

CONTENTS

PREFACE	xvii
CUMULATIVE LISTING OF VOLUMES IN SERIES	xix
CHAPTER INTRODUCTION TO PIXE	
<i>Sven A. E. Johansson</i>	
1.1. A Brief History	
1.2. Basic Principles	7
References	7
CHAPTER 2 INSTRUMENTATION, FUNDAMENTALS, AND QUANTIFICATION	19
<i>John L. Campbell</i>	
2.1. Instrumentation	19
2.1.1. Beam Preparation	19
2.1.2. Instrumentation of Specimen Chamber	24
2.1.3. Measurement of Beam Current and Integrated Charge	27
2.2. Specimens	29
2.3. X-Ray Production Processes	33
2.3.1. Characteristic X-rays	33
2.3.2. Continuous Background	35
2.3.3. Electron Bremsstrahlung	36
2.3.4. Gamma-Ray Background	40
2.4. X-Ray Spectroscopy	43
2.4.1. Choice of Spectrometer	43
2.4.2. Si (Li) Detector Calibration	44
2.4.3. Detector Lineshape and Escape Peaks	44
2.4.4. Pile-up Distortion of Spectrum	49

2.4.5. Detection Efficiency	49
2.4.6. X-Ray Absorbers	51
2.4.7. Computer Modelling of PIXE Spectra	55
2.5. Quantitative Analysis: Standardization	55
2.5.1. Relationship Between X-ray Intensities and Concentrations	55
2.5.2. Analysis of Thin Specimens: Thin-Target Sensitivity Curves	58
2.5.3. Analysis of Major and Minor Elements in Thick Specimens	61
2.5.4. Thick-Target Sensitivity Curves	63
2.5.5. Analysis of Trace Elements in Thick Specimens	65
2.5.6. Trace-Element Analysis in Specimens of Intermediate Thickness	66
2.5.7. Film Thickness Measurement and Analysis of Multiple-Layer Specimens	68
2.5.8. Data Base and Its Accuracy	70
2.6. Extraction of X-Ray Intensities from PIXE Spectra	74
2.6.1. Least-Squares Fitting and Model X-ray Spectrum	74
2.6.2. Continuous Background	76
2.6.3. Weighting of Differences	79
2.6.4. Dynamic Analysis Method	79
2.6.5. Software Packages	80
2.7. Accuracy of PIXE Analysis	81
2.8. Limits of Detection	89
2.9. Projectiles Other Than Protons	92
References	94
CHAPTER 3 THE HIGH-ENERGY ION MICROPROBE	101
<i>Frank Watt and Geoff W. Grime</i>	
3.1. Introduction	101
3.2. High-Energy Ion Microbeam Techniques	103
3.2.1. Particle-Induced X-Ray Emission	104
3.2.2. Rutherford Backscattering Spectrometry	104

3.2.3. Nuclear Reaction Analysis	104
3.2.4. Scanning Transmission Ion Microscopy	108
3.2.5. Ion Microtomography	109
3.2.6. Ionoluminescence	110
3.2.7. Secondary Electron Imaging	110
3.3. Microbeam Technology	111
3.3.1. Probe-Forming Systems	111
3.3.2. Target Chambers and Detectors	117
3.3.3. Data Acquisition and Analysis	122
3.3.4. Practical Hints on How to Achieve Small Spot Sizes	125
3.3.4.1. Beam Broadening Due to Lens Aberrations	126
3.3.4.2. Beam Broadening Due to External Sources	128
3.3.5. System Performance	133
3.4. Microbeam Applications	133
3.4.1. Biomedicine	134
3.4.2. Environmental Research	145
3.4.3. Materials Science	151
3.4.4. Art and Archaeology	153
3.4.5. Earth Sciences	156
3.5. Concluding Remarks	160
References	161

CHAPTER 4 BIOLOGICAL AND MEDICAL APPLICATIONS 167

Klas G. Malmqvist

4.1. Introduction	167
4.1.1. Biomedicine	168
4.2. Sampling	170
4.2.1. Sample Size Effects	172
4.3. Sample Preparation	172
4.3.1. Macro-PIXE	172
4.3.1.1. Drying	174
4.3.1.2. Elimination of Organic Matrix	175

4.3.1.3. Target Preparation	176
4.3.1.4. Special Sample Preparation Techniques	177
4.3.2. Micro-PIXE	179
4.3.2.1. Cryopreparation	180
4.4. Irradiation of Specimens	180
4.5. Combination with Other Methods	183
4.6. Evaluation of Data	185
4.7. Applications	186
4.7.1. Macro-PIXE	186
4.7.1.1. Medicine	187
4.7.1.2. Zoology	210
4.7.1.3. Botany	211
4.7.1.4. Environment	212
4.7.2. Micro-PIXE	214
4.7.2.1. Medicine	214
4.7.2.2. Zoology	225
4.7.2.3. Botany	226
4.7.2.4. Limnology	228
4.8. Concluding Remarks	228
References	230
CHAPTER 5 COMPOSITIONAL ANALYSIS OF ATMOSPHERIC AEROSOLS	237
<i>Thomas A. Cahill</i>	
5.1. Introduction	237
5.2. Nature of Atmospheric Aerosols	239
5.3. Early Efforts in PIXE Analysis of Aerosols	243
5.4. Collection of Atmospheric Aerosols	245
5.4.1. Settling or Dry Deposition	246
5.4.2. Filtration	246
5.4.3. Optimizing Aerosol Sampling Protocols	249
5.4.4. Impaction	251
5.5. PIXE Analysis of Atmospheric Aerosols	254
5.5.1. PIXE Analysis Matched to Aerosol Samples	255

5.5.2. Interpretation of PIXE Aerosol Data	260
5.5.3. Quality Assurance of PIXE Data	263
5.6. The Essential Transformation: PIXE Laboratory Doing Aerosols versus Aerosol Laboratory Doing PIXE	
5.6.1. Complementary Analytical Methods to PIXE	266
5.6.1.1. Mass	266
5.6.1.2. Forward Alpha-Scattering Technique	267
5.6.1.3. Proton Elastic Scattering Analysis	268
5.6.2. Other Complementary Techniques	273
5.7. Atmospheric Optics, Visibility, and Global Climate	
5.7.1. Conceptual Framework for Visibility Research	275
5.7.2. Sampling and Analysis of Causal Aerosols	
5.7.3. Sampling and Analysis of Tracer Aerosols	278
5.7.4. IMPROVE Protocol	279
5.8. Future Possibilities	301
5.8.1. PIXE and Highly Size Resolved Samples	301
5.8.2. PIXE and Portable Samplers	304
5.8.3. PIXE and Gas Analysis	306
5.8.4. PIXE Microprobe and Aerosol Research	307
5.8.5. PIXE and Global Climate	307
References	308
CHAPTER 6 APPLICATIONS IN EARTH SCIENCES	313
<i>John L. Campbell</i>	
6.1. Introduction	313
6.2. Sampling of Geological Material	314
6.2.1. Bulk Material: Macro-PIXE Analysis	314

6.2.2. Individual Grains and Crystallites: Micro-PIXE Analysis	
6.3. Practical Aspects of Analysis	317
6.3.1. Specimens and Specimen Chamber	317
6.3.2. Dynamic Range of PIXE Spectra	319
6.3.3. Role of Matrix in Trace-Element Analysis	
6.3.4. Limits of Detection: Precision and Accuracy	326
6.4. Applications	329
6.4.1. Overview	329
6.4.2. Extraterrestrial Material	330
6.4.3. Mineralogy and Petrology of Massive Sulfide Ore Deposites	337
6.4.4. Igneous Petrology and Mineralogy	343
6.4.5. Chemical Zoning Studies	349
6.4.6. Fluid Inclusions	354
6.4.7. Various Applications	355
6.5. Ancillary Techniques	360
References	362
CHAPTER 7 APPLICATIONS IN ART AND ARCHAEOLOGY	
<i>Klas G. Malmqvist</i>	
7.1. Introduction	367
7.2. General Analytical Problems	370
7.2.1. Material Properties	370
7.2.2. External Beam	372
7.2.3. Microbeams	373
7.3. Applications	375
7.3.1. Stone Material and Gem Stones	376
7.3.1.1. Gem Stones	376
7.3.1.2. Obsidians	377
7.3.1.3. Surface Characterization	378
7.3.2. Pottery and Related Materials	381
7.3.3. Glass	384

7.3.4. Metals	389
7.3.4.1. Bronze	389
7.3.4.2. Copper and Copper Alloys	392
7.3.4.3. Tin	394
7.3.4.4. Iron	394
7.3.4.5. Noble Metals	395
7.3.5. Osteology	398
7.3.6. "Paperlike" Materials	401
7.3.6.1. Experimental Arrangement	401
7.3.6.2. Inks and Printing Techniques	403
7.3.6.3. Letter Identification	405
7.3.6.4. Stamps	406
7.3.7. Pigments and Paintings	407
7.4. Conclusions	412
References	412
CHAPTER 8 COMPARISON WITH OTHER METHODS: FUTURE PROSPECTS	419
<i>Sven A. E. Johansson and John L. Campbell</i>	
References	433
INDEX	435