

Index

A

- absorbance, 457. *See also* infrared (IR) absorption
- absorption, matrix effect, 361
- accepted reference value (ARV), 43 (table)
- accuracy, 43 (table), 116, 406
- added internal standard method, 368–369
- additive elements, 145, 147 (table), 187, 188, 582, 601
- administrative reviews, 84
- aerosol, 174 (table), 174–175, 176, 214, 215. *See also* nebulizers
- Aids to Analysis*, 106–107
- algorithms, 364–370
- alkali elements, 178
- alternative fuel standard (AFS), 625
- aluminum, 194, 254–255
- amines, 500, 501
- anlyte, 223
- analytical chemistry, 208
- Analytical Chemistry Journal*, 209
- analytical instrumentation, 27 (table)
- analytical performance, 53 (table)
- analytical techniques, 3, 211 (table).
See also specific techniques
- analyzer, 258, 292–293, 398, 399, 405, 406 (table), 410–411
mercury, 571, 573 (table), 573–575
See also specific types
- analyzing crystal, 351–354, 353 (table), 356
- Anderson-Darling (AD) statistic, 80, 82
- anions, 503–504, 505, 506 (figure)
- ANOVA, 43 (table)
- aqueous metallic standards, 139
- aqueous solution, 178, 191, 223
- argon, 358
- arsenic compounds, 246
- ashing, 164, 191–192, 194 (figure), 228, 608
- asphaltenes, 189
- aspiration rate, 171, 173 (table)
- assignable cause, 43 (table)
- assigned test value (ATV), 43 (table)
- ASTM Committee E13, 481
- ASTM International Committee D02, 3, 146, 598, 600
- ASTM Proficiency Test Programs (PTP), 56–57 (table), 116, 146 (table), 386–389, 551 (table), 553–554, 598
- ASTM Research Report RR-D02, 552
- ASTM Standard Guide D7372, 57
- ASTM test methods, 26, 32 (table), 34 (table), 36 (table), 69–70 (table), 122, 128, 129–130 (table), 131
 - atomic absorption spectrometry and, 145 (table), 145–146
 - chromatography and, 523–524
 - crude oil and, 607
 - energy dispersive X-ray fluorescence and, 385–386, 386–389
 - inductively coupled plasma–atomic emission spectrometry and, 185–190, 187 (table)
 - ion chromatography and, 506–509, 507 (figure), 508 (figure), 510
 - wavelength dispersion X-ray spectrometry and, 371*See also specific test methods*
- ASTM ULSD ILCP Program, 554–558, 555 (table), 556 (table), 557 (table), 613, 637–638
- atmospheric pressure ionization (API) projects, 293
- atom/ion intensity ratio, 182
- atomic absorption spectrometry (AAS), 4, 7 (table), 135–137, 136 (figure), 147, 148–153 (table)
 - application, 142–145, 143 (table)
 - ASTM test methods, 145 (table), 145–146

- calibration and, 33–34, 34 (table), 138–140
- crude oil and, 610, 610 (table)
- differentiation, 157
- flame conditions in, 140 (table)
- instruments, 140–141
- interference, 137–138
- lubricants, 144 (table)
- measurements, 152–153 (table), 610 (table), 611 (table)
- of metals, 139 (table)
- sample introduction, 138
- used oil and, 586
- See also* graphic furnace atomic absorption spectrometry (GFAAS)
- atomic emissions detector, 527–528, 527 (figure), 528 (figure)
- atomic fluorescence spectroscopy (AFS), 246, 280, 283
 - instrumentation, 247–153, 248–250 (figure), 253 (figure), 258
 - mercury and, 262–267, 263 (figure), 272, 279–280, 283, 569
 - on-line technique, 576
- atomic spectroscopic techniques, 151 (table), 612 (table). *See also specific techniques*
- atomization, 156–164, 161 (table), 163 (figure), 166, 167
- atomizer, 135
- attenuated total reflectance (ATR), 482–483, 482 (figure)
- auto suppressor, 497–499
- automotive fuels, 223–228.
 - See also specific fuel*
- autosampler, 162

B

- B100, 626
- background absorption interferences, 137
- barite, 222
- barium, 116, 217
- barium sulfate, 502
- beam filter, 387, 379 (figure)
- Beer's Law, 135, 485

- bias, 43 (table), 75, 91–92.
 - See also* relative bias
- binary blends, 320
- biodiesel. *See also* biofuel
- biofuel, 17, 18 (table), 23, 227–228, 456–457, 457 (figure), 600, 625–626
 - economics of, 626–628
 - interlaboratory crosscheck programs and, 637–638
 - production, 626–628
 - sources, 626
 - sulfur and, 559–561
 - testing and, 628–637, 629 (table), 637 (table)
- bitumen, 436–437, 437 (figure), 438 (figure)
- blank determination, 40
- Bloom, N. S., 567, 576
- boiling point, 289, 301, 303, 448 (table), 519–522, 521 (figure)
- Botto, R. I., 208
- Bouquet, M., 295–296
- box and whisker graphs, 82 (table), 92, 98–100, 99 (figure)
- Bragg's law, 353, 394 (figure), 394
- “breaking radiation,” 374
- Bremsstrahlung, 374
- burner system, 140
- Burnett, J., 295–296
- Bush, George W., 625

C

- calcium, 89 (figure)
- calibration, 24, 25 (table), 25–27, 29 (figure), 43 (table), 65, 112
 - in atomic absorption spectrometry (AAS), 33–34, 34 (table)
 - in gas chromatography, 39–40, 520, 521, 533 (figure)
 - in graphite furnace atomic absorption spectrometry (GFAAS), 160–162
 - in inductively coupled plasma–atomic emission spectrometry (ICP-AES) and, 34–35, 181–182

- in infrared analysis, 38–39, 487, 488
- mercury and, 262
- in monochromatic wavelength dispersive X-ray fluorescence and, 400–401, 402
- in neutron activation analysis (NAA), 36
- in nuclear magnetic resonance (NRM) analysis, 39
- photometric test methods and, 32, 32 (table)
- procedures, 26–27
- sulfur, 35
- temperature measuring devices and, 28
- wavelength dispersive X-ray spectrometry and, 370–371
- X-ray fluorescence (XRF) spectrometry test methods and, 36–38, 36–37 (table)
- calibration blends, 325 (table)
- calibration coke gas requirements, 325
- calibration curve, 33, 34, 35, 37–38, 264 (figure), 303, 400, 404 (figure), 534 (figure)
- calibration cylinders, 339 (table)
- calibration documentation, 32
- calibration frequency, 30–31
- calibration gas cylinder requirements, 334, 336 (table)
- calibration gases, 332 (table)
- calibration mixture, 39–40
- calibration practices, 48–49
- calibration reference material, 114–116, 115 (table), 116–117
- calibration requirements, 320–323
- calibration schedule. *See* calibration frequency
- calibration solutions, 181–182
- calibration standards, 25 (table), 26, 29–30, 43 (table), 113 (table), 114, 135, 137, 138
- californium, 418
- calorific value, 340
- capability, 103. *See also* test method capability trends; *TPI_{industry}*
- carbon, 426 (table), 434, 452, 455–456, 455 (figure), 456 (figure), 459, 461 (figure), 461 (table), 462 (figure)
- carbon balance, 338
- carbon fraction parameters, 445 (table)
- carbon particle emission, 183
- carbonyl functionalities, 474 (table)
- cation analysis, 502 (figure)
- caustic washing, 502, 504 (figure)
- cellulose ethanol, 627
- certification methods, 116
- certified reference material (CRM), 25 (table), 43 (table), 113 (table)
- channeltron, 314
- characteristic radiation, 350–351, 356
- charts. *See* quality control charts
- check standard, 25 (table), 44 (table), 113 (table)
- Chemical Analysis: A Series of Monographs on Analytical Chemistry and Its Applications*, 209
- chemical interferences, 137
- chemical shift anisotropy (CSA), 458
- chemical shift ranges, 425 (table), 426 (table)
- chemical speciation, 220
- chemical suppression, 497–499, 497 (figure), 498 (figure)
- chloride, 335, 634–636
- chlorine, 400 (table), 401 (table)
- chromatogram, 272 (figure)
- chromatographic atomic spectrometric methods, 269
- chromatography, 4–5, 511, 523–524
 - gasoline analysis and, 519
 - hydrocarbon analysis and, 515–519
 - instrumentation and, 511–514, 522–523, 524–530
 - simulated distillation and, 519–523, 520 (table)
 - See also specific types*
- class I apparatus, 27
- class II apparatus, 27
- class III apparatus, 27

cleaning, 157
coal, 437–439, 439 (figure), 459–461
 mercury in, 565, 570–571, 571
 (table), 572 (table)
coal combustion residues, 570–571
Cochran test, 61
coke oven gas, 324
coke production process, 323–328,
 324 (table), 326–327 (table), 329
 (figure)
Coker mid-distillate, 485 (figure)
cold vapor atomic absorption
 spectrophotometry (CVAAS), 142,
 142 (table), 569, 570
collection optic, 398 (table), 399
 (figure)
collimators, 354
combustion air requirement index
 (CARI), 342
combustion ion chromatography,
 506–509, 507 (figure), 508 (figure)
Combustion IP Prep Station, 508,
 506–509, 507 (figure), 508 (figure)
commercial condensate, 267–280,
 267–268 (table)
common cause, 44 (table)
compensation methods, 370
composition-property relations, 448
 (table), 452 (table)
Compton correction, 362–364, 370
condensate samples, 265, 266, 272
condition monitoring, 488–492
conductivity detector, 497–499
conostan mercury standard, 266
consensus values, 127 (table)
continuous improvement, 79, 87
 (figure)
continuum absorption, 159
control chart, 31, 44 (table), 48 (table)
control limits, 44 (table)
copper, 628–629
corn, 627
correlation spectroscopy, 432 (figure)
Council of European Nations (CEN)
 Interlaboratory Study, 552, 553
 (table)
cross check, 54–55, 75, 148 (table),
 405, 407 (table)

cross talk, 321, 321 (table)
crude oil, 145–146, 165 (table),
 217–220, 300–301 (table), 302
 (figure), 414 (figure), 441, 450, 621
 (table)
 analysis, 607–620
 gas chromatography and, 515,
 516 (figure)
 inductively coupled plasma–
 atomic emission spectrometry
 (ICP-AES) analysis of, 189–194,
 191 (table), 192 (table), 193
 (table), 194 (table)
 mercury in, 571–572, 572 (table)
 reference material, 620–621
 sampling and, 607–610, 607
 (table)
 sulfur in, 541, 542 (table)
 trace elements, 505–507, 506
 (table)
crystal optics, 394–397

D

D1688A, 628–629
D2445, 290, 307–308 (table)
D2622, 105, 543, 546, 630–631
D2650, 289
D2786, 290
D2789, 290
D3239, 290
D4294, 385, 546–547
D4806, 628
D4814, 628
D4927, 547
D4951, 548, 630
D5185, 548, 592
D5292-99, 452
D5453, 549
D5708, 609 (table)
D5798, 628
D5863, 609 (table)
D6259, 64
D6299, 64
D6300, 64
D6445, 386
D6481, 386
D6617, 64–65
D6667, 550

D6708, 65
D6751, 628
D7039, 548, 633–634
D7171, 435
D7212, 386
D7220, 386
D7372, 74
D7414, 601
D7415, 601
D7417, 601
D7590, 601
D7624, 601
D7691, 609 (table)
data distributions, 86. *See also*
 histograms
data normality checks, 86
De Jongh algorithm, 366–367
degrees of freedom, 44 (table)
density of mixture, 342
detection limit, 44 (table), 142, 142
 (table), 147, 149–150 (table)
 graphite furnace atomic
 absorption spectroscopy and,
 162
 in hydrocarbons, 199
 inductively coupled plasma–
 atomic emission spectrometry
 (ICP-AES) and, 179 (table), 193
 (figure)
 mercury testing and, 266–267
detector, 141, 378–382, 411, 412, 511
 chromatography and, 524–530
 conductivity, 497–499
 infrared, 481
 in wavelength-dispersive X-ray
 fluorescence (WD-XRF)
 spectrometry, 355–357
 See also specific detectors
detector filter, 379
diesel, 163, 389, 406 (table), 430
 (figure), 431 (figure), 433 (figure),
 441–442, 445–446, 451 (figure), 534
 (figure), 541, 543 (table)
diffraction, 352 (figure), 352
diffuse reflectance measurement, 483
 (figure)
diffusion, 435
dilution rate, 227

diphenylmercury (DPM), 264, 265
direct dilution, 189, 191
direct injection high-efficiency
 nebulizer (DIHEN), 225
direct injection high-efficiency
 nebulizer–inductively coupled
 plasma isotope dilution mass
 spectrometry, 225
dispersive systems, 477–478
distortionless enhancement by
 polarization transfer (DEPT),
 431–432
Dixon test, 61
doubly curved crystal (DCC), 392,
 393–398
drift correction monitors, 38
drinking water, 503
Dryfus, S., 217, 218
Dumarey equation, 274
duplicate intralaboratory test results,
 61–62
Duyck, 217, 220

E

E1301, 74
electrolytic eluent, 495
electron impact ionization, 289, 312
 (figure)
electron impact-mass spectrometry
 (EI-MS), 291–292
electron-hole pair, 380
electronic transitions, 376 (figure)
electrothermal atomic absorption
 spectrometry (ETAAS), 223
electrothermal vaporization (ETV),
 215
element loss, 158, 159
element oxides, 158–159
elemental analysis, 216 (table)
elemental determinations, 210
elemental distribution, 193 (table)
elemental properties, 158
eluent, 494–495, 499
emission interferences, 137
emissions, 35, 541
Energy Policy Act (2005), 625–626
energy-dispersive X-ray fluorescence
 spectrometer, 287 (table), 377

(figure), 377–382, 378 (figure), 380 (figure), 381 (figure), 382 (figure), 383 (figure), 384 (figure)
engineers, 208
enhancement, matrix effect, 361–362
environmental degradation, 627
Environmental Protection Agency (EPA), 389, 554, 558, 565, 568, 571, 574
equipment, 28, 29 (table). *See also* instrumentation; temperature measuring device
equivalent precision, 61, 63
ethanol, 625, 626–627
 interlaboratory crosscheck and, 637–638
 testing and, 628, 629 (table), 630–637
ethanol-gasoline blend, 559–560, 561 (table), 626
ethylene cracker effluent gas analysis, 328–330, 330–333
ethylene cracking furnace, 330 (figure)
ethylene oxide, 335 (table), 337 (table)
excitation optics, 397, 398 (table)
exploration, 502
explosion-proof, 280

F

Faraday cup, 313, 313 (figure)
fatty acid methyl esters (FAME), 456–457, 458, 549, 600
filter furnace, 166
filter-based infrared spectrophotometer, 479
final blend gasoline analysis, 519
fit for use, 44 (table)
flagged data, 84–85
flame atomic absorption spectrometry (FAAS), 223
flame ionization detector (FID), 511
flame photometric detector, 528–530, 529 (figure)
flame source, 140
flow counter gas proportional detector, 355, 357–358

fluid catalytic cracker (FCC), 428 (figure), 450
fossil fuels, 118, 233–236
Fourier-transform (FT) instruments, 47, 478–479, 479 (figure), 489 (figure)
Fourier-transform infrared spectroscopy (FT-IR), 235, 489–492, 594–598
fragmentation, 333 (table), 337 (table)
free carbon index (FCI), 455–456
free induction decay (FID), 424–425
F-test, 81, 83, 93, 94
fuel gas production gas analysis, 340–346
fuel gas sources, 343–345 (table)
fuel oils, 163, 181 (table), 186 (table)
fume hoods, 177
fundamental parameter method, 362

G

Gallegos, E. J., 294–295
gamma ray measurements, 410–412, 414 (figure)
gas amplification factor, 357
gas chromatogram, 522 (figure), 523 (figure), 524 (figure)
gas chromatographer, 511–512, 512 (figure)
gas chromatography analysis, 12 (table), 12–14, 39–40, 446–447, 449, 449 (figure). *See also specific techniques*
gas chromatography–atomic fluorescent spectrometry (GC-AFS), 272
gas chromatography–inductively coupled plasma–mass spectrometry (GC-ICP-MS), 226, 230, 232, 270
gas chromatography–mass spectrometry (GC-MS), 211, 297–311
gas chromatography–mass spectrometry–fluorescent indicator (GC-MS-FID), 302 (figure), 307–308 (table)

gas chromatography-microwave
induced plasma-atomic emission
spectrometry (GC-MIP-AES), 269
gas displacement pump, 176
(figure)
gas feed furnace effluent, 331
gas-filled detector, 380
gasoline, 145, 163, 196, 197, 200
(table), 201-202, 428 (figure), 450,
516 (figure), 516 (table), 519
GC-field ionization mass
spectrometry (GC-FIMS), 523-524
generic laboratory equipment,
29 (table)
goniometer, 354-355
good laboratory practice (GLP), 44
graphite furnace, 16, 159, 166, 167
(figure)
graphite furnace atomic absorption
spectrometry (GFAAS), 156, 161
(table), 166-167, 585
applications, 162-166
crude oil and, 610
instrumentation, 156-158,
159-160
interferences, 158-159
measurements, 161 (table)
procedures, 160-162
graphs, 82 (table), 100-102, 101
(figure), 102 (figure)
Grating spectrophotometer, 477
(figure)
Gray, A. L., 211
group type analysis, 304-305 (table)
guard column, 495-496

H

health hazard, 236
heat stable salts (HSS), 500, 501
(table), 501 (figure)
heavy oil analysis, 191 (table),
192-193, 450-451
hexamethyldisiloxane (HMS), 203
hexanes, 198 (figure), 199 (table), 200
(table)
high field nuclear magnetic
resonance (NRM) spectroscopy,
429-434, 443-462

high performance liquid
chromatography, 229, 230, 531,
531-532 (table), 532-534
high performance liquid
chromatography-inductively
coupled plasma-mass spectrometry
(HLPC-ICP-MS), 230
high vacuum chamber, 317 (figure)
high-resolution Ge(Li) detector, 411
high-resolution mass spectrometry,
293-297, 295 (table)
high-resolution nuclear magnetic
resonance (NRM) spectroscopy,
427-429, 439-443, 440 (figure), 441
(figure), 442 (figure), 443-457
histograms, 82 (table), 86-91, 87-91
(figure)
historical statistics, 93
hollow cathode lamps, 140
Houk, R. S., 211
Hwang, J. D., 567-568
hydrocarbon feedstock, 309-310
(table)
hydrocarbons, 195-201, 221, 232
(figure)
infrared (IR) absorption detailed
analysis and, 515-519, 517
(table), 518 (table)
infrared (IR) and, 475-477
liquid, 268-270, 277-280, 282
(figure)
mercury in, 258-259, 262,
268-270, 277-280, 281 (figure)
type analysis, 299-300 (table), 532
types, 446
vaporization of, 264 (table)
See also crude oil; separation
mechanisms
hydrodemetalization, 229
hydrotreating heavy vacuum gas oil
(HVGO), 309, 309-310 (table)
hyperpure germanium detector, 411

I

ICP Information Newsletter, 209
ICP-MS detection system, 530, 530
(figure)
ID-ETV-ICP-MS, 235

- in torch vaporization (ITV), 215
- Indian Oil Corporation, 446–447, 449
- inductively coupled plasma–atomic emission spectrometry (ICP-AES), 7 (table), 66–67, 170, 174
 - crude oil and, 616, 616 (table), 617 (table)
 - detection limits and, 179 (table)
 - petroleum industry methods and, 185–204
 - short term precision and, 180 (table)
 - solvent selection and, 170–171, 172, 174 (table), 174–175, 204–205
 - used oil and, 588, 591–594, 591 (table)
 - See also* organic inductively coupled plasma–atomic emission spectrometry (ICP-AES)
- inductively coupled plasma–atomic emission spectrometry (ICP-AES) test methods, 34–35, 66–67 (table)
- inductively coupled plasma–mass spectrometry (ICP-MS), 192–193, 209, 210, 223–224, 236
 - books, 212–214 (table)
 - crude oil analysis and, 217–220, 610–613, 612 (table), 617 (table)
 - fossil fuels and, 233–236
 - historical development and, 210–211, 214–216
 - metal determination, 221–223
 - specialization analysis and, 229–232
- influence coefficient algorithms, 364–370
- infrared (IR), 473, 475–477, 476 (figure). *See also* infrared spectroscopic analysis
- infrared (IR) absorption, 473–476, 481
- infrared detector, 481
- infrared spectroscopic analysis, 11 (table), 38–39, 69, 473–477, 484–488, 489–492
 - instrumentation and, 477–481
 - sampling and, 481–484
- injection, 495
- inspection, 42
- instrumental neutron activation analysis (INAA), 222, 411, 412 (table), 413, 420, 572–573
- instrumentation
 - atomic absorption spectrometry (AAS) and, 135–137, 136 (table), 140–141. *See also* atomic absorption spectrometry
 - atomic florescent spectrometry and, 247–248, 251 (figure), 253 (figure), 258
 - energy-dispersive X-ray fluorescence spectrometry and, 377–382, 377 (figure), 378 (figure), 380 (figure), 381 (figure), 383 (figure)
 - graphite furnace atomic absorption spectrometry (GFAAS) and, 156–158, 159–160, 160–162
 - inductively coupled plasma–atomic emission spectrometry (ICP-AES) and, 66, 176–178, 195–197, 197 (figure)
 - inductively coupled plasma–mass spectrometry (ICP-MS) and, 211, 214, 216
- infrared spectroscopic analysis and, 477–481
- ion chromatography and, 494–500, 495 (figure)
- mass spectrometry and, 287–289, 288 (figure), 315–318, 316 (figure), 317 (figure)
- monochromatic wavelength dispersive X-ray fluorescence and, 392–397
- nebulization and, 195–197, 199–201
- nuclear magnetic resonance (NRM) spectroscopy, 426–434
- X-ray fluorescence (XRF) spectrometry and, 349, 351 (figure), 351–360

- interferences, 66, 137
 - graphite furnace atomic absorption spectrometry (GFAAS) and, 158–159
 - monochromatic wavelength dispersive X-ray technology and, 403–404, 405 (table)
 - organic inductively coupled plasma–atomic emission spectrometry (ICP-AES) and, 183–185
 - sulfur and, 547, 548
 - interlaboratory crosscheck programs, 589–601. *See also* ASTM ULSD ILCP
 - interlaboratory test results, 61–63
 - internal standard method, 364, 368
 - internal standards (IS), 183–184
 - International Union of Pure and Applied Chemistry (IUPAC), 138
 - intertechnique comparison, 147 (table)
 - Intralaboratory Cross Check Program (ILCP), 75, 76, 77–78 (table), 79, 80 (table), 94, 97 (figure), 119, 122, 613, 637–638
 - investigations, 84, 85 (table)
 - ion chromatograph, 494–500, 495 (figure), 496 (figure). *See also* ion chromatography (IC)
 - ion chromatography (IC), 494–500, 495 (figure), 514, 523, 636 (table)
 - combustion, 506–509, 507 (figure), 508 (figure)
 - methods, 500–509, 509–510 (table)*See also* ion chromatograph
 - ion masses, 291 (table)
 - ion trap mass spectrometers, 316
 - ionization, 289–290, 293, 312–313, 357
 - ionization interferences, 137
 - ionization modes, 298
 - ionization technique, 289–290
 - Iowa, 627
 - IP value, 314–315
 - iron, 216, 605, 607
 - irradiation, 36, 410–412
 - isotope dilution–inductively coupled plasma–mass spectrometry, 225
 - isotope dilution mass spectrometry (IDMS), 578
 - isotope dilution–cold vapor–inductively coupled plasma–mass spectrometry (ID-CV-ICP-MS), 577–578
- J**
- jet fuel, 9 (figure), 585
 - Johann geometry, 395 (figure), 395–396
 - Johansson geometry, 395 (figure)
 - Joint Oil Analysis Program (JOAP), 585
 - Journal of Analytical Atomic Spectrometry* (JAAS), 209
- K**
- Kelly, W. R., 118
 - Kirchoff, Gustav, 4
- L**
- laboratory capability, 51–52, 54
 - laboratory precision, 51–52, 74, 128, 130 (table), 131
 - laboratory quality management, 48–57
 - laboratory records, 82 (table)
 - laboratory staff, 84
 - laboratory standards, 53. *See also* reference material
 - Lachance (Cola) algorithm, 367–368
 - Lachance-Traill algorithm, 364–365
 - laser ablation (LA), 215
 - laser ablation–inductively coupled plasma–isotope dilution mass spectrometry, 225–226
 - LC analysis, 14 (table)
 - LC-ELSD, 303 (table)
 - lead, 143–144, 162, 227, 234–235
 - Lienemann, C. P., 220, 221
 - light absorption, 136
 - light rare earth elements (REEs), 218
 - light source, 136
 - “like dissolves like,” 171
 - linear regression, 400

liquid chromatography, 512–514, 513 (figure), 533 (figure)
 high performance, 531, 531–532 (table), 532–534
liquid feed furnace effluent, 331 (table)
liquid petroleum gas (LPG), 500, 502
liquid-state nuclear magnetic resonance (NRM) spectroscopy, 443–457
logarithmic spiral doubly curved crystal (DCC), 396–397
log-spiral collection optics, 398
low field nuclear magnetic resonance (NRM) spectroscopy, 427–429, 434–443, 436 (figure)
low flow nebulizers, 197, 199–200
low-resolution nuclear magnetic resonance (NRM) spectroscopy, 426–427
low-resolution quantitative methods, 289–293
lube additives, 71 (table)
lube oil, 89 (figure), 125–126 (table), 127 (table), 128 (table), 299 (table)
 calibration resource material, 122–123, 127–128
lubricating oils, 122–123, 127–128, 144 (table), 147 (table), 148 (table), 164, 187–190, 193–194, 228–229, 388 (table), 543 (table), 593
Lumex method, 575
L'Vov, Boris, 156

M

magnet systems, 426
magnetic field, 160, 424, 426, 434–439, 439–443, 443–462
magnetic mass spectrometers, 292
magnetic-sector mass spectrometers, 316
mass balances, 28
mass doublets, 295 (table)
mass spectra, 21
mass spectrometry, 287, 320–323, 500
 analysis and, 323–346
 gas chromatography, 297–311

 high resolution, 293–297, 295 (table)
 instrumentation and, 287–289, 288 (figure), 315–318, 315 (figure), 316 (figure), 317 (figure)
 low resolution, 289–293
 principles, 311–315, 312 (figure), 313 (figure), 314 (figure)
 sampling techniques, 318–319, 319 (figure)
 See also process mass spectrometry; *specific types*
matrix correction, 362–370, 403 (figure), 404 (table)
matrix effects, 360–371, 401–403, 576. *See also* interference
matrix elimination, 504–506
matrix interferences, 137, 183–184
 “matrix matched,” 182
matrix modifiers, 159, 190, 191
mean, 83, 105–107
mean (X) graphs, 100–102, 101 (figure), 102 (figure)
measurement compatibility, 112
membrane sampling system, 319
mercury, 246, 247, 252, 261 (figure), 565–567, 566 (table), 579 (table), 580
 analytical methodology, 568, 572–578
 collection efficiency of, 258 (table)
 commercial condensate and, 267–268, 267 (table), 268–280
 in hydrocarbons, 258–259, 262, 277–280, 281 (figure)
 instrumentation for, 270–273
 in natural gas, 253–258, 257 (figure), 260 (table), 261–267, 267–283
 on-line determination, 273–275
 in petrochemicals, 253–255, 260 (table), 261 (table), 262–267
 in petroleum products, 569–572.
 See also specific fuels
 sampling, 567, 568
 speciation, 269–273
 storage, 567–568

See also atomic florescent spectrometry (AFS), instrumentation
mercury analyzer, 258
mercury speciation, 577 (table)
mercury values, 219–220
metal concentration, 33, 613 (table), 614 (table)
metal determination, 135, 142–143, 146 (table). *See also* atomic absorption spectrometry (AAS)
metals, 72 (table)
 calibration and, 33
 trace, 145. *See also* trace elements
 wear, 144, 188
 See also specific metal
method development, 112
micellar electrokinetic capillary chromatograph (MECC) method, 230
Michelson interferometer, 478, 478 (figure), 479
microchannel plate, 313–314, 314 (figure)
microemulsions, 192, 218
microwave digestion, 190, 191, 194, 219, 233
middle distillates, 292
middle-distillate fuels, 189
molecular absorption, 159, 160
molecular weight, 306 (table)
molybdenum, 203 (figure)
monochromatic wavelength-dispersive X-ray fluorescence (MWD-XRF), 392, 393 (figure), 405–408
 doubly curved crystal (DCC) and, 393–397
 focused beam and, 392–393
 sulfur and, 548
 sulfur chlorine and, 398–401, 398 (table), 399 (table)
monochromator, 135, 136, 141
Morrison, G. H., 118
Moseley, Henry, 374
motor oil, 582–584
MS analysis, 8 (table)

multichannel gamma ray analyzer, 410–411
multicollector (MC), 216
multiple linear regression (MLR), 450
multivariate calibration techniques, 322–323

N

Nadkarni, R. A., 70, 118, 174, 224
naphthas, 194–195, 201–204, 202 (figure), 203 (figure), 203 (table), 204 (table), 220
naphthenes, 515, 518 (table)
natural gas, 246–247, 256 (figure), 500, 502
 condensate, 267, 268, 269–270
 liquid, 275–277, 277 (figure), 278 (figure)
 mercury in, 253–259, 260 (table), 261 (figure), 262–267, 267–283, 569–570. *See also* mercury sampling techniques and, 256–258
 See also atomic florescent spectrometry (AFS)
Natural Institute of Science and Technology (NIST), 45 (table), 554–555, 620–621
 calibration standards and, 30
 reference materials, 120–122 (table)
 standard reference material and, 54, 55 (table), 217–218.
 See also standard reference material
near infrared (NIR)
 spectrophotometer, 484
nebulizers, 141, 175–176, 178, 188, 195–197, 214–215
 low flow, 197–200
 See also specific types
neuron activation analysis, 118
neurotoxin, 227
neutron activation analysis (NAA), 36, 410–412, 413 (figure), 419 (table)
 crude oil and, 617, 618 (table)
 fast, 414–418, 416 (table)
 radiochemical, 412–413
 substoichiometric, 418

neutron source, 418
nickel, 163 (figure), 164, 198 (figure),
216, 605, 607
Nippon Instrument Corporation's
(NIC) mercury analyzer, 573–575
NIST SRM 1848, 588, 593 (table)
NIST Standard Reference Material
1848, 123 (table), 124 (table)
nitration, 491 (figure)
nitric oxide (NO), 297
nitrogen, 417, 605
nitrogen chemiluminescence
detector, 525 (figure), 526 (figure),
526–527
nonspecific absorption, 159–160
non-spectroscopic techniques, 16
(table)
NP-LC, 532
NRM analysis, 10 (table)
nuclear magnetic resonance (NRM)
spectroscopy, 423–426, 229
(figure), 430 (figure), 431 (figure),
447 (figure), 451 (figure), 453
(figure), 462–463
instrumentation and, 429–434
low field, 427–429, 434–439,
439–443
low-resolution, 426–427
high field, 429–434, 443–462
high-resolution, 427–429, 439–
443, 440 (figure), 441 (figure),
442 (figure), 443–457
nuclear magnetic resonance (NRM)
spectroscopy parameters, 39,
443–447, 445 (table), 446 (table),
453–454, 458–459

O

off-gas sampling, 334 (figure), 337
(table)
offshore oil, 218
oil analysis, 17 (table). *See also*
specific oil
olefins, 515
on-line analysis, 323, 324, 328
on-line sulfur determination, 558–559
¹H. *See* nuclear magnetic resonance
(NRM) spectroscopy

organic inductively coupled plasma–
atomic emission spectrometry
(ICP-AES), 170–175, 171 (table)
analysis procedures, 178–183,
181 (table), 186 (table)
detection limits, 179 (table)
inferences, 183–185
instrumentation and, 175–178
See also inductively coupled
plasma–atomic emission
spectrometry (ICP-AES)
organic liquids, 199 (table)
organomercurial compounds, 269,
270–271, 272 (table)
organometallic standards, 33, 139,
144
organo-silicon compounds, 202,
216–217
outliers, 45 (table), 60–61
out-of-statistical-control data, 45
(table), 50, 51
oxidation, 489 (figure), 490 (figure)
oxygen, 177–178, 195, 217, 417

P

“particle size independent” method,
188–189
peak profiles, 160–161
pentanes, 198 (figure)
performance improvements, 53
(table)
peristaltic pump, 66–67, 175, 176
(table)
petroleum coke, 194
petroleum products. *See specific*
products
phosphate antiwear additives, 601
phosphino-polycarboxylates (PPCA),
222–223
phosphorus, 164, 222, 632
phosphorus compounds, 528–529
photoelectric process, 350–351
photometric test methods, 32, 32
(table)
photomultiplier tube, (PMT), 525
PIONA multidimensional analyzer,
516, 517 (table), 518 (table)
pipelines, 254

- platinum group elements (PGEs), 234
 - pneumatic nebulizers, 175, 221
 - pneumation, 197, 200–201
 - point-focusing doubly curved crystal optics, 395
 - polarization, 382, 383 (figure)
 - polars, 171
 - polyethylene, 338, 339 (table), 339–340
 - polyethylene production gas analysis, 338–340, 341 (table)
 - polytetrafluoroethylene (PTFE), 257
 - pooled limit of quantization (PLOQ), 45 (table)
 - pooled standard deviation, 81
 - porphyrins, 605–606
 - Practice for Applying Statistical Quality Assurance Techniques to Evaluate Analytical Measurement System Performance (D6299), 64
 - Practice for Determination of a Pooled Limit of Quantization (D6259), 64
 - Practice for Determination of Precision and Bias for Use in Test Methods for Petroleum Products and Lubricants (D6300), 64
 - Practice for Laboratory Bias Detection Using Single Test Result (D6617), 64–65
 - Practice for Statistical Assessment and Improvement of the Expected Agreement Between Two Test Methods That Purport to Measure the Same Property of a Material (D6708), 65
 - precision, 45 (table), 74, 94, 128–131, 130 (table), 322
 - crude oil and, 613 (table), 614 (table), 619 (table)
 - mercury testing and, 265–266
 - sulfur and, 630–637, 634 (table), 635 (table)
 - See also* precision ratio (PR); precision test program (PTP)
 - precision ratio (PR), 45 (table), 49
 - preventative action, 52
 - problem solving, 208, 210 (table)
 - process capacity index (CpK), 44 (table)
 - process mass spectrometry, 311–315
 - instrumentation and, 315–318, 315 (figure), 316 (figure), 317 (figure)
 - sampling techniques, 318–319, 319 (figure)
 - process nuclear magnetic resonance (NRM) instrumentation, 427–429
 - product specification, 63
 - proficiency test programs (PTP), 74–75, 76–84, 84–97, 98–110, 116
 - proficiency test programs (PTP) report, 82 (table)
 - proficiency test programs (PTP) toolkit, 79, 82 (table)
 - proficiency testing, 45 (table), 75
 - proportional counter, 380 (table), 384 (figure)
 - proton chemistry, 430 (figure)
 - proton types, 425, 444 (table)
 - PSA method, 575–576
 - pulse height selection, 356–357
 - pumping device, 175, 315 (figure)
 - pyrolysis, 157, 160
 - pyrolysis curve, 163 (figure), 164
- Q**
- quadrupole inductively coupled plasma–mass spectrometry (QICP-MS), 215
 - quadrupole mass analyzers, 292–293
 - qualitative analysis, infrared, 484–485
 - qualitative wavelength–dispersive X-ray fluorescence (WD-XRF) spectrometry analysis, 352
 - quality assurance, 42, 48, 45 (table).
See also laboratory quality management; quality control; quality protocols; statistical data handling
 - quality components, 65–73
 - quality control, 42, 45 (table), 53, 54
 - quality control charts, 50, 51, 82 (table)
 - quality control frequency, 49, 50 (table)

quality control sample, 46 (table), 49–50
quality control standard, 113 (table), 114
quality disputes, 61–63
quality index, 46 (table)
quality management, 46 (table)
quality protocols, 65–73
quantitative analysis, 360–362, 485–486
quantitative wavelength-dispersive X-ray fluorescence (WD-XRF) spectrometry analysis, 352
quantum detector, 481

R

radiochemical neutron activation analysis (RNAA), 413–413
radioelement, 415
radioisotope, 277
rare earth elements (REEs), 218
Rasberry-Heinrich algorithm, 365–360
Rayleigh scattering, 362–363
readouts, 142
recovery performance, 264, 265 (figure), 265, 266 (table)
reference composition, 366
reference material (RM), 25 (table), 30, 46 (table), 53–54, 112, 113 (table), 114–116, 115 (figure), 120–122 (table)
 calibration, 114–116, 115 (table), 116–117
 crude oil and, 620–621, 621 (table)
 National Institute of Science and Technology (NIST) and, 120–122 (table)
 storage, 115 (table)
 sulfur determination and, 561, 561–563 (table)
 See also reference material (RM) values; reference standards
reference material (RM) values, 116–117
referenced standards, 40–41 (table), 48, 108–110 (table)

refining, 500–502
Reformulated Gasoline Program, 224
relative bias, 46 (table), 98
relative standard deviation (RSD), 104–105, 105 (figure), 105–107, 106 (figure), 107 (figure)
renewable fuels standard (RFS), 625
repeatability, 31, 46 (table), 61–62, 405, 408 (figure)
replicate testing, 61
representative sample, 46 (table)
representative sampling, 64–65
reproducibility (R), 46 (table), 405, 408 (figure), 555, 556–557, 557 (table)
residual fuel oil, 117, 118 (table), 119 (table), 145–146, 233
 inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis of, 189–194, 191 (table), 192 (table), 193 (table), 194 (table)
resolving power (RP), 293–294
reststrahlen, 482
result tables and statistical summary, 82 (table)
reverse phase liquid chromatography (RP-LC), 513–514
robust statistics, 82 (table)
root cause investigation guide, 82 (table)
rotating disc electrode emission spectrometry, 586, 588
rounding-off, 59–60, 61 (table)
Rowland circle, 394–395 (figure)
 $R_{\text{these data}}$, 103
run chart, 46 (table)

S

Saint Pierre, 228
salt monitoring, 501 (figure).
 See also heat stable salts (HSS)
sample analysis, 161–162, 182–183
sample dilution, 188, 190
sample distribution, 79
sample introduction, 138

- sample preparation technique,
190–192, 504–509
- sample solution, 136
- sample storage, 37
- sampling, 64–65, 65 (table), 256–258,
257 (table)
 crude oil and, 607–610, 607
 (table)
 infrared, 481–484
- sampling system, 274 (figure), 274,
278 (figure), 584–585
- saturation vapor pressure, 174
(table)
- scan/selective ion monitoring (SIM),
287
- scattering crystal, 382
- scintillating crystal, 359
- scintillation detector, 355, 359–360
- scrubbing, 500
- selenite (Se-IV), 230
- selenocyanate (SeCN), 230
- semiconductor detector, 380–381
- separation column, 495–496, 511
- separation mechanism, 512, 513.
 See also separation column
- short-term precision, 180 (table)
- Si, 203, 203 (table), 204 (table)
- sigma detection limits, 198 (figure)
- signal-to-noise ratio, 382, 383
- silicon, 144, 194, 201–204, 417–418
- “silicon crisis,” 201
- silicon-drift detector (SDD), 381, 381
(figure)
- simulated distillation, 519–523, 520
(table)
- single pulse excitation (SPE) MAS,
457–459
- single-channel analyzer (SCA), 399
(figure)
- site precision, 47 (table), 97
- size exclusion chromatography (SEC),
229
- slurry analysis, 166
- S-O compounds, 549 (table), 633
(table)
- SOA standard, 49, 50
- sodium, 216, 605, 606
- software, 275
- solid state nuclear magnetic
resonance (NRM) spectroscopy,
433–434, 457–462, 460 (table), 463
(table)
- solvent aspiration rate, 172 (table),
173 (table)
- solvent selection, 170–171, 172–174
(table), 174–175
- solvents, 162
- sour gases, 500
- soybeans, 627
- speciated isotope dilution mass
spectrometry (SIDMS), 278
- speciation, 229, 269
- spectral interference calibration, 182
- spectral interferences, 137
- spectral residuals, 486–487
- spectrochemical analysis, 3. *See also*
 specific methods
- spectrometer considerations, 178
- spectrometers, 38–39, 292, 298,
315–316, 316 (figure), 317–318,
349, 351 (table), 351–360,
428–429, 429 (figure). *See also*
 specific types
- spectrophotometers, 477–481, 477
(figure)
- spectroscopic methods, 17, 18–22
(table), 23
- spectroscopic techniques, 15–16
(table), 17 (table), 621 (table), 622
(table). *See also* *specific*
 techniques
- spectroscopy, 3–4
- spike compounds, 225, 226
- spike recovery, 203 (table), 204
(table)
- spray chambers, 176–177, 178, 184,
201
- stability test, 321–322
- standard addition method, 138
- standard deviation, 47 (table), 81,
83–84, 94, 105–107. *See also*
 relative standard deviation
- standard error of the mean, 80–81
- Standard Guide for Analysis and*
Interpretation of Proficiency Test
Program Results (D7372), 74

*Standard Guide for Proficiency
Testing by Interlaboratory
Comparisons* (E1301), 74

standard reference material (SRM),
47 (table), 53, 54, 113 (table),
117–119

crude oil and, 620–621

genesis of, 19, 122

graphite furnace atomic absorption
spectroscopy and, 162

from the National Institute of
Science and Technology, 578,
579 (table)

ware metal and, 592 (table)

Standard Test Method for Aromatic
Carbon Contents of Hydrocarbon
Oils by High Resolution Nuclear
Resonance Spectroscopy (D5292-
99), 452

Standard Test Method for Aromatic
Types Analysis of Gas-Oil Aromatic
Fractions by High Ionizing
Voltage Mass Spectrometry
(D3239), 290

Standard Test Method for Chemical
Composition of Gases by Mass
Spectrometry (D260), 289

Standard Test Method for
Hydrocarbon Type Analysis of Gas-
Oil Saturates Fractions by High
Ionizing Voltage Mass
Spectrometry (D2789), 290

Standard Test Method for
Hydrocarbon Types in Low
Olefinic Gasoline by Mass
Spectrometry (D2789), 290

Standard Test Method for
Hydrocarbon Types in Middle
Distillates by Mass Spectrometry
(D2445), 290

Standard Test Method for Hydrogen
Content of Middle Distillate
Petroleum Products by Low-
Resolution Pulsed Nuclear
Magnetic Resonance Spectroscopy
(D7171), 435

state-of-statistical-control chart, 47
(table)

statistical data handling, 57–65

statistical quality control (SQC), 47
(table)

statistical run rules, 50–52

statistics, 82 (table)

steam cracking, 328

stoichiometric air requirement, 342

storage. *See* reference material,

storage; sample storage

substoichiometric RNAA, 418

sulfate, 491 (figure), 634–635

sulfonate recovery, 633 (table)

sulfur, 15–16 (table), 99–100, 541–542,
605, 619, 619 (table), 620 (table),
630–638

in biofuels, 559–560

certified reference materials and,
561

in crude oil, 541, 542 (table)

in diesel, 87 (figure), 88 (figure),

90 (figure), 91 (figure), 97

(figure), 116, 451, 453 (table)

emissions, 224

in fossil fuels, 235, 541–542

in fuel oil, 216–217, 230, 541

interlaboratory studies and,
552–553

in jet fuel, 99 (figure)

on-line determination and, 558–559

oxides, 224

proficiency testing and, 553–554

relative standard deviation and,

103 (figure), 107 (figure)

in RFG, 103 (figure)

speciation, 526 (table)

test methods and, 542–551, 545

(table), 550 (table), 551 (table),

555 (table)

in ULSD, 92 (figure), 93, 94

(figure), 95 (figure)

See also ASTM ULSD ILCP

Program; sulfur determination

sulfur calibration, 35

sulfur chemiluminescence detection
(SCD), 231

sulfur chemiluminescence detector,
524–526, 525 (figure), 526
(figure)

sulfur determination, 384, 387, 389
(table), 389, 631–632, 633–634, 634
(table). *See also* sulfur
sulfur oxides, 541–542
supercritical fluid chromatography
(SFC), 514, 531, 535 (figure), 536
suppressed conductivity detection,
503 (figure)
suppressor, 497–499
surrogate mixtures, 488

T

T measurements, 435
temperature measuring device, 28
terminology, 43–48 (table)
test method capability trends, 103,
104
test methods
 biofuels and, 628–637
 chromatography and, 523–524
 comparison, 128
 crude oil and, 608, 608 (table),
 609, 609 (table)
 energy dispersive X-ray
 fluorescence and, 385–386,
 386–389
 graphite furnace atomic
 absorption spectroscopy and,
 164–166
 ion chromatography and, 506–
 509, 507 (figure), 508 (figure),
 510 (table)
 liquid chromatography and,
 531–532 (table)
 mercury and, 566, 569 (table), 570
 nuclear magnetic resonance
 (NMR) spectroscopy and, 440–
 441, 446–447, 449, 449 (figure)
 PIONA analyzer and, 517 (table)
 sulfur determination and,
 542–551, 544 (table), 545
 (table), 550 (table), 551 (table),
 555 (table), 628–637
 used oil and, 585–598, 591
 (table), 596 (table), 599 (table),
 602 (table)
See also ASTM test methods;
 specific test methods

test performance index (TPI), 47
(table), 49, 50 (table), 52 (table)
test result rounding, 59
test results, 59, 61–63
testing frequency, 49, 64
tetraethyllead (TEL), 197
tetralin, 184, 185 (figure), 193
(figure), 194 (figure), 202
tetramethylsilane (TMS), 202–204
thermal conductivity detector (TCD),
511
thermal ionization mass spectrometry
(TIMS), 216
thermal properties, 158
¹³C. *See* nuclear magnetic resonance
(NRM) spectroscopy
³⁴S/³²S isotope ratio, 225, 235
time domain nuclear magnetic
resonance (NRM) spectroscopy,
426–427
time-of-flight mass spectrometers,
298, 316, 317 (figure)
time-of-flight mass spectrometry
(TOF-MS), 215
timers, 28
tolerance, 30–31
toolkit. *See* proficiency test programs
(PTP) toolkit
torches, 177
total diatomics, 306 (table)
total ion chromatogram (TIC), 298
toluene solutions, 202, 203, 204
(table), 263–264
TPI_{industry}, 82 (table), 95–97, 96
(table), 97 (table), 103–104, 103
(figure), 104 (figure)
trace contaminate analysis, 507
(figure)
trace elements, 117, 118 (table), 119
(table), 145, 160, 165 (table), 219,
220, 411
 crude oil and, 605–607, 607
 (table). *See also* metal
trace metals, 145, 194–195, 216–217,
221–223
traceability, 25 (table), 26, 48, 112
transmittance, 475
trimethylarsine (TMAs), 246

troubleshooting, 208
true value, 47 (table)
T-test, 82 (table), 83, 84
tube furnace, 258

U

ultrasonic nebulizers (USN), 176, 177 (figure), 195–197, 196 (figure)
ultraviolet fluorescence (UV-FL), 549, 550
ultraviolet/visible light absorbance (UV/Vis), 500
uncertainty, 75
uncontrolled variables, 106
United States, 627–628
universal calibration, 195–196
used oil, 582, 602
 crosscheck programs and, 598–601, 598 (table)
 sampling, 584–585
 testing, 585–598, 591 (table), 596 (table), 599 (table), 602 (table)
USN microporous membrane desolvator (USN-MMD), 195, 197 (figure)

V

vacuum distillates, 163
vacuum gas oil (VGO), 450
vacuum system, 211, 287, 314–315, 317 (figure)
vanadium, 216, 217, 236, 605, 607
vapor pressure osmometry (VPO), 300
vaporization, 264 (table)
vaporization chamber, 262, 264
variance, 47 (table)
verification, 24–25
versatility, 288
viscosity, 143, 455
viscosity index (VI), 145
volatile elements, 166
volatile hydrocarbons.
 See hydrocarbons
volatility, 171, 174, 194–195, 204 (table)
volumetric glassware, 28

W

Walsh, Sir Alan, 4, 135
wavelength, 160, 198 (figure), 352–354, 363, 611, 611 (table).
 See also wavelength-dispersive X-ray fluorescence (WD-XRF) spectrometry
wavelength dispersive X-ray fluorescence (WD-XRF) spectrometry, 349, 351–360
 matrix effects and, 361–370, 371 (table)
 sulfur and, 543, 546, 547
wear metals, 144, 188, 582, 583 (table), 584 (table), 587 (table), 589, 589–590 (table), 592 (table), 595 (table)
weld crack, 255 (figure)
Winter Conference on Plasma Spectrochemistry, 208, 209–210
Wilhelm, Robert, 4
Wilhelm, S. M., 566
Wobbe index, 340
WSD spectrometer, 351 (figure)

X

X-ray attenuation, 349–350
X-ray cups, 38
X-ray diffraction, 352
X-ray fluorescence (XRF) spectrometry, 36–38, 36–37 (table), 376 (figure), 391
 ASTM test methods and, 385–386, 386–389
 crude oil and, 617–620, 620 (table)
 principles, 374–377, 375 (figure), 376 (figure)
 sulfur and, 544, 546, 548
 See also energy-dispersive X-ray fluorescence spectrometer; wavelength dispersive X-ray fluorescence (WD-XRF) spectrometry
X-ray fluorescence analysis, 9 (table), 68–69. *See also* wavelength dispersive X-ray fluorescence (WD-XRF) spectrometry; X-ray fluorescence (XRF) spectrometry

X-ray fluorescence test methods,
36–38, 68 (table), 69
X-ray source, 377
X-ray transmission (XRT)
instrumentation, 559
X-ray tube, 359–360, 378, 378
(figure), 392

xylene, 183–184, 184 (figure), 202

Z

Zeeman effect, 160, 575
Z-score, 75, 82 (table), 92–95, 94
(figure), 97 (table)