

REVIEWS IN MINERALOGY  
AND GEOCHEMISTRY

Volume 78                    2014

Spectroscopic Methods in  
Mineralogy and  
Materials Sciences

EDITORS

**Grant S. Henderson**

*University of Toronto  
Toronto, Canada*

**Daniel R. Neuville**

*IPGP-CNRS  
Paris, France*

**Robert T. Downs**

*University of Arizona  
Tucson, Arizona*

ON THE FRONT COVER:

The cover image shows a crystal of Fluorite, along with a ball and stick model of the structure overlain by the Raman spectrum. Courtesy of Joel Dyon, IPGP.

*Series Editor: Jodi J. Rosso*

MINERALOGICAL SOCIETY OF AMERICA  
GEOCHEMICAL SOCIETY

# *Spectroscopic Methods in Mineralogy and Materials Sciences*

78

*Reviews in Mineralogy and Geochemistry*

78

## TABLE OF CONTENTS

1

### **Modern X-ray Diffraction Methods in Mineralogy and Geosciences**

*Barbara Lavina, Przemyslaw Dera,  
Robert T. Downs*

INTRODUCTION .....	1
GENERAL ASPECTS .....	2
Brief introduction to X-ray diffraction theory .....	2
Ideal structures, real structures, liquids .....	5
Information obtained from X-ray diffraction experiments .....	6
X-ray: characteristics, sources, choice .....	7
X-RAY DIFFRACTION TECHNIQUES .....	10
Single crystal monochromatic diffraction (SXD) .....	10
Laue method .....	13
Powder diffraction .....	15
Peak and whole pattern fitting .....	21
The atomic pair distribution function technique (PDF) .....	25
ACKNOWLEDGMENTS .....	27
REFERENCES .....	27

2

### **Fundamentals of XAFS**

*Matthew Newville*

INTRODUCTION .....	33
X-RAY ABSORPTION AND FLUORESCENCE .....	35
A SIMPLE THEORETICAL DESCRIPTION OF XAFS .....	40
A rough explanation of the EXAFS equation .....	42
The EXAFS $\chi(E)$ is proportional to the amplitude of the scattered photoelectron at the absorbing atom .....	43
$\lambda(k)$ : The inelastic mean free path .....	44
$S_0^2$ : intrinsic losses .....	45
Multiple scattering of the photoelectron .....	46

Disorder terms and $g(R)$ .....	46
Discussion .....	48
<b>XAFS MEASUREMENTS: TRANSMISSION AND FLUORESCENCE.....</b>	<b>49</b>
Transmission XAFS measurements.....	51
Fluorescence and electron yield XAFS measurements .....	51
Self-absorption (or over-absorption) of fluorescence XAFS.....	54
Deadtime corrections for fluorescence XAFS.....	56
<b>XAFS DATA REDUCTION .....</b>	<b>57</b>
Pre-edge subtraction and normalization .....	58
Background subtraction .....	59
EXAFS Fourier transforms.....	62
<b>XAFS DATA MODELING .....</b>	<b>65</b>
Running and using FEFF for EXAFS calculations .....	65
First-shell fitting .....	66
Fit statistics and estimated uncertainties .....	67
Second-shell fitting.....	70
<b>REFERENCES .....</b>	<b>73</b>

### **3           X-ray Absorption Near-Edge Structure (XANES) Spectroscopy**

*Grant S. Henderson, Frank M.F. de Groot,  
Benjamin J.A. Moulton*

<b>PREFACE .....</b>	<b>75</b>
<b>INTRODUCTION .....</b>	<b>76</b>
Interaction of X-rays with matter .....	76
Binding energy .....	76
Single electron excitation approximation and selection rules .....	77
Calculations of XANES spectra .....	77
<b>EXPERIMENTAL ASPECTS OF XANES .....</b>	<b>78</b>
Doing a XANES experiment at a beamline.....	78
Data reduction .....	79
<b>XANES DETECTION MODES .....</b>	<b>80</b>
Transmission detection of XANES .....	80
Electron yield detection of XANES .....	80
Fluorescence yield detection of XANES.....	81
Partial Fluorescence Yield detection of XANES .....	81
Electron energy loss spectroscopy and X-ray Raman .....	81
XANES microscopy .....	82
<b>XANES ANALYSIS OF METAL K-EDGES .....</b>	<b>82</b>
Special energy positions of X-ray absorption edges .....	82
The pre-edge region.....	83
The edge region and peaks at higher energies in the XANES region .....	84
XANES analysis of metal L-edges.....	85
Multiplet analysis of L-edges .....	85
<b>ALITATIVE SPECTRAL ANALYSIS OF THE L-EDGES .....</b>	<b>86</b>
Energy shifts .....	86

Intensities of the <i>L</i> -edges.....	86
The branching ratio.....	86
Polarization dependence and XMCD .....	86
<b>XANES ANALYSIS OF LIGAND <i>K</i>-EDGES .....</b>	<b>86</b>
<b>APPLICATIONS OF XANES IN MINERALOGY AND GEOCHEMISTRY .....</b>	<b>86</b>
Transition metals: <i>K</i> -edges .....	86
Transition metals: <i>L</i> -edges.....	92
Silicon and aluminum <i>K</i> - and <i>L</i> -edges .....	94
Alkalais (Li, Na, K, Rb, Cs).....	100
Alkaline-Earths (Be, Ca, Mg, Sr, Ba).....	102
Ligand edges (C, O, B, S, P) .....	106
<b>SOME EXAMPLES OF STUDIES UTILIZING XANES .....</b>	<b>121</b>
Assessing trace element substitution in minerals: Cerium speciation ( $\text{Ce}^{3+}/\text{Ce}^{4+}$ ) in Ti-rich minerals .....	121
Assessing changes in oxidation state of Nb and Ta with varying $f_{\text{o}}$ at 1.5 GPa as a possible explanation for the negative Nb/Ta anomaly or “arc signature” of melts .....	122
<i>In situ</i> high-temperature determination of Cr oxidation state in basaltic melts: A novel XANES furnace design .....	123
The behavior of Br in $\text{CO}_2$ -bearing fluids in low-temperature geological settings: A Br <i>K</i> -edge study on synthetic fluid inclusions .....	124
<b>ACKNOWLEDGMENTS.....</b>	<b>125</b>
<b>REFERENCES .....</b>	<b>125</b>

## 4

### Probing of Pressure-Induced Bonding Transitions in Crystalline and Amorphous Earth Materials: Insights from X-ray Raman Scattering at High Pressure

*Sung Keun Lee, Peter J. Eng, Ho-kwang Mao*

<b>INTRODUCTION .....</b>	<b>139</b>
<b>BRIEF REMARKS ON THEORETICAL BACKGROUNDS AND</b>	
<b>XRS EXPERIMENTS AT HIGH PRESSURE.....</b>	<b>141</b>
Brief theoretical backgrounds .....	141
Comparison with other core-electron excitation spectroscopy and traditional experimental probes at high pressure.....	143
XRS experiments .....	146
<b>PRESSURE-INDUCED STRUCTURAL CHANGES IN CRYSTALLINE AND</b>	
<b>AMORPHOUS EARTH MATERIALS: INSIGHTS FROM X-RAY RAMAN</b>	
<b>SCATTERING .....</b>	<b>147</b>
Application of <i>K</i> -edge XRS to materials under high pressure .....	148
Insights from quantum chemical calculations .....	161
<b>REMAINING CHALLENGES AND OUTLOOK: APPLICATIONS OF NEW <i>K</i>-, <i>L</i>-,</b>	
<b><i>M</i>-EDGE XRS, XRS WITH MOMENTUM TRANSFER, <i>IN SITU</i> HIGH-</b>	
<b>TEMPERATURE AND HIGH-PRESSURE XRS STUDY FOR</b>	
<b>MULTI-COMPONENTS GLASSES .....</b>	<b>164</b>

**6****Analytical Transmission Electron Microscopy***Rik Brydson, Andy Brown,  
Liane G. Benning, Ken Livi*

INTRODUCTION .....	219
INTRODUCTION TO ANALYTICAL	
TRANSMISSION ELECTRON MICROSCOPY (TEM) .....	219
Basic design of transmission electron microscopes (TEM) .....	219
Interactions between the electron beam and the specimen.....	222
The specimen.....	227
Recent developments in analytical TEM.....	228
ELEMENTAL QUANTIFICATION – EDX AND EELS .....	229
EDX.....	229
Example of the practical application of EDX: clay minerals.....	232
EELS .....	236
EEL SPECTROMETRY .....	239
EEL low-loss spectroscopy .....	239
EELS core-loss fine structure .....	242
EDX AND EELS IMAGING.....	245
EXAMPLE OF THE PRACTICAL APPLICATION OF EELS:	
EELS OF MANGANESE IN MINERALS AND ENVIRONMENTAL HEALTH .....	247
Introduction .....	247
Analytical considerations for EELS determination of manganese valence.....	247
Near edge structure of Mn $M_{2,3}$ -edge.....	248
Near edge structure of Mn $L_{2,3}$ -edge .....	248
Quantification of valence by $L_{2,3}$ -ELNES .....	249
Beam damage .....	251
Applications.....	252
GENERAL APPLICATION OF EELS, SAED AND EDX.....	253
Use of (S)TEM to assess transport and retardation mechanisms of	
trace metal contaminants .....	253
Developments in TEM specimen preparation .....	255
Developments in analyzing poorly crystalline, beam sensitive materials .....	261
CONCLUSIONS.....	263
REFERENCES .....	265

**7****High Resolution Core- and Valence-Level XPS  
Studies of the Properties (Structural, Chemical  
and Bonding) of Silicate Minerals and Glasses***H.W. Nesbitt, G.M. Bancroft*

INTRODUCTION .....	271
XPS studies of silicates .....	271
Technical advances .....	272
Focus of the review .....	273

FUNDAMENTAL PRINCIPLES OF XPS .....	273
Photoionization and analysis depths.....	273
Non-conductors and sample charging .....	275
Photopeak assignments and intensities.....	276
Depth of analysis .....	277
Linewidths .....	277
Si 2p AND O 1s LINETHICKNESSES: EXPERIMENT AND THEORY .....	282
Evidence for minimum linewidths for silicates .....	282
Si 2p vibrational contributions.....	287
O 1s vibrational contributions .....	289
Effects of phonon broadening .....	289
Experimental and fitting considerations .....	290
Chemical shifts in silicates .....	291
Surface core-level shifts in silicates .....	292
CORE LEVEL BULK APPLICATIONS.....	294
Crystalline silicates.....	294
Silicate glasses: general aspects .....	297
Silicate glasses: O 1s spectra, and NBO and BO linewidths ..	303
Silicate glasses: uncertainties in BO% from O 1s spectra.....	305
Determination of free oxide O <sup>2-</sup> and its importance .....	309
CORE LEVEL SURFACE STUDIES OF SILICATES .....	312
Adsorption on silicate and oxide surfaces .....	312
Leaching of silicates .....	314
VALENCE LEVEL BULK APPLICATIONS .....	317
Nature of the contributions to the valence band .....	317
ACKNOWLEDGEMENTS .....	323
REFERENCES .....	323

# 8 Analysis of Mineral Surfaces by Atomic Force Microscopy

Jacques Jupille

INTRODUCTION .....	331
EXPERIMENTAL METHODS .....	332
AFM set-ups .....	333
Experimental conditions .....	337
DISSOLUTION, PRECIPITATION AND GROWTH .....	338
Determination of reaction rates at crystal surfaces from step velocities .....	339
Size and shape of clay minerals .....	343
Limits of the AFM observation .....	343
AFM rates versus bulk rates .....	346
FORCE MEASUREMENTS .....	347
Hydration forces .....	348
Determination of the point of zero charge (PZC) .....	349
Kelvin Force Probe Microscopy (KPFM) .....	351
ATOMICALLY RESOLVED SURFACE STRUCTURES .....	354
Structures in contact mode .....	354

Surface structures analyzed by AFM in dynamic mode.....	355
CONCLUSIONS.....	360
ACKNOWLEDGMENTS.....	362
REFERENCES .....	363

## 9

## Optical Spectroscopy

*George R. Rossman*

INTRODUCTION .....	371
GENERAL CONCEPTS .....	372
UNITS .....	375
Wavelength and energy.....	375
Intensities.....	375
THE EXPERIMENT – SAMPLE AND EQUIPMENT CONSIDERATIONS .....	376
Types of spectrometers .....	376
NOMENCLATURE OF THE DIFFERENT SPECTRA.....	377
INTENSITIES AND SELECTION RULES.....	377
The Laporte selection rule .....	377
Spin-forbidden transitions .....	378
QUANTITATIVE CONCENTRATIONS FROM OPTICAL SPECTRA .....	378
IDENTIFICATION OF THE OXIDATION STATES OF CATIONS.....	379
A GALLERY OF SPECTRA OF METAL IONS COMMONLY RESPONSIBLE FOR THE OPTICAL SPECTRA OF MINERALS .....	379
Titanium.....	379
Vanadium.....	379
Chromium.....	380
Manganese.....	381
Iron .....	382
Cobalt .....	384
Nickel .....	384
Copper .....	384
Rare Earth Elements and Uranium .....	386
INTERVALENCE CHARGE TRANSFER .....	388
Intervalence charge transfer in low-symmetry crystals .....	388
BAND GAPS .....	390
RADIATION-INDUCED COLOR CENTERS .....	390
VIBRATIONAL OVERTONES AND COMBINATIONS .....	392
ARTIFACTS .....	392
Interference fringes.....	392
Wood's grating anomaly .....	393
TEMPERATURE AND PRESSURE DEPENDENCE .....	393
ABSORPTION BAND INTENSIFICATION .....	394
COMPILEATIONS OF MINERAL OPTICAL SPECTRAL DATA .....	395
CONCLUDING THOUGHTS.....	396
REFERENCES .....	397

# 10

## Spectroscopy from Space

*Roger N. Clark, Gregg A Swayze,  
Robert Carlson,  
Will Grundy, Keith Noll*

ABSTRACT .....	399
INTRODUCTION .....	400
DETECTION OF MINERALS AND THEIR SPECTRAL PROPERTIES .....	402
MINERAL AND FROZEN VOLATILES SPECTRAL SIGNATURES .....	406
H <sub>2</sub> O (ice) .....	406
SO <sub>2</sub> ice .....	406
Nitrogen ice (N <sub>2</sub> ) .....	406
Hydrocarbons and other ices .....	407
Methane ice (CH <sub>4</sub> ) .....	408
MINERALS AND COMPOUNDS IN THE SOLAR SYSTEM	
DETECTED WITH SPECTROSCOPY .....	408
Terrestrial planets .....	408
Asteroids and comets .....	415
Jupiter system .....	416
Saturn system .....	422
Uranus system .....	427
The Neptune system and beyond .....	428
SUMMARY .....	430
ACKNOWLEDGMENTS .....	431
REFERENCES .....	432

# 11

## SR-FTIR Microscopy and FTIR Imaging in the Earth Sciences

*Giancarlo Della Ventura, Augusto Marcelli,  
Fabio Bellatreccia*

INTRODUCTION .....	447
FTIR MICROSCOPY AND IMAGING TECHNIQUES .....	449
SYNCHROTRON-RADIATION FTIR SPECTROSCOPY IN MINERAL SCIENCES .....	453
Introduction .....	453
Applications in mineral sciences .....	455
FTIR IMAGING .....	464
Introduction .....	464
The distribution of H and C in minerals .....	465
Imaging of inclusions in minerals .....	468
FTIR imaging of dynamic processes .....	472
CONCLUSIONS .....	474
ACKNOWLEDGMENTS .....	474
REFERENCES .....	474

## 12

### Carryover of Sampling Errors and Other Problems in Far-Infrared to Far-Ultraviolet Spectra to Associated Applications

*Anne M. Hofmeister*

INTRODUCTION AND PURPOSE .....	481
EXPERIMENTAL METHODS .....	482
EXTRACTION OF SPECTRAL PROPERTIES FROM LABORATORY MEASUREMENTS .....	482
Ideal interactions of light with perfect, single crystals .....	482
Limitations of real measurements .....	488
Errors originating in instrumentation .....	488
Concerns in obtaining quantitative spectra from powders .....	489
Concerns regarding thin-film spectra obtained in the diamond anvil cell .....	490
Propagation of errors .....	491
Errors arising during data processing and extracting spectral parameters .....	491
Emission spectra .....	492
EXAMPLES OF SAMPLING PROBLEMS IN THE LABORATORY .....	497
Overly large grains in absorbing regions .....	497
Too small of crystals for the near-IR transparent region .....	497
Information on <i>d-d</i> transitions in the UV may pertain to band assignments .....	499
REMOTELY SENSED SPECTRA AND OBSERVATIONAL DATA .....	500
Ascertaining surface mineralogy of large bodies .....	501
Ascertaining the mineralogy of the 10 $\mu\text{m}$ feature in observational data .....	503
DEDUCING DIFFUSIVE RADIATIVE TRANSFER FROM SPECTRA .....	504
CONCLUSIONS .....	505
ACKNOWLEDGMENTS .....	505
REFERENCES .....	506

## 13

### Advances in Raman Spectroscopy Applied to Earth and Material Sciences

*Daniel R. Neuville, Dominique de Ligny,  
Grant S. Henderson*

BRIEF HISTORICAL PERSPECTIVE AND SIMPLE THEORY .....	509
Quantum mechanical theory .....	512
INSTRUMENTATION .....	513
Excitation line .....	513
Notch filters, optical spectrometer or grating .....	514
Optics, monochromators, detectors .....	515
Different manufacturers and instrument types .....	515
Confocal system .....	516
Data acquisition and reduction .....	517
Baseline correction and normalization .....	521

OTHER TYPES OF RAMAN SPECTROSCOPY .....	521
Hyper-Raman scattering (HRS) .....	521
Surface Enhanced Raman Scattering (SERS) .....	522
APPLICATIONS.....	523
Crystalline spectra .....	523
Amorphous materials.....	524
Silicate glasses.....	524
Aluminosilicate glasses .....	528
Borosilicate glasses .....	529
Titanosilicate glasses .....	530
Iron silicate glasses.....	530
Volatiles in glasses.....	531
Fluid inclusions .....	532
<i>In situ</i> Raman spectroscopy .....	533
CONCLUSIONS.....	536
REFERENCES .....	536

## **14 Brillouin Scattering and its Application in Geosciences**

*Sergio Speziale, Hauke Marquardt,  
Thomas S. Duffy*

INTRODUCTION .....	543
HISTORICAL BACKGROUND .....	544
PHYSICAL PRINCIPLES OF THE BRILLOUIN EFFECT .....	545
Brillouin scattering in fluids .....	547
Brillouin scattering in solids.....	549
BRILLOUIN SPECTROSCOPY .....	551
Basic experimental setup .....	551
Light source .....	552
Scattering geometry .....	552
The spectrometer .....	553
Detectors.....	556
Measurements on transparent materials .....	557
Measurements of surface Brillouin scattering on opaque materials and thin films .....	558
Brillouin scattering at ambient or near-ambient conditions .....	562
Determination of Pockel's coefficients .....	566
Brillouin scattering at extreme conditions.....	566
ANALYSIS OF THE BRILLOUIN SPECTRA AND RECOVERY OF THE ELASTIC TENSOR.....	571
Linear elasticity of anisotropic solids.....	572
Determining the elastic constants.....	573
What is the information from Brillouin scattering that is relevant to Earth science? .....	576
APPLICATIONS OF BRILLOUIN SPECTROSCOPY IN GEOSCIENCES .....	577
Experimental techniques to determine the anisotropic elasticity of Earth materials .....	577

Lithosphere and upper mantle .....	580
Transition zone .....	581
Lower mantle .....	582
FRONTIERS .....	583
Elasticity under deep mantle conditions .....	583
Combining Brillouin scattering with other techniques to characterize elastic anisotropy at high pressures .....	587
Surface Brillouin scattering at extreme conditions .....	587
ACKNOWLEDGMENTS .....	588
REFERENCES .....	588

## 15

## NMR Spectroscopy of Inorganic Earth Materials

*Jonathan F. Stebbins, Xianyu Xue*

INTRODUCTION .....	605
THE BASICS .....	606
Nuclear spins, NMR frequencies and signal intensities .....	606
How NMR experiments are done .....	610
Anisotropy, motional averaging, and magic-angle spinning .....	611
CHEMICAL SHIFT VS. STRUCTURE .....	612
QUADRUPOLAR INTERACTIONS AND STRUCTURE .....	615
MAGNETIC DIPOLAR INTERACTIONS AND INDIRECT	
SPIN-SPIN COUPLINGS .....	619
MORE ADVANCED NMR METHODS .....	621
FIRST-PRINCIPLES CALCULATIONS OF NMR PARAMETERS .....	624
NUCLEAR SPIN RELAXATION .....	624
APPLICATIONS TO CRYSTALLINE SILICATES, OXIDES AND	
OTHER INORGANIC MATERIALS .....	625
Structural order/disorder in minerals .....	625
<sup>1</sup> H NMR in minerals .....	629
NMR crystallography .....	631
APPLICATIONS TO GLASSES, MELTS AND OTHER AMORPHOUS MATERIALS ..	631
Volatile-free silicate glasses .....	631
Volatile-containing glasses .....	635
Other amorphous materials .....	636
Silicate and oxide melts .....	637
DYNAMICS, KINETICS AND TRANSITIONS .....	638
Phase transitions .....	638
Interactions of water with minerals and glasses .....	638
Aqueous solutions: ambient to elevated pressures .....	639
MINERALS CONTAINING ABUNDANT UNPAIRED ELECTRON SPINS .....	640
ACKNOWLEDGMENTS .....	642
REFERENCES .....	642

# 16

## Electron Paramagnetic Resonance Spectroscopy: Basic Principles, Experimental Techniques and Applications to Earth and Planetary Sciences

*Yuanming Pan, Mark J. Nilges*

INTRODUCTION .....	655
BASIC PRINCIPLES AND SPIN HAMILTONIAN .....	656
Electron resonance condition and EPR spectra .....	656
Spin Hamiltonian .....	657
GUIDES TO EPR EXPERIMENTS AND SPECTRAL ANALYSES .....	662
Samples and techniques for generating paramagnetic species .....	662
Continuous-wave (CW) EPR .....	663
Pulse ESEEM and ENDOR .....	667
<i>Ab initio</i> calculations of EPR parameters .....	672
APPLICATIONS TO EARTH AND PLANETARY SCIENCES .....	673
EPR as a structural probe of point defects in minerals .....	673
<i>In situ</i> high-temperature and high-pressure EPR experiments .....	675
Optically detected magnetic resonance (ODMR) and mineral coloration .....	680
EPR as structural probe for other Earth and planetary materials .....	680
Quantitative EPR analysis .....	682
ACKNOWLEDGMENTS .....	684
REFERENCES .....	684

# 17

## Theoretical Approaches to Structure and Spectroscopy of Earth Materials

*Sandro Jahn, Piotr M. Kowalski*

INTRODUCTION .....	691
THEORETICAL FRAMEWORK .....	692
Quantum-chemical methods .....	693
Density Functional Theory (DFT) .....	696
Excitation methods .....	702
Classical force field methods .....	705
Molecular dynamics .....	707
STRUCTURE DETERMINATION AND OPTIMIZATION .....	708
VIBRATIONAL SPECTRA .....	712
Lattice dynamics in the harmonic approximation .....	713
Atomic dynamics via time correlation functions .....	714
Infrared absorption spectroscopy .....	717
Raman spectra .....	719
ELECTRONIC EXCITATION SPECTRA .....	721
UV-vis .....	721
XAFS and XRS .....	723
EELS and ELNES .....	726
XPS .....	727

SPECTROSCOPY RELATED TO NUCLEAR EXCITATIONS .....	728
NMR .....	728
Mössbauer spectroscopy .....	731
CONCLUDING REMARKS .....	731
ACKNOWLEDGMENTS .....	732
REFERENCES .....	732

## 18

### High-pressure Apparatus Integrated with Synchrotron Radiation

*Guoyin Shen, Yanbin Wang*

INTRODUCTION .....	745
SYNCHROTRON TECHNIQUES APPLICABLE TO HIGH-PRESSURE RESEARCH .....	746
Synchrotron radiation .....	746
High-pressure synchrotron techniques .....	748
HIGH PRESSURE TECHNIQUES INTEGRATED WITH SYNCHROTRON RADIATION .....	757
The large volume press (LVP) .....	757
Diamond anvil cell techniques .....	763
Dynamic shockwave techniques .....	766
A BRIEF OUTLOOK .....	767
Expanding $P$ - $T$ range .....	767
New HP synchrotron techniques .....	767
ACKNOWLEDGMENTS .....	768
REFERENCES .....	768

## 19

### *In situ* High-Temperature Experiments

*Daniel R. Neuville, Louis Hennet,  
Pierre Florian, Dominique de Ligny*

PREFACE .....	779
INTRODUCTION .....	779
LEVITATION TECHNIQUES .....	780
Introduction .....	780
Acoustic levitation .....	781
Electromagnetic levitation .....	781
Electrostatic levitation .....	781
Aerodynamics levitation .....	782
Experimental techniques .....	784
APPLICATIONS OF AERODYNAMICS LEVITATION .....	784
NMR experiments .....	784
X-ray absorption spectroscopy (XAS) .....	786
SAXS and SANS .....	787
X-ray and neutron diffraction .....	787

---

*Spectroscopic Methods – Table of Contents*

---

WIRE OR PLATE HEATING SYSTEM.....	788
Description, temperature and atmosphere control.....	788
Raman spectroscopy.....	790
X-ray diffraction.....	791
X-ray absorption.....	794
ADVANTAGES, DIFFERENCES AND CONCLUSIONS.....	795
ACKNOWLEDGMENTS.....	797
REFERENCES .....	797