractive Measurements	31
1.4.4	Open-Path Fourier Transform Infrared (OP-FTIR) Spectroscopy Measurement Method	32
1.4.5	Application in Interface Characterization	33
1.4.6	Application in Reaction Kinetics	34
1.4.7	Application in Environmental Analysis and Testing	36
1.4.7.1	Chemical Identification of Microplastics	36
1.5	Summary	37
	References	38
<b>2</b>	<b>Raman Spectroscopy and Its Application in Atmospheric Research</b>	<b>41</b>
2.1	Basic Theories and Principles	42
2.1.1	Basic Theory of Light Scattering	42
2.1.2	Scattering Experiment	43
2.2	Main Types of Raman Spectroscopic Techniques	43
2.2.1	Interaction Between a Molecule and an Electromagnetic Field in Raman Spectroscopy	45
2.2.2	Raman Spectra	46
2.2.3	Intensities in Raman Spectra	51
2.2.4	Influence of Molecular Orientation and Symmetry in Raman Spectroscopy	52
2.2.5	Surface-Enhanced Raman Spectroscopy	54
2.2.6	Tip-Enhanced Raman Spectroscopy	55
2.2.7	Nonlinear Raman Spectroscopy	56
2.2.8	Stimulated Raman Scattering	57
2.2.9	The Hyper-Raman Effect	58
2.2.10	Stimulated Raman Gain and Anti-Raman Scattering	58
2.2.11	Coherent Anti-Stokes Raman Spectrum and Coherent Stokes Raman Spectrum	58
2.2.12	Comparison Between Raman Spectra and Infrared Spectra	59
2.3	Experimental Facility	60
2.3.1	Structural Overview and Basic Components of a Raman Spectrometer	60
2.3.1.1	Excitation Light Source	60
2.3.1.2	External Optical Path System	62
2.3.1.3	Monochromator, Rayleigh Scattering Optical Filter, and Michelson Interferometer	62
2.3.1.4	Detection and Recording System	63
2.3.2	Dispersive Spectrometers	66
2.3.3	Triple Subtractive Instrument	67
2.3.4	Rayleigh Line Filters	68
2.4	Applications of Raman Spectroscopy in Atmospheric Research	70
2.4.1	Qualitative and Quantitative Analysis	70

2.4.2	Application in Gas Detection	71
2.4.3	Application in the Detection of Pollutants and Microplastics	72
2.4.4	Application in the Detection of Nanoparticles	75
2.5	Summary	76
	References	77
<b>3</b>	<b>Ultraviolet-Visible Absorption Spectroscopy and Its Application in Atmospheric Research</b>	<b>79</b>
3.1	Overview	79
3.1.1	Classification by UV-vis Spectrophotometry	80
3.1.2	Selective Absorption of Light	80
3.2	Basic Principle of UV-vis Absorption Spectroscopy	81
3.2.1	Generation Mechanism of UV-vis Absorption Spectrum	81
3.2.2	Absorption Law and Factors Affecting the UV-vis Absorption Spectrum	82
3.2.2.1	Lambert Law	83
3.2.2.2	Beer Law	83
3.2.2.3	Beer–Lambert Law	83
3.2.2.4	Additivity of Absorbance	84
3.2.2.5	Deviation and Correction of the Beer–Lambert Law	84
3.2.2.6	Deviation Caused by the Non-monochromaticity of the Incident Light	84
3.2.2.7	Deviation Caused by the Solution Concentration	86
3.2.2.8	Deviation Caused by Chemical Factors	86
3.2.2.9	Chromophore and Auxochrome	87
3.2.2.10	Conjugation Effect	89
3.2.2.11	Solvent Effect	90
3.2.2.12	Stereoscopic Effect	91
3.2.2.13	pH Effect	92
3.3	Classification of UV-vis Spectrophotometers and Experimental Facility	92
3.3.1	Components of a UV-vis Spectrophotometer	92
3.3.1.1	Light Source	92
3.3.1.2	Monochromator	93
3.3.1.3	Absorption Cell	94
3.3.1.4	Detector	94
3.3.1.5	Record Display System	95
3.3.2	Classification of Spectrophotometers	95
3.3.2.1	Single-Beam UV-vis Spectrophotometer	96
3.3.2.2	Photodiode Array Spectrophotometer	96
3.3.2.3	Double-Beam UV-vis Spectrophotometer	97
3.3.2.4	Dual-Wavelength UV-vis Spectrophotometer	98
3.3.3	Quantitative Analysis with UV-vis Spectroscopy	99
3.3.3.1	Standard Curve Method	99
3.3.3.2	Standard Addition Method	99
3.3.3.3	Differential Spectrophotometry	99
3.3.3.4	Quantification of Multicomponent Systems	100
3.3.3.5	Multiplication Subtraction Method	100

3.3.3.6	Photometric Titration	101
3.3.3.7	Derivative Spectrophotometry	101
3.4	Applications of UV-vis Absorption Spectroscopy in Atmospheric Research	102
3.4.1	Application in Chemical Oxygen Demand Monitoring	102
3.4.2	Application in the Determination of Heavy Metals in Water	104
3.4.3	Application in the Determination of Nitrate Nitrogen in Water	104
3.4.4	Application in the Characterization of Atmospheric Brown Carbon	104
3.4.5	Application in the Analysis of Dissolved Organic Carbon	105
3.5	Summary	106
	References	107
<b>4</b>	<b>Fluorescence Spectroscopy and Its Application in Atmospheric Research</b>	<b>111</b>
4.1	Overview	111
4.2	Basic Principle of Molecular Fluorescence	112
4.2.1	Generation of Molecular Fluorescence	112
4.2.2	Fluorescence Spectrum	115
4.2.2.1	Fluorescence Excitation Spectrum	115
4.2.2.2	Fluorescence Emission Spectrum	115
4.2.2.3	Synchronous Fluorescence Spectrum	115
4.2.2.4	Three-Dimensional Fluorescence Spectrum	117
4.2.2.5	Single-Molecule Fluorescence Spectrum	117
4.2.2.6	Characteristics of Fluorescence Emission Spectrum	117
4.2.3	Fluorescence Parameters and Factors Affecting the Fluorescence Intensity	119
4.2.3.1	Fluorescence Parameters	119
4.2.3.2	Factors Affecting Fluorescence Intensity	120
4.2.4	EEM Deconvolution	122
4.3	Experimental Facility	123
4.3.1	Components of a Fluorescence Spectrophotometer	124
4.3.2	Ideal Fluorescence Spectrophotometer	126
4.4	Application of Fluorescence Spectroscopy in Atmospheric Research	127
4.4.1	Application in Quantitative Analysis	127
4.4.2	Application in the Analysis of Single-Component and Multicomponent Systems	128
4.4.3	Application in the Analysis of Aqueous-Phase Processes	129
4.4.4	Application in the Characterization of Continental Aerosol	134
4.4.5	Application in the Analysis of Matter Transfer in Marine Aerosol	136
4.4.6	Application in the Detection of PAHs	137
4.5	Summary	138
	References	139
<b>5</b>	<b>Optical Microscopy, Electron Microscopy, and Atomic Force Microscope – Application in Atmospheric Research</b>	<b>143</b>
5.1	Introduction	143
5.1.1	Basis of Microscopic Imaging	144
5.2	Classification and Working Principles of Microscopes	145

5.2.1	Confocal Laser Scanning Microscope	145
5.2.1.1	The Imaging Principle of CLSM	146
5.2.2	Transmission Electron Microscope	147
5.2.2.1	The Imaging Principle of TEM	147
5.2.3	Scanning Electron Microscope	149
5.2.3.1	Working Principle of SEM	150
5.2.4	Atomic Force Microscope	151
5.2.4.1	The Principle of AFM	152
5.3	Experimental Facility	153
5.3.1	CLSM Instrument and Sample Preparation	153
5.3.1.1	Sample Preparation	153
5.3.2	TEM Instrument and Sample Preparation	154
5.3.2.1	Sample Preparation in TEM Analysis	155
5.3.3	SEM Instrument and Sample Preparation	155
5.3.3.1	SEM Sample Preparation Techniques	158
5.3.4	AFM Instrument and Sample Preparation	159
5.3.4.1	Instrument and Working Mode	159
5.3.4.2	Sample Preparation	160
5.4	Application of Microscopic Techniques in Environmental Research	160
5.4.1	Application of CLSM in Environmental Bioassay	160
5.4.1.1	Applications in the Field of Biology and Nanotoxicology	160
5.4.1.2	Applications in Environmental Toxicology	161
5.4.2	Application of TEM in the Analysis of Single Particle Morphology	161
5.4.2.1	Applications on Particle Types and Their Mixing States	162
5.4.2.2	Applications on Microscopic Observation of Metal-Containing Particles	162
5.4.2.3	Application of SEM in the Analysis of the Morphology of Atmospheric Particulate Matter	163
5.4.3	Application of SEM in Aqueous-Phase Analysis	164
5.4.4	Application of SEM in the Characterization of Atmospheric Aerosol	165
5.4.5	Application of SEM in Soil	165
5.4.6	Application of AFM in Interface Interactions	166
5.4.6.1	Applications in Characterizing Interfacial Processes	166
5.4.6.2	Scanning Probe Modification Technique	167
5.5	Summary	168
	References	168
<b>6</b>	<b>Mass Spectrometry and Its Application in Atmospheric Research</b>	<b>171</b>
6.1	Introduction	171
6.1.1	Classification	172
6.2	Principles of Mass Spectrometers	172
6.2.1	Ion Source	173
6.2.1.1	ESI	173
6.2.1.2	EI	174
6.2.1.3	CI	175
6.2.1.4	MALDI	175

6.2.2	Mass Analyzer	176
6.2.2.1	Quadrupole Mass Analyzer	176
6.2.2.2	ToF Mass Analyzer	176
6.2.2.3	Magnetic Sector Mass Analyzer	178
6.2.2.4	Electrostatic Sector Mass Analyzer	178
6.2.2.5	Trapped-Ion (or Ion Trap) Mass Analyzers	179
6.2.3	Detectors	180
6.3	Experimental Facility	180
6.3.1	Inductively Coupled Plasma Mass Spectrometry	180
6.3.1.1	Sample Introduction System	180
6.3.1.2	Ion Source	181
6.3.1.3	Interface	181
6.3.1.4	Ion Focusing System	181
6.3.2	Accelerator Mass Spectrometry (AMS)	181
6.3.3	Aerosol Mass Spectrometry	182
6.3.4	Proton-Transfer Reaction Mass Spectrometry	182
6.3.5	Second Ion Mass Spectrometry	184
6.3.6	MALDI Time-of-Flight Mass Spectrometry	184
6.3.7	Combination of Mass Spectrometry Techniques with Other Separation Techniques	185
6.4	Applications of Mass Spectrometry in Atmospheric Research	187
6.4.1	Application in the Detection of Organic Gases	187
6.4.2	Application in Multi-elemental Analysis	187
6.4.2.1	Elemental Analysis	187
6.4.2.2	Metal Speciation	188
6.4.2.3	Analysis of Nanoparticles	189
6.4.3	Application in Aqueous-Phase and Soil Analysis	189
6.4.3.1	Analysis of Dissolved Organic Matter in Water	189
6.4.3.2	Analysis of Organic Aerosol Composition	189
6.4.3.3	Exploring the Formation and Degradation Mechanism of Complex Organic Pollutants	190
6.4.3.4	Detection of Pollutants in Water Environment	191
6.4.3.5	Detection of VOCs in Water and Soil	191
6.4.4	Application in Informative Maps of Sample Surfaces	192
6.5	Summary	192
	References	193
	<b>Index</b>	<b>197</b>