Index

Note: Page numbers in *italics* refer to figures and tables.

Abundance sensitivity, 35–36, 251
Accelerator mass spectrometry (AMS), 2, 24, 420, 424, 460
Accuracy, 141
Achondrites, 281
Allanite, 256
α-decay, 7–8
β-decay, 7–8
"Anomalous" isotope fractionation. *See* Mass-independent isotope fractionation
Anthropogenic effects, 7
Antimony, 380–381, 512
Apatite, 255–256
"Apparent absorption", 445, 469, 470, 471, 474
Archeology, 373, 378, 382
Archeometric applications, 373
– current applications, 375
–– inorganics, glass and iron, 377–378
–– lead, 375–377
–– neodymium, 379
–– organics, skeletal matter, 378–379
–– osmium, 379
–– strontium, 377
– new applications, 380
–– antimony, 380–381
–– boron, 381–382
–– copper, 380
–– tin, 380
Archeometry, 373, 375, 380
Atomic structure, 1–2
Atomic weights, 113, 144, 149–150, 442
Avogadro constant, 113, 144, 150
Azotobacter vinelandii, 355

Baddeleyite, 249, 254, 256, 257
– measurement bias, 141
Biogeochemistry, 367
Bohr model, 1
Boron, 25, 381–382
Bundesanstalt für Materialforschung und -prüfung (BAM), 150

Ca–Al-rich inclusions (CAIs), *279*
Caged radical pair, 23
Cadmium, 5, 306
Calcium, 458–462
Calibration
– external bracketing, 117
– external gravimetric, 116–117
– internal, 117
– internal double-spike, 117
– with double-spike method, 126–130
– with internal correction
–– inter-elemental correction, 130–131
–– intra-elemental correction, 130
– with internal correction, 130
Capillary electrophoresis (CE), 212
– CE–ICP-IDMS electropherograms, *227*
Cathodoluminescence (CL) image, of zircon, *245*
Cause–effect diagram, 175
Central Bureau for Nuclear Measurements (CBNM), 150
Certified reference materials (CRMs), 144
Ceruloplasmin, 474
Chemical balance studies, in humans, 436
Chemical species
– definition, 495
– distribution of, 495, *496*
Chondrites
– classification of, *278*, 280

Isotopic Analysis: Fundamentals and Applications Using ICP-MS,
First Edition. Edited by Frank Vanhaecke and Patrick Degryse.
© 2012 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.
Published 2012 by WILEY-VCH Verlag GmbH & Co. KGaA

Chondritic meteorites, 279–281
Chondritic uniform reservoir (CHUR), *260*
Chromatography
– coupling with MC-ICP MS, 498
–– acquisition, mass bias correction, and data treatment strategy, 503–507
–– consequences of transient nature of signal, 507–508
–– gas chromatography (GC), 90, 500–503
–– instrumentation, 499, 500
–– liquid chromatography (LC), 90, 500
Chromium, 57, 129, 147, 148
"Cold" balance studies, 436
Colorless glass, 381
Columbite-tantalite, LA–ICP-MS U–Pb dating of, 256
COMAR database, 151
Compartmental modeling, 448
Compartmental modeling techniques, 447–448
– for calcium, 459
– for iron, 463
– for magnesium, 470
Concordia, 242, 243
Conventional quality value, 141
Conventional true value, 141
Cool plasma conditions, 51–52
Copper, 107, 357, 380, 474–476
Cosmic rays and terrestrial matter, interaction between, 6, 23–24
Cosmochemical isotopic variations, 281
Cosmochemistry, 275, 285
Cosmochemistry, isotopic analysis in, 275
– application of multi-collector inductively coupled plasma mass spectrometry, 275
– cosmochemical isotopic variations, 281
– cosmogenic isotopic variations, 305–307
– extinct radioactive decay systems, 296–299
– extraterrestrial samples, 276–277
–– chondritic meteorites, 279–281
–– classification of meteorites, 277–278
–– non-chondritic meteorites, 281
– isotope fractionation, 299–305
– long-lived radioactive decay systems, 293
–– ^{147}Sm–^{143}Nd decay system, 293–294
–– ^{176}Lu–^{176}Hf decay system, 294–295
–– ^{87}Rb–^{87}Sr decay system, 293
–– U/Th-Pb decay systems, 295–296
– MC-ICP-MS use in, 285
–– analytical procedures, 287–289
–– specific advantages, 285–286
– nucleosynthetic isotope anomalies, 289–293
– radiogenic isotopic variations from
–– cosmogenic isotope anomalies, 284–285
–– extinct radioactive nuclides, decay of, 282–283
–– long-lived radioactive nuclides, decay of, 282
–– mass-dependent isotope fractionation, 284
–– nucleosynthetic isotope anomalies, 283–284
Cosmogenic isotope anomalies, 284–285
Cosmogenic isotopic variations, 305–307
Crime scene investigation, 393–395
Cr isotope ratios
– and paleoredox conditions of atmosphere, 329–337
Cyclonic spray chamber, 48

Daly detector, 80, *81*
Davidite, 257
Delta (δ) notation, 179
Delta reference material, 144–145
δ-value, 144, 145
Depleted mantle (DM), *260*
Depleted uranium (DU), 25, 425
Detection limit, limit of detection (LOD), 173
Detector issues, 62–66
– detector dead time, 62–66
– electron multiplier operating principles, 62
Detector technologies, for multi-collection, 87–90
Diagenesis, 344, 345
Discordia, 244
Discrimination exponent, 121–122
Discrimination function, 122–123
Divalent metal transporter 1 (DMT1), 443
Double-focusing sector field mass spectrometer, 38–43
Double isotopic label, fecal balance studies for, 445–446
Double-spike calibration, 126–131, 303
– internal, 117
– uncertainty modeling and, 132–133
Dry plasma conditions, 288
Duodenal cytochrome B (DcytB), 443–444

Electron multiplier operating principles, 62
Electrostatic sector as energy filter, *40*
Electrothermal vaporization inductively coupled plasma mass spectrometry (ETV–ICP-MS), 203

Elemental speciation, 495, 497
Elemental speciation, ICP-IDMS in, 212
– principles, 212–214
– species-specific ICP-IDMS, 214–221
– species-unspecific ICP-IDMS, 221–229
Element metabolism, 447
Elements, isotopic composition of, 1
– atomic structure, 1–2
– atomic structure and natural abundance of elements and isotopes, relation between, 3
– isotopes, 2–3
– natural isotopic composition, 5
–– cosmic rays and terrestrial matter, interaction between, 23–24
–– effects caused by now extinct radionuclides, 13
–– elements with radiogenic nuclides, 7–13
–– human-made variations, 24–26
–– mass-dependent isotope fractionation, 13–20
–– mass-independent isotope fractionation, 20–23
Element tracing in environmental science, 356–360
Element turnover studies, 449–450
Empirical external normalization, 468
Enriched IRMs, *148*
Environmental analysis, 495, 496
Environmental pollution, monitoring, 404–408
Environmental science, element tracing in, 356–360
Equilibrated chondrites, 280
Error, 141
Errorchron, 236, *237*
Erythrocyte incorporation technique, 462, 463
ESI (electrospray ionization), 224
European Reference Materials (ERMs), 150–151
Even–even isotopes, 4
Excimer-based lasers, 49
Exponential versus the power law, 120
Extended X-ray absorption fine structure (EXAFS) spectra, 326
External calibration, *116*
External gravimetric calibration, 116–117
"External" standard deviation, 142
Extinct radioactive decay systems, 282, *283*, 296–299
Extraterrestrial materials, 6, 275, 276–277, 286, 296, 303
Extrinsic labeling, 443

Faraday collector, 94–96
Fast atom bombardment (FAB), 467
Fecal balance studies
– with double isotopic label, 445–446
– with single isotopic label, 444–445
Femtosecond LA technique, 107–108
Fe oxyhydroxide, 326–327
Fishbone diagram. *See* Cause–effect diagram
Food authentication, 399–404
Forensic applications, 393, 408–411
– crime scene investigation, 393–395
– environmental pollution, monitoring, 404–408
– food authentication, 399–404
– future outlook, 411–412
– nuclear forensics, 396–399
Fossil fuels, trace element analysis of, 205–207
Fractionation, 318, 323, 332, 334
Fractionation factor, 318

Gas chromatography–ICP-MS, 216–218
Geiger–Marsden experiment, 1
Geochemistry, 317, 319, 320
Geochronological dating, 235
– isotopic systems, *238*, 242
–– ICP-MS analysis, 265–266
–– LA–ICP-MS U–Pb Dating of zircon, 244–254
–– laser ablation U/Th-Pb dating of other phases, 254–257
–– Lu–Hf isochrons with garnet, 258–259
–– Lu–Hf on phosphates, 259
–– Lu–Hf system, 257–258
–– Pt–Re–Os on mantle peridotites, 263–265
–– Re–(Pt–)Os system, 261
–– Re–Os dating of black shales, 262–263
–– Re–Os molybdenite dating, 262
–– solution Pb–Pb dating, 257
–– U/Th-Pb, 242–244
–– zircon Hf isotopic model ages, 259–261
– practicalities, 240
–– ICP-MS versus TIMS, 241–242
–– isobaric overlap, 240–241
– principles, 235
–– closure temperature, 237–240
–– single phase and isochron dating, 235–237
Geosphere, schematic representation of, *352*
Geosphere–biosphere interface, 351
– elements typifying, 354–355

Geosphere–biosphere interface, 351, 354, 367
Geosphere effect on vegetation and animals, 360–364
Glass, 377–378
Global ocean paleoredox
– molybdenum isotope ratios, 320–329
Glossary of Analytical Terms (GAT), 141
Glow discharge mass spectrometry (GDMS), 420

Hafnium, 201, 294
Halogens, 512–513
Heavy rare earth elements (HREEs), 258
HED meteorites, 281
Heptodin, 410
^{182}Hf–^{182}W chronometer, 13
Hf–W isochron, 298
High-magnesium calcite (HMC), 365
Hot particles, analysis of, 397
Humic substance metal complexes, fractionation of, 221, 223–224
Hydride generation (HG), 207, 473
Hyphenated ICP-IDMS, in quantitative proteomics, 212, 221, 225

ICP-isotope dilution mass spectrometry (IDMS), 175
ICP-MS in stable isotope-based metabolic studies, 451
– mass spectrometric sensitivity, 454
– measurement accuracy and quality control, 454–457
– measurement precision, 451–453
ICP-TOF-MS, 61, 402
Inductively coupled plasma (ICP) ion source, 32–34
Inductively coupled plasma isotope dilution mass spectrometry (ICP-IDMS), 184, 189
– elements accessible to, 194–195
– in elemental speciation, 212
–– principles, 212–214
–– species-specific ICP-IDMS, 214–221
– transuranium elements, determination of, 211
Inductively coupled plasma mass spectrometry (ICP-MS), 80, 93, 113, 114, 140, 165, 189, 201, 241, 275, 276, 354, 419, 436
– in forensics, 391
– versus TIMS for Geochronology, 241–242
Influence quantities, of isotope amount ratio measurements, 177
– data presentation with isotope notation, 179–180
– isotope amount ratio determination, 177
–– internal versus external correction for mass bias, 178–179
–– mass bias correction and drift effects, 178
–– single-collector versus multi-collector ICP-MS, 177–178
– sample preparation, 177
– sampling, 177
Institute for Reference Materials and Measurements (IRMM), *147*, *148*, 150, 156, 430
Instrumental mass discrimination, 66–68, 113, 114
Inter-elemental correction method, 130–131
Interface, microbes at, 355–356
Intermediate measurement precision, 170, 174
Intermediate precision condition of measurement, 170
Internal calibration, *116*, 117
Internal double-spike calibration, 117
Internal isotope ratio precision (RSD), *60*, 58, 174
International Geosphere–Biosphere Programme (IGBP), 353
Intra-elemental correction method, 130
Intrinsic labeling, 443
Ion microprobe technique, 102
Ion source, 31, 32
Ion transmission efficiency, 124
Iron, 355, 377–378, 462–464
Iron meteorites, 281, 298–299
Isochron dating, 235–237
Isotope amount ratio determination, 177
– internal versus external correction for mass bias, 178–179
– mass bias correction and drift effects, 178
– single-collector versus multi-collector ICP-MS, 177–178
Isotope archeology, 382
Isotope dilution mass spectrometry (IDMS), 139, 189, 190, 438, 475
– elements accessible to ICP-IDMS analysis, 194–195
– in elemental speciation
–– principles, 212–214
–– species-specific ICP-IDMS, 214–221
–– species-unspecific ICP-IDMS, 221–229

– principles of, 190–194
– spike isotope selection and optimization of its amount, 194–199
– uncertainty budget and limit of detection, 199–200
Isotope dosage, for radiotracers, 452
Isotope fractionation, 6, 77, 78, 81, 84–85, 87, 88, 90, 93, 102–106, 113, 115–117, 125, 130, 139, 165–167, 174, 176, 177, 180–182, 236, 240, 248, 275, 276, 287, 299–305, 419, 421–423, 425, 427, 429, 430, 431, 450–451
– mass-dependent, 6, 13–20
–– in chemical reactions, 16–20
–– in physical processes, 15–16
– mass-independent, 6–7, 20–23
Isotope labeling techniques, 442–444
Isotope notation, data presentation with, 179–180
Isotope ratio applications, quality control in, 165
– measurement uncertainty, 174
–– alternative approach, 181
–– influence quantities, 177–180
–– method validation, 182–184
–– metrological traceability, 181–182
–– uncertainty budget estimation, example of, 180–181
Isotope ratio data, standardization of, 107–108
Isotope ratio determination, correction for instrumental mass discrimination in, 113
– conventional correction models, logic of, 118–119
– correction models, integrity of
–– discrimination exponent, 121–122
–– discrimination function, 122–123
–– Russell's law, 120–121
–– second-order terms, 123
– double spikes, calibration with, 126–130
– exponential versus the power law, 120
– history, 113–114
– internal correction, calibration with, 130
–– inter-elemental correction, 130–131
–– intra-elemental correction, 130
– linear law, 119–120
– mass bias correction models, systematics of, 115
–– external bracketing calibration, 117
–– external gravimetric calibration, 116–117
–– internal calibration, 117
–– internal double-spike calibration, 117
– mass bias in, 114–115
– regression model, 124–126
– uncertainty evaluation, 131
–– double-spike method, 132–133
Isotope ratio mass spectrometry (IRMS), 165, 351–352, 410, 411
Isotope ratio measurement with single-collector ICP-MS, 56
– detector issues, 62–66
– instrumental mass discrimination, 66–68
– isotope ratio precision, 57–62
Isotope ratios of metals as paleoredox proxies. *See* Metal isotopes as paleoredox proxies
Isotopes, 2–3
Isotopes as indicators of paleoenvironments, 360
Isotope tracers, 351
Isotopic analysis, reference materials in, 139
– abundance ratios determination, 145–149
– present status, 153–154
– reference materials, 149–153
–– historical development, 149–151
–– requirements for, 151–153
– related problems, 154–156
– solution, 156–157
– terminology, 141–145
Isotopic composition, of elements. *See* Elements, isotopic composition of
Isotopic reference materials (IRMs), 140, 144, 149–153, 151
– enriched, *148*
– historical development, 149–151
– radioactive, *152*
– requirements for, 151–153
– with natural-like isotopic composition, *147*

Johnson noise, 89

K-factor, 145
Kinetic energy discrimination, 54
Kinetic isotope fractionation, 332
– thermodynamic isotope fractionation
Kirchhoff's law, 96

LA–ICP-MS, 48–49, 93, *101*, 201–203, 397, 398, 409, 410, 411–412
LA–ICP-MS U–Pb dating
– of allanite, 256
– of apatite, 255–256
– of baddeleyite, 257
– of columbite-tantalite, 256
– of davidite, 257
– of monazite, 254–255
– of perovskite, 256–257
– of rutile, 255–256

– of titanite, 255–256
– of uraninite, 257
– of zircon, 244–249
–– data processing, 254
–– ICP-MS equipment, 250–251
–– isobaric overlap, common Pb and oxide formation, 251–254
–– laser ablation system, 249–250
La Jolla standard, 166
LA–MC-ICP-MS
– application for isotopic measurements, 287–288
Lamivudine, 410
Laser ablation (LA), advances in, 93
– advantages of, 105
– isotope
–– fractionation, 102–106
–– ratio data standardization, 107–108
–– ratio measurements, 93–94
– multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS), 93
– multiple ion counting, 101–102
– signal smoothing device, 99–101
– stable signal intensity profiles, 94–98
– thermal ionization mass spectrometry (TIMS), 93
Laser ablation (LA) system, 241, 249–250, 254
Laser ablation in, 93
– cosmochemical isotopic variations, 281
– cosmochemistry
–– applications of, 289
–– use in, 285
– cosmogenic isotopic variations, 305–307
– coupling chromatography with, 498
–– acquisition, mass bias correction, and data treatment strategy, 503–507
–– consequences of transient nature of signal, 507–508
–– gas chromatography (GC), 500–503
–– instrumentation, 499, 500
–– liquid chromatography (LC), 500
– environmental and other applications, 509
–– antimony, 512
–– halogens, 512–513
–– lead, 511
–– mercury, 509–511
–– sulfur, 511–512
– extinct radioactive decay systems, 296–299
– extraterrestrial samples, 276–277
–– chondritic meteorites, 279–281
–– meteorites, classification of, 277–278
–– non-chondritic meteorites, 281
– future trends, 513–515
– in cosmochemistry isotopic analysis, 275
– in elemental speciation, 495
– isotope fractionation, 299–305
– isotope ratios measurement using the combination of chromatography and, *499*
– long-lived radioactive decay systems, 293
–– ^{147}Sm–^{143}Nd decay system, 293–294
–– ^{176}Lu–^{176}Hf decay system, 294–295
–– ^{87}Rb–^{87}Sr decay system, 293
–– U/Th-Pb decay systems, 295–296
– mass bias in, 114–115
– MC-ICP-MS use in, 285
–– analytical procedures, 287–289
–– specific advantages, 285–286
– nucleosynthetic isotope anomalies, 289–293
– on-line versus off-line separation, 497–498
– radiogenic isotopic variations from
–– cosmogenic isotope anomalies, 284–285
–– decay of extinct radioactive nuclides, 282–283
–– decay of long-lived radioactive nuclides, 282
–– mass-dependent isotope fractionation, 284
–– nucleosynthetic isotope anomalies, 283–284
– techniques, 354
Laser ablation inductively coupled plasma isotope dilution mass spectrometry (LA–ICP-IDMS), *201*, 202–203, 205, 206, 209, 210
Laser ablation–inductively coupled plasma mass spectrometry. *See* LA–ICP-MS
Laser-induced breakdown spectroscopy (LIBS), 103
Law of uncertainty propagation, 132
Lead, 10–13, 102, 296, 375–377, 394, 398, 400, 402, 404, 430, 511
Limit of detection (LOD), 182–184, 452
Limit of determination, 183–184
Limit of quantification (LOQ), 183–184, 452
Linear correction law, 118
Linear mass bias model, 119–120
Long-lived radioactive decay systems, 282, *283*, 293
– ^{147}Sm–^{143}Nd decay system, 293–294
– ^{176}Lu–^{176}Hf decay system, 294–295
– ^{87}Rb–^{87}Sr decay system, 293
– U/Th-Pb decay system 295–296
Low gas pressure cell (LPC) device, 104
Low-magnesium calcite (LMC), 365
^{176}Lu–^{176}Hf decay system, 294–295
Lu–Hf isochron diagram
– for chondrites and eucrites, *295*

Lu–Hf System, 257–258
– concept of model ages, 260
– isochrons with garnet, 258–259
– on phosphates, 259
Lunar meteorites, 281

Magmatic iron meteorites, 281
Magnesium, 469–471
– absorption, 470
– stable isotopes, 469
Magnetic sector mass spectrometer, 78
MALDI (matrix-assisted laser desorption/ ionization), 224
Mantle extraction age, *264*
Marine environment, tracing in, 364–367
Marine paleoredox proxy, 338–344
Mass bias correction models
– in MC-ICP-MS, 114–115
– systematics of, 115
–– external bracketing calibration, 117
–– external gravimetric calibration, 116–117
–– internal calibration, 117
–– internal double-spike calibration, 117
Mass-dependent isotope fractionation, 6, 13–20, 284
Mass fractionation
– mass discrimination and, comparison of, *67*
Mass fractionation factor, 19
Mass-independent isotope fractionation, 20–23
Mass resolution, 34–35
Mass spectrometry (MS), 31–32, 419–420
– characteristics, 34
–– abundance sensitivity, 35–36
–– comparison of, *45*
–– mass resolution, 34–35
–– mass spectral range, 36
–– scanning speed, 36
– double-focusing sector field mass spectrometer, 38–43
– quadrupole filter, 36–38
– time-of-flight analyzer, 43–45
Mattauch–Herzog geometry, 41–42, 82
MC-ICP-MS
– cosmochemistry, 285
–– application of, 289
–– use of, 285
– external normalization, 287
– external standardization technique, 287
– internal normalization technique, 287
– laser ablation (LA) systems in, 287
– specific advantages of, 285–287
MC-ICP-MS use in, 285
– analytical procedures, 287–289
– specific advantages, 285–286
Mean ocean molybdenum (MOMo), 179
Measurand, 168
Measured quantity value, 169
Measurement accuracy, 141
Measurement bias, 141, 172
Measurement error, 141
Measurement precision, 141–142, 169
Measurement repeatability, 142, 170
Measurement reproducibility, 142, 170
Measurement trueness, 143
Measurement uncertainty, 142, 167, 168, 172, 174, 181
– alternative approach, 181
– influence quantities, 177
–– data presentation with isotope notation, 179–180
–– isotope amount ratio determination, 177–179
–– sample preparation, 177
–– sampling, 177
– method validation, 182
–– inter-laboratory studies, 184
–– limit of detection (LOD), 182–184
–– limit of determination, 183–184
–– limit of quantitation (LOQ), 183
– metrological traceability, 181–182
– uncertainty budget estimation, example of, 180–181
Mediterranean outflow water (MOW), 366
Mercury, 509–511
Mercury-tagged bioconjugates, 229
Metal deposits, 356–360
Metal isotopes as paleoredox proxies, 317, 319
– Cr isotope ratios and paleoredox conditions of atmosphere, 329–337
– critical area for further work, 344–346
– molybdenum isotope ratios and global ocean paleoredox, 320–329
– uranium isotope ratios and marine paleoredox, 338–344
Meteorites, 275, 276, 277–278
Method validation, 182
– inter-laboratory studies, 184
– limit of detection (LOD), 182–184
– limit of determination, 183–184
– limit of quantitation (LOQ), 183
Metrological comparability of measurement results, 171
Metrological traceability, 143, 170–171, 181–182

Microbes at interface, 355–356
Micro-drilling technique, 107
Mixed oxide fuel (MOX), 422
Model age, 260, 264–265
Molybdenite (MoS_2), 262
Molybdenum, 291, 360, 476–477
Molybdenum isotope ratios
– and global ocean paleoredox, 320–329
Monazite, LA–ICP-MS U–Pb dating of, 254–255
Multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS), 42, 77, 78, 80, 113, 115, 165, 177, 276, 306, 317, 351, 352, 354, 360, 362, 374, 403–404, 407, 409, 464, 468, *499*
– chromatography, 495
– detector technologies for, 87–90
– early multi-collector mass spectrometers, 78–79
– mass resolution and resolving power, 81–84
– measurement validation, three-isotope plots for, 84–87
– variable multi-collector mass spectrometers, 79–81
Multi-isotopic elements, periodic table of, 286
Multiple ion counting, 101–102
Multiple species-specific spiking, 219–221
Multipole collision/reaction cell, 52–55
– overcoming spectral interference via chemical resolution, 53–54
– overcoming spectral interference via collisional deceleration and kinetic energy discrimination, 55

National Bureau of Standards (NBS), 150
National Institute of Standards and Technology (NIST), 150
Natural ferromanganese sediments, 326
Nd:YAG lasers, 49, 50, *247*
Negative thermal ionization mass spectrometry (NTIMS), 454, 473, 474, 477
Negatron, 7
Neodymium, 293, 294, 366, 379
Neptune, 79, 81, 84, 115, 121, 509
Nevada Test Site (NTS), 428
Nier–Johnson double focusing geometry, 42–43
Non-chondritic meteorites, *278*, 281
Non-magmatic irons meteorites, 281, 298, 303
Nordtest calculation, 181
Now extinct radionuclides, 13
Nuclear applications, 419
– future developments, prospects for, 431
– nuclear forensics, 429–431
– process control and monitoring in the nuclear industry, 422–424
– rationale, 419–422
– U and Pu, isotopic studies of distribution of, 424–429
Nuclear field shift effects. *See* Nuclear volume effects
Nuclear force, 1
Nuclear volume effects, 22, 23
Nucleon, 1, 2, *3*, 4
Nucleosynthetic isotope anomalies, 283–284, 289–293
Nucleus, 1, 2, 4, 7, 22, 338, 342
Nugget effects, 209

Oncorhynchus tshawytscha, 361
On-line isotope dilution LA–ICP-MS, 203
On-line photochemical vapor generation, 207
On-line versus off-line separation, 497–498
Organics
– of skeletal matter, 378–379
Osmium, 130, 209, 261, 379
Output voltage, 96, 97

Pacific Proving Ground (PPG), 427–428
Paleoenvironments, 360
– isotopes as indicators of, 360
Paleoredox proxies. *See* Metal isotopes as paleoredox proxies
Paleoredox proxy, 322, 323, 328, 337, 340
Pallasites, *88*, 281
Parathyroid hormone (PTH), 458
Pb–Pb dating, solution of, 257
Pb–Tl isochron data, *300*
Pd–Ag isochron data, *300*
Penning ionization, 33
Perovskite, LA–ICP-MS U–Pb dating of, 256–257
Petroleum products, sulfur speciation in, 221–223
Planck's constant, 150
Plasma, 54, 80
– appearance, 446–447
– deconvolution techniques, 446–447
– definition of, 32
Platinum group elements (PGEs), 175
– determination of, 207–210
Plutonium, 426–427
Poisson counting statistics, 58, 59

Positron, 7
"Post-column" spiking, 213
Precision, 141–142
Primitive achondrites, 281
Protein analysis, 224–229
Provenance, 373, 377
Pseudo-high resolution, 83
Pt-Re-Os on mantle peridotites, 263–265

Quadrupole-based ICP-MS, 45–47, 58, 192, 251
Quadrupole filter, 36–38
Quality control, 165
Quantity value, 142

Radioactive decay, 7–8
Radioactive IRMs, *152*
Radiogenic isotopic variations from
– cosmogenic isotope anomalies, 284–285
– decay of extinct radioactive nuclides, 282–283
– decay of long-lived radioactive nuclides, 282
– mass-dependent isotope fractionation, 284
– nucleosynthetic isotope anomalies, 283–284
Radiogenic nuclides, 5–6, 7–13
– lead, 10–13
– parent–daughter pairs, 13
– radioactive decay, 7–8
– strontium, 9–10
Radioisotopes, 420
– techniques, 437
Rare earth element (REE), 379
Rayleigh equation, 15
Rayleigh fractionation, 333, 334
Rubidium, 10
^{87}Rb–^{87}Sr decay system, 293
Rb–Sr isochron method, *237*
Re-(Pt-)Os system, 261
Reactive oxygen species (ROS), 471
Recommended dietary allowance (RDA), 471
Red blood cells, 462
Redox conditions, reconstruction of, 319
Reduced mass, definition of, 17
Reference material, 139, 143
Reference quantity value, 142–143
– reference value, 173
Regression model, 117, 124–126
Relative abundance of nuclide, 2
Re–Os
– dating of black shales, 262–263
– isochron, 345
– molybdenite dating, 262
Repeatability, 142
– condition of measurement, 170
Reproducibility, 142
– condition of measurement, 170
Resolving power, 84
Resonance ionization mass spectrometry (RIMS), 420
Reverse isotope dilution, 193
Rhenium depletion age, 265
Russell's law, 120–121
Rutile, LA–ICP-MS U–Pb dating of, 255–256

Sag, 64–65
Saha equation, 33
Sample introduction strategies, in ICP-MS, 47–50
"Saturnian" model, 1
Scott-type double-pass spray chamber, 48
Secondary electron multiplier, 89, 90
Secondary ionization mass spectrometry (SIMS), 102, 285, 393, 420
Sector field ICP-MS
– high mass resolution with, 55–56
Seed electrons, 33
^{77}Se-labeled selenomethionine, 215
Selenium, 471–474
– absorption, 472
– stable isotopes, 471
Sensitive high-resolution ion microprobe (SHRIMP), 244
Shewanella oneidensis, 334
Single-collector inductively coupled plasma mass spectrometry, 31, 397
– basic operating principles, 34
–– comparison of characteristics, 45
–– double-focusing sector field mass spectrometer, 38–43
–– mass spectrometer characteristics, 34–36
–– quadrupole filter, 36–38
–– time-of-flight analyzer, 43–45
– inductively coupled plasma ion source, 32–34
– isotope ratios measurement, 56
–– detector issues, 62–66
–– instrumental mass discrimination, 66–68
–– isotope ratio precision, 57–62
– mass spectrometry, 31–32
– quadrupole-based ICP-MS, 45–47
– sample introduction strategies in, 47–50
– spectral interferences, 50
–– cool plasma conditions, 51–52
–– high mass resolution with sector field ICP-MS, 55–56

–– multipole collision/reaction cell, 52–55
Single-collector instruments, 178
Single isotopic label, fecal balance studies for, 444–445
Skeletal matter, 378–379
^{147}Sm–^{143}Nd decay system, 293–294
Sm–Nd isochron dating, 265
SMOW (Standard Mean Ocean Water), 156
SNC meteorites, 281
Sodium carbonates, 381
Space-charge effects, 67
Speciation, 212, 215, 216, 221
Species-specific ICP-IDMS, 214–221
– for identification of species transformations, 218–219
– multiple spiking, 219–221
– speciation analysis, 215–217
Species-unspecific ICP-IDMS, 221–229
– humic substance metal complexes, fractionation of, 223–224
– protein analysis, 224–229
– sulfur speciation, in petroleum products, 221–223
Spectral interferences, 50
– cool plasma conditions, 51–52
– high mass resolution with sector field ICP-MS, 55–56
– multipole collision/reaction cell, 52–55
Spray chambers, 48
– calcium, 458–462
– Stable isotope techniques, 435, 437, 438, 444, 473
– copper, 474–476
– essential elements, 435–436
– ICP-MS in stable isotope-based metabolic studies, 451
–– mass spectrometric sensitivity, 454
–– measurement accuracy and quality control, 454–457
–– measurement precision, 451–453
– iron, 462–464
– isotope labeling techniques, 442–444
– magnesium, 469–471
– mineral, studying for, 435
– molybdenum, 476–477
– selenium, 471–474
– stable isotopic labels versus radiotracers, 436–438
– stable isotopic tracers, quantification of, 438–442
– for trace element metabolism in humans, 444
–– compartmental modeling, 447–448
–– element turnover studies, 449–450
–– fecal balance studies, with double isotopic label, 445–446
–– fecal balance studies, with single isotopic label, 444–445
–– isotope fractionation effects, 450–451
–– plasma appearance, 446–447
–– tissue retention, 448–449
–– urinary monitoring, 447
– zinc, 464–469
Stable isotopic labels
– versus radiotracers, 436–438
Stable isotopic tracers
– quantification of, 438–442
Standard Mean Ocean Water (SMOW), 167
Stony-irons, 281
Strontium, 131, 237, 377, 402–403
Sulfur
– in protein quantification, 225–229
– isotopic analysis of, 511–512
– speciation, in petroleum products, 221–223
Surface ionization techniques, 78
Systematic measurement error, 171–172

Tachycineta bicolor, 361
Tandem introduction system, 48
Tera–Wasserburg diagram, *252, 253*
Terrestrial matter and cosmic rays, interaction between, 6, 23–24
Tetramethylammonium hydroxide (TMAH), 216
Thermal ionization (TI)-IDMS, 189
Thermal ionization mass spectrometry (TIMS), 32, 40, 80, 93, 115, 165, 241, 285, 333, 354, 420, 424
– versus ICP-MS for Geochronology, 241–242
Thermal vaporization (TV)–ICP-IDMS, 205, 206
Three-isotope plots, 84–87
Time-of-flight (TOF) analyzer, 43–45, 61
Tin, 380
Tissue retention, 448–449
Titanite, LA–ICP-MS U–Pb dating of, 255–256
Traceability, 143
Trace element metabolism, in humans, 189, 435, 437, 444
– compartmental modeling, 447–448
– element turnover studies, 449–450
– fecal balance studies, for double isotopic label, 445–446
– fecal balance studies, for single isotopic label, 444–445

– isotope fractionation effects, 450–451
– plasma appearance, 446–447
– tissue retention, 448–449
– urinary monitoring, 447
Trace elements and elemental species determination, using ICP-IDMS, 189
– examples, 200
–– electrothermal vaporization inductively coupled plasma mass spectrometry (ETV–ICP-MS), 203
–– fossil fuels, trace element analysis of, 205–207
–– laser ablation–inductively coupled plasma mass spectrometry (LA–ICP-MS), 201–203
–– on-line photochemical vapor generation, 207
–– platinum group elements, trace amounts of, 207–210
–– silicon determination in biological samples, 203–205
–– transuranium elements, ultra-trace amounts of, 211–212
–– trends in ICP-IDMS Trace Analysis, 200–201
– isotope dilution mass spectrometry (IDMS), 189
–– elements accessible to, 194–195
–– principles of, 190–194
–– spike isotope selection and optimization of its amount, 195–199
–– uncertainty budget and limit of detection, 199–200
Tracers, 437
Trackability, 143
Transferrin isoforms, determination of, 225
Triethyllead (TEL), 216
Trimethyllead (TML), 216
Trueness, 143
True quantity value, 143
True value, 143
"True" isotope abundance ratio, 145

U and Pu, isotopic studies of distribution of, 424–429
Ultraviolet photochemical vapor generation (UV-PVG), 207
Uncertainty budget estimation, example of, 180–181
Uncertainty evaluation, 131–132
– and double-spikes, 132–133
– modeling and double spikes, 132–133
Uncertainty of measurement, 172
Unequilibrated chondrites, 280
Uraninite, LA–ICP-MS U–Pb dating of, 257
Uranium isotope ratios
– and marine paleoredox, 338–344
Urinary monitoring, 447
U/Th-Pb, 242–244
U/Th-Pb decay systems, 295–296

VIM3 International Vocabulary of Metrology, 167
Volcanic massive sulfide (VMS), 357

Wet plasma conditions, 288

Zinc, 356–357, 464–469
Zircon
– Hf isotopic model ages, 259–261
– LA–ICP-MS U–Pb dating of, 244–249
–– data processing, 254
–– ICP-MS equipment, 250–251
–– isobaric overlap, common Pb and oxide formation, 251–254
–– laser ablation system, 249–250
Zirconium, 291, 292