

CONTENTS

PART ONE. INSTRUMENTATION

1. Introduction: Atoms, Molecules, Ions, and Isotopes	3
Mass Spectrometry in Industrial Research	3
Early Concepts and Experiments	4
Radioactivity and the Isotopes of Lead	5
Ions and Isotopes of Neon	7
Aston's Mass Spectrograph	7
The Mass Scale	8
The Discovery of Deuterium	10
Isotopic Ratio Measurements: 1930–1940	10
World War II to 1960	11
Contemporary Developments	13
2. Ion Sources	15
Electron Bombardment	16
Chemical Ionization	19
Surface Ionization	21
Surface Ionization-Diffusion	24
The Vacuum Spark	26
Photoionization and Resonance Ionization	28
Inductively Coupled Plasmas	30
Laser Microprobe	31
Ion Bombardment	33
Fast Atom Bombardment	36
Californium-252 Plasma Desorption	38
Field Ionization and Desorption	39
Pyrolysis	42

Miscellaneous Sources	43
⁶³ Ni Beta Emission	43
Microwave Discharge	43
Electrohydrodynamic	44
Collision-Induced Dissociation	44
The Isotopic Dilution Method	45
3. Types of Spectrometers	51
Single Magnetic Analyzers	51
The 180° Sector	51
The 60° Sector	56
The 90° Sector	57
Electrostatic Analyzers	59
Double Focusing Spectrometers	61
Quadrupole Mass Filters	66
Time-of-Flight	70
Fourier Transform Ion Cyclotron Resonance	73
Ion Microprobe/Microscope Analyzers	79
Laser Microprobe Instrumentation	82
4. Tandem Systems and Special Types	89
Tandem Magnetic Analyzers	89
Inhomogeneous Field Magnets	92
The 255° Sector	92
Multistage Systems	94
Reverse Geometry and Multitrajectory Instruments	96
Tandem Double Focusing and Hybrid Systems	99
Tandem Quadrupoles	105
Static Gas Analyzers	107
Atmospheric Pressure Analyzers	108
Ion Scattering Spectrometry	110
Photoelectron-Photoion Coincidence Spectrometers	113
Resonance Ionization Mass Spectrometry	114
Accelerator-Spectrometer Systems	115
5. Detection of Ion Beams	120
Single and Multiple Faraday Collectors	120
Ion-Sensitive Emulsions	122

Electron Multipliers	125
Electrostatic Focusing	125
Channel Electron Multipliers	127
Magnetic	129
Scintillation/Photomultiplier Detector	129
Ion-to-Electron Converters	130
Counting Rate Losses	133
“Zero” Background Ion Detection	134
P-N Junctions	135
Microchannel Plates	138
Position-Sensitive Detectors	142
Photodiode Arrays and Charge-Coupled Devices	144
Ion Imaging with MCP/Phosphor/CCD Combinations	146
MCP/CCD-Hybrid Ion Detector	148
Detection of Neutral Beams	150
6. Computer-Aided Data Processing	154
Data Acquisition	161
Data Enhancement	172
Deconvolution	179
Data Reduction	185
Database Search Methods	188
Quantitative Analysis	193
7. Chromatography/Mass Spectrometry	202
Gas-Liquid Chromatography/Mass Spectrometry	202
Measuring the Chromatographic Signal	204
GC Measurements with the Mass Spectrometer	205
Measurements with Linked GC and MS Detectors	206
Total Ion Current Monitoring	210
Selective Ion Monitoring	211
Selective Monitoring of Multiple Ions	212
The GC/MS Interface	214
Jet Separators	215
Effusion Separators	216
Membrane Separators	216
Open-Split Coupling	219
Direct Coupling of Capillary Columns	219
GC/GC/MS Coupling	220

Liquid Chromatography/Mass Spectrometry	221
<i>HPLC Detectors</i>	222
The HPLC/MS Interface	222
<i>Manual Collection and Injection</i>	223
<i>Moving Belt Interfaces</i>	223
<i>Atmospheric Pressure Ionization</i>	224
<i>Direct Liquid Introduction</i>	225
<i>Thermospray</i>	225
<i>Supercritical Fluid Chromatography/Mass Spectrometry</i>	230

PART TWO. ENGINEERING AND THE PHYSICAL SCIENCES

8. Geochemistry and Geochronology	239
“Cosmic” Abundances of the Elements	239
Terrestrial Abundances and Isotopic Composition	241
Naturally Occurring Radionuclides	243
Trace Isotope Detection by Accelerator-Mass Spectrometry	245
Ion-Laser Microprobe Assay of Crystals	248
Isotopic Ratios of the Noble Gases	250
Geochemistry of Carbon and Sulfur	253
Geological Age from Uranium and Lead	256
The Rhenium-Osmium Chronometer	260
$^{40}\text{Ar}/^{39}\text{Ar}$ Dating of Minerals	262
Rubidium-Strontium Dating	264
Samarium-Neodymium and Lutetium-Hafnium Systematics	267
^{10}Be in Marine Geochemistry	269
The Platinum Group Elements	271
Analyses of Meteorites	272
The Allende Meteorite	274
$^{18}\text{O}/^{16}\text{O}$ Ratios and Paleotemperatures	277
Thermal Histories and Plate Tectonics	280
Petroleum Geology	284
9. Atmospheric, Lunar, and Planetary Measurements	290
Structure of the Earth’s Atmosphere	291
Balloons and Sounding Rockets	295

Satellites	302
Lunar Exploration	306
Planetary Exploration	308
<i>Mars</i>	309
<i>Venus</i>	312
<i>Jupiter</i>	321
Comets	323
10. Metals, Glasses, Ceramics, and Composites	335
Analysis of Metals and Alloys	335
Diffusion in Metals	337
Hydrogen Diffusion in Aluminum	342
Detection of Phase Change	343
Laser Surface Alloying	344
Ion Implantation of Metals	345
<i>Corrosion Resistance</i>	347
<i>Reduction in Wear Rates</i>	348
Ion Beam Depth Profiling	350
Grain Boundaries and Microstructure	352
Multielement Thin Films and Ion Beam Synthesis	355
Catalysts	359
Silicate Glasses	362
Metallic Glasses	364
Ceramics	366
Composites	369
Ion Emission Accompanying the Fracture of Polymers	374
11. Electronic Materials and Devices	380
Semiconductors and Impurity Analysis	380
Impurity Profiling by SIMS	383
Ion Implantation of Devices	389
Ion Beam Milling and Etching	392
Thin Films and Semiconductor Interfaces	396
Diffusion Measurements	399
Very Large Scale Integrated (VLSI) Microcircuits	402
“Soft Errors” in Computer Memories	405
Optical Waveguides	407
Optoelectronic Devices	413
Superconductors	416
<i>The Isotope Effect</i>	419

Josephson Junctions	420
Superionic Conductors	421
12. Electrophysics	428
Laser and RF Isotope Separation	428
Ions from Laser-Produced Plasmas	430
Channeling in Single Crystals	432
Secondary Ion Emission	435
<i>Energy Distributions and Yields</i>	435
<i>Cluster Ions and Organic Molecules</i>	440
Neutral and Ionic Clusters	443
Electron Emission from Ion Impact	445
Electrical Discharges and High Temperature Vapors	448
Ion Mobilities in Gases	453
Temperature Measurement of Rarefied Gases	454
Temperature Measurements in Shock Waves	455
High-Charge State Multiphoton Ionization	457
13. Energy System Diagnostics: Solar, Fossil, Fission, Fusion	461
Solar Cells	461
<i>Photovoltaics</i>	462
<i>Electrochemical Cells</i>	467
Fossil Power Generation	468
<i>Synthetic Gaseous Fuels</i>	469
<i>Trace Elements in Coals and Petroleum</i>	470
<i>Combustion</i>	470
<i>Fly Ash</i>	473
<i>Water Chemistry of Steam Turbines</i>	476
Fission and Nuclear Physics	477
<i>The Mass-Energy Scale</i>	478
<i>Neutron Cross Sections and Half-Lives</i>	482
<i>Fission Yields</i>	486
<i>Assay of Nuclear Fuel</i>	487
<i>Nuclear Reactor Materials</i>	489
<i>Surveillance of Radioactive Wastes</i>	492
Fusion Research and Engineering	495
<i>The Lawson Criterion and Plasma Temperatures</i>	496
<i>Assay of Deuterium-Tritium Fuel</i>	498

<i>Breeder Materials and Lithium Isotopes</i>	499
<i>First Wall Interactions</i>	500
<i>Laser Fusion Ion Spectrometry</i>	503
14. On-Line Monitoring and Process Control	509
On-Line Mass Spectrometers	510
Chemical Applications	512
<i>Processing Petroleum Fuels</i>	514
<i>Catalytic Processing of Petrochemicals</i>	516
<i>Fermentation Chemistry</i>	518
Industrial Applications	522
<i>Polymeric Curing</i>	522
<i>Blast and Basic Furnace Operation</i>	524
<i>Fluidized Bed Combustion</i>	525
Controlled Spacecraft and Submarine Atmospheres	526
<i>Spacecraft</i>	527
<i>Orbital Space Stations</i>	530
<i>Biologically Closed Systems</i>	533
<i>Submarines</i>	533
Specialized Measurements	540
<i>Gaseous Inclusions</i>	540
<i>Trace Levels of Volatiles in Polymers</i>	540
<i>High Temperature Corrosion and Oxidation</i>	543
<i>Earthquake Prediction</i>	543
<i>Acoustic Mass Spectrometry of Natural Gas</i>	545
PART THREE. ENVIRONMENTAL MEASUREMENTS AND THE LIFE SCIENCES	
15. Air and Water Monitoring	553
Atmospheric Aerosols	553
Techniques for Monitoring Aerosols and Particulates	555
Airborne Metallic Elements	559
Lead in the Atmosphere and Hydrosphere	562
Volcanic Ash	563
Naturally Occurring Radionuclides in the Environment	566
Diesel Emissions	568

Photoionization of Air Contaminants	570
Toxic Substances	571
<i>PCDDs and PACs</i>	572
<i>PCDFs</i>	575
Ground Water Quality Control	578
Aromatic Hydrocarbons in Lake Sediments	580
Pollution Source Identification	582
Atmospheric Tracers	584
16. Agriculture and Food Science	590
Soil Fertility	591
Photosynthesis and Plant Growth	594
Herbicides, Insecticides, and Fungicides	596
Pheromones and Synthetic Attractants	600
Flavors and Aromas	602
<i>Fruits and Juices</i>	603
<i>Meats and Vegetables</i>	608
<i>Beverages</i>	611
<i>Miscellaneous Products</i>	613
Food Colorants	614
Verification of Natural Foods and Extracts	615
Metals in the Food Chain	619
Food Toxicants	622
Nitrosamines	624
Canning, Packaging, and Storage	627
17. Biomedical Applications	634
Mass Spectrometry as a Biomedical Imaging System	634
Stable vs. Radioisotopes	635
Trace Elements in Nutrition	636
DNA Analysis	642
Body Fluids	644
Screening of Diseases	648
Blood Gases	651
Respiratory Gases	652
Breath Metabolites	657
Energy Expenditure Measurements	657
Mass Spectrometry of Bacteria Particles	658
Applications in Industrial Medicine	661

18. Pharmacology	668
Isotopically Labeled Species	669
Structural Elucidation of Drug Metabolites	671
Drug Receptor Interaction	673
Pharmacokinetics by Selected Ion Monitoring	674
Analgesics and Anesthetics	677
Characterization of Antibiotics	680
<i>Sulfa Drugs by LC/MS/MS</i>	683
Antiarrhythmic, Antihypertensive, and Antidepressant Drugs	683
Chelating and Antitumor Agents	688
Comparison of Drug Blood Levels (EI/CI)	688
Percutaneous Absorption of Drugs	689
Pharmaceutical Packaging Materials	690
19. Toxicology and Forensic Science	693
Quantitation of Drugs in Blood	694
Illegal Drugs in Sports	695
Tandem Mass Spectrometry of Drugs	697
Toxicity of Metal Compounds	700
Post-mortem Assays of Body Fluids and Tissues	700
Dioxin Analyses	703
Marine Toxins	704
Geographical Source of Drugs by Isotopic "Fingerprinting"	706
Forensic Geology	707
Explosives	709
Arson Accelerants	713
Dyes and Protective Sprays	713
Metals, Glasses, Waxes, Paints, and Oils	715
Detection of Fraudulent Documents	718
20. New Frontiers in Mass Spectrometry and Ion Beam Technology	721
Archaeology	722
Astrophysics and Cosmology	723
The Superheavy Elements and Rare Particles	724
Ion Beam Lithography	726
Ion Beam Modification of Materials	732

- Neutral Beams for Fusion and Space Propulsion 734
- Hypersonic Boundary Layer Analysis 737
- Plasma Ion Beam Probes 737
- Accelerator-Mass Spectrometry 739
- Analysis by Rutherford Backscattering 746
- Particle Induced X-Ray Emission 748
- Spectrometry of Very Large Molecules 751
- Ion Beam Radiotherapy 753

Appendices

- 1. Isotopic Abundances of the Elements 759
- 2. Ionization Potentials, Electron Affinities, Work Functions, and Melting Points 763

- Index** 767