

## Index

### a

- absorption coefficient 286
- AC impedance analysis 239, 255, 257
  - Al/LiCoO<sub>2</sub>/electrolyte/carbon/Cu battery analysis 249–253
  - Al/LiCoO<sub>2</sub>/electrolyte/MCMB/Cu cell analysis 253, 254
  - diffusion coefficient 257
  - electrochemical method 239
  - electrode characteristic analysis, applications 247–249
  - equivalent circuit model 241–247
  - ionic conductivity 256
  - phase difference 240
  - principle 239–241
  - relative permittivity 254, 255
- active material slurry
  - electrode production 99
  - preparation of 329
- adsorption isotherms, IUPAC
  - classification 314
- adsorption kinetics, of carbon sample 315
- AFM. *See* atomic force microscopy (AFM)
- AFM equipment structure 301
- AFM *in situ* cell, structure 302
- Al current collector foil, C–H groups, comparison 224
- alloys 120
  - change in potential
  - of Sn–Li and Si–Li with varying lithium composition 122, 125
  - cracking in metal alloys 123
  - discharge capacity 121
  - Li, Li–Al, and Li–Si alloys 120
  - lithium alloying of loosely arranged micrometal particles 124
  - metal/alloy–carbon composites 128
  - minimizing volume expansion 123
  - multiphase lithium alloys 125
  - Sn–Co–C alloying 128, 129
  - Sn–Li equilibrium phase 122
- aluminum corrosion 226, 227
- aluminum current collectors, corrosion 259
- aluminum–electrolyte interfacial reactions 226
- aluminum metal cylindrical holder 298
- aluminum metal, thermodynamically unstable 225
- ammonium chloride (NH<sub>4</sub>Cl) 2
- amorphous carbon 100
  - carbon raw materials, and carbonization 117
  - electrochemical reactions
    - of low-crystalline carbon 102–108
    - of noncrystalline carbon 108–110
    - gaseous carbonization 117
    - liquid-phase carbonization 117, 118
    - reactions involving electrolytes 110–114
    - solid-phase carbonization 118
    - structure of 100–102
    - structural model 101
    - thermochemical characteristics 114–117
- animal electricity 1
- anode capacity 323
  - design of 323
  - potential balance, adjustment of 323
- anode degradation 324
- anode–electrolyte interfacial reactions
  - additives effect 212–214
  - interfacial reactions
    - at graphite (carbon) 209–211
    - noncarbonaceous anode and electrolytes 214–216
    - of lithium metal 203–209

- SEI layer thickness 211, 212
- anode materials 89
  - amorphous carbon 100–118
  - carbon materials 92–118
  - characteristics of 91
  - conditions 90, 91
  - development history of 89
  - graphite 92–100
  - half cell capacity 320
  - initial irreversible capacity of 321
  - lithium metal 91, 92
  - nitride anode materials 135–137
  - noncarbon materials 118–120
  - Li, Li–Al, and Li–Si alloys 120–123
  - metal/alloy-carbon composites 128, 129
  - metal oxides 130–135
  - metal thin-film electrodes 130
  - overview of 90, 91
- anode voltage 340
- anodic reactions, in organic electrolyte solutions 227
- anti-Stokes lines 277
- Armand reaction 19
- atomic force microscopy (AFM) 300, 301
- ATR. *See* attenuated total reflection (ATR)
- attenuated total reflection (ATR) 273
- audio quality, voltage 340
- audiovisual transmission devices 340
- Avogadro's number 314
  
- b**
- Baghdad battery 2
- basal-to-edge ratio 210
- batteries 9
  - capacity 15, 16, 320, 321, 344–347
  - anode 323
  - determined from open-circuit voltages of 320
  - evaluation of 347
  - of LiCoO<sub>2</sub> 321
  - measurement of 346, 347
  - characteristics 15
  - cycle life 17
  - discharge curves 17–19
  - energy density 16
  - power 16, 17
  - components 9
  - design 319, 320
  - basic principles 319
  - cathode/anode capacity ratio 323–325
  - electrode potential/battery voltage design 321–323
    - practical aspects of 325–327
    - discharge performance of 350
    - disruption of lithium ions 343
    - resistance 344
    - types 2
- battery cycle life 17
  - factors affecting 344
  - problems 343
  - significance of 342
- battery manufacturing process 327
  - assembly process 331–334
    - cathode tab welding/crimping/x-ray inspection/washing process 334
    - electrolyte injection process 334
    - jelly roll insertion/cathode tab welding/beading process 332, 333
    - winding process 331, 332
  - electrode coating 329, 330
  - electrode manufacturing process 328
  - electrode slurry, preparation of 328, 329
  - flow chart of 328
  - formation process
    - procedures and functions 334, 335
    - purpose of 334
  - roll pressing process 330
  - slitting process 330, 331
  - vacuum drying process 331
- battery performance 337
  - charge/discharge curves 341
    - adjustment of 339, 340
    - significance of 337–339
  - charge/discharge rate 347–349
  - discharge performance of 342
  - electrical energy 337
  - energy density 351
  - lithium secondary batteries 351
  - mobile applications 351, 352
  - overcharging 341
  - power density 351
  - temperature characteristics
    - high 350
    - low 349, 350
  - transportation applications 352
  - typical cycle life problems 343
- battery safety 325
  - basics of 65–68
  - and cathode materials 68, 69
  - reactions involving 69
  - thermal reactions 67
- battery voltage 321. *See also* voltage
  - electrode potential, relationship 322
- BET. *See* Brunauer-Emmett-Teller (BET)
- binders 181
  - functions 181, 182

- PVdF binders 185–187
- requirements of 182–185
- SBR/CMC binders 187–189
- Born–Oppenheimer approximation 78
- Bragg angle 265
- Bragg scattering 295
- Bragg's law 263
  - basal spacing 263
  - of diffraction 263, 264
- Brunauer-Emmett-Teller (BET) 312, 315
  - isotherms 314
  - plot 313
  - surface analysis 311–315
- C**
- cadmium 3
- California Air Resource Board (CARB) 352
- capacity 15, 16
  - degradation 324
  - effect of temperature on 19
  - metal elements, form alloys with lithium 119
- CARB. *See* California Air Resource Board (CARB)
- carbon anode
  - lithium ion batteries, design of 55
  - lithium secondary battery, redox reactions of 23
  - SEI characteristics of 213
- carbonate solvents
  - electrochemical decomposition of 195
  - lithium secondary batteries 148
  - LUMO energy levels 204
  - oxidative decomposition reactions of 196
  - reduction reactions of 196
- carbon–electrolyte interface 210
- carbon/electrolyte/lithium cell 248
- carbonization reactions 117
  - carbon raw materials and 117
  - gaseous 117
  - liquid-phase 117, 118
  - solid-phase 118
- carbon (SWCNT)/lithium battery
  - cross-sectional sem image of 299
  - electrolyte, thermal characteristics of 305
- cathode capacity, potential balance 322
- cathode degradation 324
- cathode–electrolyte interfacial reactions 216
  - interfacial reactions
    - phosphate cathode materials 223–225
  - oxide cathode materials
    - interfacial reactions 218–223
    - native surface layers of 217, 218
    - SEI layers of 218
- cathode materials 21, 23
  - battery characteristics of 28
  - charge and discharge curves 339
  - demand characteristics of 26, 27
  - development history 21
  - discharge potential curves 24–26
  - half cell capacity 320
  - initial irreversible capacity of 321
  - layered structure compounds 27–30
    - LiCoO<sub>2</sub> 30–34
    - LiMO<sub>2</sub>(M=Mn, Fe) 37–40
    - LiNi<sub>1-x</sub>Co<sub>x</sub>O<sub>2</sub> 34–37
    - lithium-rich phases 44–46
    - Ni–Co–Mn three-component system 40, 41
    - Ni–Mn System 41–44
  - Li<sub>x</sub>TiS<sub>2</sub>, structure 22
  - octahedral and tetrahedral sites 29
  - olivine composites 52
    - LiFePO<sub>4</sub> 52–55
    - LiMPO<sub>4</sub> (M=Mn, Co, Ni) 55–57
  - principle cathode materials 27
  - redox reaction of 23, 24
  - spinel composites 46
    - LiMn<sub>2</sub>O<sub>4</sub> 46–51
    - LiM<sub>x</sub>Mn<sub>2-x</sub>O<sub>4</sub> (M=Transition Metal) 51, 52
  - structure of densest oxygen layer 28
  - structure of layered LiMO<sub>2</sub> 30
  - TEM image 217
  - thermal stability of 65, 69, 70
    - LiCoO<sub>2</sub> complex oxide 70
    - LiFePO<sub>4</sub> active material 74, 75
    - Ni-Co-Mn three-component oxide 71, 73
    - spinel LiMn<sub>2</sub>O<sub>4</sub> 73, 74
  - vanadium composites 57, 58
- cathode physical properties 75–77
  - first-principles calculation 77
  - prediction from 76
  - potential difference 76
  - redox couple 76
- cathode tab welding process 334
- cathode voltage 341
- CCV. *See* closed-circuit voltage
- cell composition 249
- cell technology, development of 3
- chalcogen compounds 22
- charge balance 321, 322
- charge-coupled detector 277
- charge transfer 250
  - from electrochemical reactions 259
  - in electrode materials 231

- Faraday constant 259
- lithium secondary batteries 256
- rate-limiting process 14
- SEI layer 201
- charging voltage 13
- chemical ionization 310
- chromatography 306
- closed-circuit voltage (CCV) measures 231
- CO
  - gas 200
  - K-shell absorption edge 287
- C–O bond,  $\beta$ -decomposition 198
- Co–Co peak intensity 292
- Cole-Cole plot 241, 250
- lithium secondary battery 251
- conducting agents 189
- dispersibility 190
- modification of 191
- types of 189, 190
- and wettability of electrodes 190
- confocal microscopy 278
- constant capacity cutoff control 236
- constant current/constant voltage (CC/CV) 341, 347
- constant voltage charging 236
- conventional TEM (CTEM) 294
- CoO cathode material, SAED patterns 297
- core-shell particle shape 299
- Coulomb energy 78, 79
- Coulomb interactions 78
- covalent bonds 270
  - electromagnetic waves 270
  - graphene layers 92
  - infrared rays 270
  - $\text{Li}_2$  107
- CRT display 298
- crystalline materials 293
- crystalline phase identification 263, 264
- crystallinity 264
- crystallite size 264
- CTEM. *See* conventional TEM (CTEM)
- current 14, 16, 17, 19, 156, 178, 232, 348, 351.
  - See also* voltage
- current break 334
- current collectors 191
  - aluminum corrosion 226–228
  - aluminum surface, passive layers formation 228
  - anode 192
  - cathode 192
  - lithium bis-perfluoroalkylsulfonimide ( $\text{LiN}(\text{SO}_2\text{CF}_3)_2$ ) 226
  - native layer of aluminum 225, 226
  - requirements 192
  - role of 191
- current density 15, 18, 57, 60, 78, 79, 148, 267, 342
- current–voltage curves 232
- CV. *See* cyclic voltammetry (CV)
- cyclic carbonates
  - free radical state, resonance structure 199
  - oxidative decomposition reactions 199, 200
  - vinylene carbonate 200
- cyclic voltammetry (CV) 232
  - characteristics of 237
  - comparison 237
  - current–voltage 233, 234
  - graphite anode 232
  - redox reactions 232
  - reduction peak 211
  - *in situ* 303
- cylindrical batteries
  - dimensions of 346
  - electrochemical design factors of 326
  - physical design factors 325
- d**
- dark field (DF) images 295
- Debye–Waller factor 290
- DEC. *See* diethylene carbonate
- density functional theory (DFT) 79, 196
  - calculations 197
  - for EC 196
- DFT. *See* density functional theory
- diethylcarbonate 231
- diethyl carbonate
  - DSC thermogram of 306
  - lithium ethylene dicarbonate 207
- diethylene carbonate (DEC) 196
- differential scanning calorimetry (DSC) 302
  - of cathode, anode, and electrolyte 68
  - for EC 207
  - heat flux, equipment structure 304
  - of  $\text{Li}_x\text{CoO}_2$  71, 72
  - $\text{Li}_x\text{FePO}_4$  75
  - $\text{Li}_x\text{NiO}_2$  73, 74
  - thermogram 304
  - of EC/DEC 306
  - polyethylene terephthalate 305
- differential thermal analysis (DTA) 301
  - calorimetric 305
  - thermal capacity and enthalpy change 304
- diffraction
  - Bragg’s law of 263, 264
  - X-ray 265

- diffusion coefficient 250
  - of ions 257
  - of lithium 238
- diffusion, one-dimensional 250
- dimethyl carbonate (DMC) 6, 196, 232
  - electrochemical reduction potential of 196
  - graphite Timrex KS 44, charge/discharge curves 111
  - lithium metal/platinum electrodes, cell consists of 232
  - organic solvents, physicochemical properties of 143
  - oxidation potential 196
- dione 200
- discharging 10
  - lithium metal alloys 121
  - voltage 13
- DMC. *See* dimethyl carbonate (DMC)
- DSC. *See* differential scanning calorimetry (DSC)
- DTA. *See* differential thermal analysis
- e**
- EC. *See* ethylene carbonate (EC)
- EDS. *See* energy dispersive spectroscopy (EDS)
- electric current 1
- electric dipole 275
- electric potential 11, 12
  - battery 16
  - *versus* capacity 23
  - cathode material 24, 25, 75
  - circuit voltage 12
  - current flow 16
  - d-orbital electrons 25
  - electrodes 12
  - voltage 12
- electric resistance 343
- electric vehicles (EVs) 3
- electrochemical analysis 231, 234
  - constant current method
    - constant capacity cutoff control 236
    - cutoff voltage control 234–236
  - constant voltage method
    - charging 236
    - potential stepping test 236, 237
  - cyclic voltammetry 232–234
  - linear sweep voltammetry 232
  - open-circuit voltage 231, 232
- electrochemical cells 9
- electrochemical decomposition, nonaqueous electrolytes 195–200
- electrochemical equilibrium 236
- electrochemical oxidation 10
  - electrochemical quartz crystal microbalance (EQCM) analysis 257
    - charge transfer, from electrochemical reactions 259
    - corrosion reactions 259
    - device 258
    - electrochemical reactions 257
    - film deposition 258
    - $\text{LiMn}_2\text{O}_4$  film 260
    - mass changes 259
    - oscillation frequency 258
    - piezoelectric quartz crystals 257
  - electrochemical reaction 11, 12
    - discharge 11
      - curves 18
    - electrode/cathode 11, 14
    - of graphite 94
    - kinetics 195
    - $\text{LiMn}_2\text{O}_4$  218
    - of  $\text{Li}_2\text{MnO}_3$  46
    - lithium channel 55
    - lithium ion batteries 142
    - of low-crystalline carbon 102
    - of noncrystalline carbon 108
    - redox reactions 10
    - separators 173
  - electrode coating process 329
  - electrode density 327
  - electrode/electrolyte configurations 319
  - electrode-electrolyte interfacial reactions 195, 200
    - electrode materials and electrolytes 195
      - $\text{Li}^+$  ions 200
      - lithium metals 172
      - polymer electrolytes 172
      - SEI layer formation 201
  - electrode physical properties
    - application programs 83
    - battery voltage 80
    - input files 83, 84
    - lithium diffusion 80–82
    - prediction, using first-principles calculation 79
    - structural stability of electrode materials 80
  - electrode slurry
    - coating of 330
    - current collector, coating 330
    - manufacturing based on nanosized particles 134
    - preparation of 328
  - electrolyte–electrode interface 334
  - electrolytes 10, 209
    - lithium secondary batteries 195

- oxidative decomposition reactions 196, 208, 222, 274
  - oxidative reactions, at cathode material surface 344
  - solvents, electrochemical stability 198
  - electromagnetic radiation 269
  - measurement techniques for 270
  - types 272
  - electromagnetic wave 275
  - electron binding energy 283
  - electron gun 296
  - electrostatic capacity 242
  - energy dispersive spectroscopy (EDS) 300
  - EQCM analysis. *See* electrochemical quartz crystal microbalance (EQCM) analysis
  - equivalent circuit
    - of LiCoO<sub>2</sub>/carbon cell 250
    - resistance–capacitance 247
    - of series resistance 246
  - ethylene carbonate (EC) 196, 231
    - cyclic carbonates 199
    - decomposition 305
    - DEC solvent 305
    - DFT calculations for 196
    - DMC electrolyte 214
    - DSC thermogram of 306
    - electrochemical reduction potential of 196
    - Li<sup>+</sup> reductive decomposition mechanism 198
    - lithium ethylene dicarbonate 207
    - oxidation potential 196
    - thermal decomposition 199
  - EVs. *See* electric vehicles (EVs)
  - EXAFS. *See* extended X-ray absorption fine structure (EXAFS)
  - exchange–correlation energy 79
  - exothermic/endothermic reactions 304
  - extended X-ray absorption fine structure (EXAFS)
    - absorption coefficient 287
    - analysis of 290, 291
    - backscattering of electrons 288
    - structural factors 291
- f**
- Fermi contact 282
  - Fermi level 286, 287
  - FE-SEM. *See* field-emission SEM (FE-SEM)
  - field-emission SEM (FE-SEM) 298
    - equipment structure 298
    - field emission electron guns 298
  - fingerprint region 273
  - first principles calculation 40, 57
    - application programs 83
    - prediction of cathode material from 77
    - structural stability of electrode materials 80
    - understanding of 77–79
  - Fourier transform (FT) 291
    - Co–Ni oxide 292
    - infrared spectroscopy 274
    - Ni EXAFS spectrum 292
    - spectrum 290, 291
  - Fourier transform infrared spectroscopy (FTIR) 270–275
    - analysis of 204
    - *ex situ* internal reflection spectroscopy 274
    - of LiMn<sub>2</sub>O<sub>4</sub> cathode surface 221
    - lithium ethylene carbonate 274
    - lithium methyl carbonate 205
  - fragmentation pattern analysis 310
  - FT. *See* Fourier transform (FT)
  - FTIR. *See* Fourier transform infrared spectroscopy (FTIR)
  - full cell 11
- g**
- galvanostatic intermittent titration technique (GITT) 238, 239
    - current and voltage changes 238
    - electrochemical methods 257
    - experiment 238
  - gas chromatography (GC) 306
    - analysis of 309
    - equipment structure 307
    - mass spectrometry (GC–MS) 306–311
    - stationary phase 308
  - gaseous molecules, vaporization 312
  - gasket 334
  - Gaussian vs. Lorentzian 284
  - GC. *See* gas chromatography (GC)
  - generalized gradient approximation (GGA) 79
  - GGA. *See* generalized gradient approximation (GGA)
  - GITT. *See* galvanostatic intermittent titration technique (GITT)
  - grain boundary 300
  - graphite 92. *See* anode materials
    - anisotropic behavior 92, 93
    - charge/discharge curves 98
    - depth profile 286
    - design of graphite particles 94–99
    - discharge curves of batteries with 120
    - electrochemical reaction 94

- galvanostatic curve 95
- staging effects during lithium intercalation 95
- voltammetric curve 95
- impedance spectrum and equivalent circuit of 210
- Raman spectroscopy 103
- SEI layer formation in 124
- structure 92–94
- in-plane structure 96
- MPCF artificial graphite 98
- particle shapes 96, 99
- graphite anodes, exfoliation 217
- graphite/lithium cell
  - charge/discharge capacity and coulombic efficiency 235
  - differential capacity curves of 236
  - voltage controlled constant current charge–discharge curve 235
- graphite surface, SEI layer image 295
- green energy 7
- gyromagnetic ratio 280

**h**

- half cells 11
- Hartree–Fock calculations 204
- Hartree–Fock method 78
- Hartree potential 79
- HEVs. *See* hybrid electric vehicles (HEVs)
- $H_{\text{Fermi contact}}$  281
- $H_{\text{J-coupling}}$  281
- Hohenberg–Kohn theorem 78
- HOMO energy level 218
- hybrid electric vehicles (HEVs) 3, 51, 53, 342, 348
  - anode material 107
  - application 3
  - batteries 134, 348, 349, 351
  - commercial 352
  - objective of 352
- $H_{\text{Zeeman}}$  281

**i**

- ICP. *See* inductively coupled plasma (ICP)
- imide-based lithium salts 227
- impedance
  - complex plane plot of 241
  - definition of 249
  - with frequency 242
  - high-frequency region 251
  - low-frequency region, by Warburg impedance 252
  - middle-frequency region 251, 252

- very low-frequency region 252, 253
- inductively coupled plasma (ICP) 311
  - equipment structure 311
  - mass spectrometry (ICP-MS) 311
- information technology (IT) 1
- infrared 269
  - absorption 270, 273
  - electromagnetic spectrum 270
  - Fourier transform 274
  - functional groups, observation of 273
  - molecular vibrational energy, transition of 272
  - Raman spectroscopy 275
  - reflection absorption infrared spectroscopy (RAIRS) 273
  - spectrum 273
- infrared reflection absorption spectroscopy (IRAS) 273
- interfacial reactions, at graphite (carbon) 209–211
- internal reflection elements (IRE) 273
- International Center for Diffraction Data (ICDD) 263
- IRAS. *See* infrared reflection absorption spectroscopy (IRAS)
- iR drop 338
  - polarization 14, 19, 338
  - within thick electrode 339

**j**

- Jahn–Teller effect 291
- jelly roll insertion process 331
- jelly roll winder 332, 333
- Joint Committee on Powder Diffraction Standards (JCPDS) 263

**k**

- kinetic energy 79
- Kohn–Sham equations 79

**l**

- LDA. *See* local density approximation (LDA)
- lead–acid batteries 2, 3
- Leclanché (or manganese) cell 2
- $\text{LiBF}_4$ 
  - corrosion/passive layer formation 228
- LiBOB decomposition 212
- LIBs. *See* lithium ion batteries (LIBs)
- $\text{Li}/(\text{CF})_n$  batteries 21
- $\text{Li}_2\text{CO}_3$ , cathode surface 217

- LiCoO<sub>2</sub> A<sub>1g</sub> mode, Raman band changes 279
- LiCoO<sub>2</sub>/electrolyte/lithium cell 248
- LiCoO<sub>2</sub>–graphite system 340
- LiFePO<sub>4</sub>
  - electrochemical cycle characteristics 223
  - FTIR analysis 224
  - FTIR spectra 225
  - rietveld refinement of 266
- light intensity 275
- Li-ion batteries 319
  - manufacturing process 327
- Li/LiNiO<sub>2</sub> cell
  - capacity–potential curve of 223
- Li/MnO<sub>2</sub> batteries 21
- LiN(CF<sub>3</sub>SO<sub>2</sub>)<sub>2</sub>/PC electrolyte
  - aluminum corrosion mechanism 227
- linear carbonate 144
  - C=O, positive charge 197
  - dimethyl carbonate, exception of 187
  - oxidative decomposition reactions 199
  - resonance structure of the free radical state 199
  - solvents 169
- linear sweep voltammetry (LSV) 148, 226, 232, 233
- LiNi<sub>0.8</sub>Co<sub>0.15</sub>Al<sub>0.05</sub>O<sub>2</sub>
  - <sup>7</sup>Li MAS NMR spectrum with charge state of 282
- LiNi<sub>0.80</sub>Co<sub>0.15</sub>Al<sub>0.05</sub>O<sub>2</sub>–graphite–acetylene black
  - Raman microscope image of 277
- LiNi<sub>0.80</sub>Co<sub>0.15</sub>Al<sub>0.05</sub>O<sub>2</sub>–graphite-type carbon–acetylene black
  - Raman microscope image of 278
- LiNiO<sub>2</sub>, lithium deintercalation 270
- LIPBs. *See* lithium ion polymer batteries (LIPBs)
- LiPF<sub>6</sub>/EC/PC electrolytes 215
- liquid electrolytes 142
  - characteristics of 147–149
  - components of 143–147
  - development trends 161, 162
  - electrolyte additives 153–157
  - enhancement of thermal stability 157, 160, 161
  - ionic liquids 149–153
  - requirements of 142
- Li/SO<sub>2</sub> batteries 21
- Li/SOCl<sub>2</sub> batteries 21
- <sup>7</sup>Li static NMR spectrum, thermal effect 283
- LiTFSI salts 228
- lithium alkoxide 219
- lithium alkyl bicarbonates 196
- lithium alkyl carbonate 207, 208
- lithium alloying 214
- lithium anions, hydrolysis of 208
- lithium batteries 196, 306
  - cross-sectional SEM image of 299
  - electrode–electrolyte interactions in 259
- lithium bis-perfluoroalkylsulfonilimide 226
- lithium cells 196. *See also* lithium batteries
  - cycle life 200
  - cycling of 218
  - inert metal electrodes and electrolytes 196
  - SEI layer formation 201
- lithium deintercalation/intercalation
  - *in situ* XRD patterns 271
- lithium deposition 323
- lithium, diffusion coefficient 238
- lithium ethylene carbonate, molecular structure 275
- lithium ethylene dicarbonate 207, 208
- lithium intercalation–deintercalation cycle 21
- lithium ion batteries (LIBs) 5
- lithium ion mobility 350
- lithium ion polymer batteries (LIPBs) 5
- lithium iron oxide 223
- lithium metal alloys 209
  - discharge capacity 121
  - solvent, reactions between 209
- lithium metal oxides, crystal structure 320
- lithium methyl carbonate 206
  - FTIR spectrum 205
  - thermodynamically stable compound 206
- lithium polymer batteries 352
- lithium salts
  - acidic nature 218
  - electrolytes, reductive decomposition 216
- lithium secondary batteries 1, 3–7, 278, 337, 351, 353
  - capacity 345
  - changes in energy density and 4
  - characteristics 6
  - charge and discharge curves of 338
  - charge transfer 256
  - commercialization of 22
  - discharge curves of 120
  - DSC characteristics, of components 116
  - electrode of 247



- electrolytes 5, 142, 195
- energy density of 345
- equivalent circuit for electrode 248
- future of 7
- key components 6
- lithium ion, diffusion coefficient 22
- movement of  $\text{Li}^+$  4
- nonaqueous electrolytes 195
- performance, deterioration of 195
- range of potential for reactions with lithium 121
- shapes 5
- using  $\text{MoS}_2$  as cathode material 22
- voltage of 337
- local density approximation (LDA) 79
- LSV. *See* linear sweep voltammetry (LSV)
- LUMO energy 146, 147, 204, 218

**m**

- magic angle spinning (MAS) 281
- magnetic moment 280
- manganese compounds, binding energy 284, 285
- manganese dioxide ( $\text{MnO}_2$ ) cathode 2
- manganese ions 22
- MAS. *See* magic angle spinning (MAS)
- mass spectrometry (MS)
  - equipment structure 309
  - gas chromatography (GC) 306–311
  - inductively coupled plasma (ICP) 311
  - spectrum 310
- material property analysis 263
- metal oxides 130–135
  - anatase titanium dioxide 131
  - change in potential 131
  - charge/discharge curves 132
  - $\text{Li}_{2.6}\text{Co}_{0.4}\text{N}$  135
  - rutile  $\text{TiO}_2$  131, 132
  - volume change in 130
- metal thin-film electrodes 130
- methyl carbonate anions 206
- microcells 7
- molar conductivity
  - cations 256
  - ionic 256
- MS. *See* mass spectrometry (MS)

**n**

- negative electrode capacity/positive electrode capacity (N/P) ratio 323, 324
- battery life, relationship 324
- Nernst–Einstein equation 257
- Nernst equations 14

- NiCd batteries 2, 3, 337
- Ni EXAFS spectrum 292, 293
- NiMH batteries 3, 337
- NiMH cells. *See* NiMH batteries
- Ni–Mn–Co three-component system 340
- Ni–Ni bond lengths 291
- nitride anode materials 135–137
  - $\text{Li}_{2.6}\text{Co}_{0.4}\text{N}$ 
    - charge/discharge curves 135
    - rate capability characteristics 136
- N*-methyl pyrrolidone (NMP) solvent 328
- NMR spectroscopy. *See* nuclear magnetic resonance (NMR) spectroscopy
- nonaqueous electrolytes, electrochemical decomposition 195–200
- nonaqueous organic solvents
  - one-electron transfer of 197
  - reduction from one-electron transfer 197
- noncarbon materials 118–120
  - composites of lithium-reactive/nonreactive metals 125–128
  - Li, Li–Al, and Li–Si alloys 120–129
  - metal/alloy–carbon composites 128, 129
  - metal thin-film electrodes 130
  - micrometal particles in lithium reactions 123–125
  - multiphase lithium alloys 125
- nuclear magnetic resonance (NMR) spectroscopy 282
  - resonance frequency 280, 281
  - solid-state 280–282
- nuclear spin quantum number 280
- Nyquist plot 241
  - Al/LiCoO<sub>2</sub>/electrolyte/MCMB/Cu lithium secondary battery 254
  - capacitance component 243
    - for capacitance + (resistance–capacitance) equivalent circuit 247
    - carbon/electrolyte/lithium cell 248
    - for charged Li/LiMn<sub>2</sub>O<sub>4</sub> cell 219
    - electrochemical cell for permittivity measurements 254
    - equivalent circuit 246
    - for equivalent circuit of lithium secondary battery electrode 248
    - for fuel cell 253
    - inductance–capacitance component 244
    - inductance component 243
    - of LiCoO<sub>2</sub>/electrolyte/lithium cell 249
    - parallel resistance–capacitance (RC) 245
    - RC series equivalent circuits 253

- resistance component 242
  - resistance–reactance–capacitance (RLC) component 244
- o**
- OCV. *See* open circuit voltage (OCV)
- ohmic polarization. *See* iR drop
- open circuit voltage (OCV) 13, 231
- battery capacity 320
  - electrochemical cell 231
  - electrode materials 231
  - LiMn<sub>2</sub>O<sub>4</sub> film, mpe changes of 260
  - oxidation number of lithium ions 25
  - single-walled carbon nanotubes (SWCNTs) 231, 232
  - Sn–Li and Si–Li 122
- overcharging 340
- battery capacity 342
  - behavior of battery 341
  - charging of battery 38
  - oxidation number of Co 33
  - redox additives 156
- oxidative electrode 11
- oxidative reactions 232
- p**
- parallel resistance–capacitance
- equivalent circuit 245, 246
  - Nyquist plot of 245, 246
- PC. *See* propylene carbonate (PC)
- permittivity measurements
- electrochemical cell 255
  - equivalent circuit 255
  - Nyquist plot 255
- PET. *See* polyethylene terephthalate (PET)
- PITT. *See* potentiostatic intermittent titration technique (PITT)
- plug-in hybrid electric vehicles (PHEVs) 3
- polarization 13, 14, 15
- effect of current density on 15
- polyethylene terephthalate (PET)
- DSC analysis of 305
  - DSC thermogram of 305
- polymer electrolytes 162, 328
- characteristics of 171–173
  - development trends 173
  - preparation of 169–171
  - types of 162–169
- positive temperature coefficient (PTC) 334
- potassium hydroxide (KOH) 2
- potential stepping
- current–time and differentiated capacity–voltage plots 237
- potentiostatic intermittent titration technique (PITT) 238, 239
- change in current 239
  - diffusion coefficient 239
- propylene carbonate (PC) 195
- decomposition
  - *in situ* IR cell 276
  - electron transfer, oxidation reactions 199
  - graphite interfacial reactions 212
  - lithium bisoxalato borate (LiBOB) 212
  - oxidation reactions from electron transfer 199
  - reduction reactions of 195
  - ring-opening reactions 196
  - undergoes ring-opening oxidative reactions 220
- PTC. *See* positive temperature coefficient (PTC)
- r**
- radiation intensities 284
- RAIRS. *See* reflection absorption infrared spectroscopy (RAIRS)
- Raman cell, *in situ* 279
- Raman scattering 275, 277
- Raman spectroscopy 270, 275–279
- for crystalline graphite 101
  - carbon materials 103
  - energy absorption 276
  - hyperspectral imaging 277
  - light intensity 275
  - used to observe molecular vibrations 277
- Randles circuit 218
- Rayleigh–Ritz variational theorem 78
- Rayleigh scattering 275
- RC. *See* resistance–capacitance (RC)
- redox reactions at electrodes 10
- reductive electrode 11
- reflection absorption infrared spectroscopy (RAIRS) 273
- resistance–capacitance (RC) 245, 247
- equivalent circuits 252
  - model conditions of 253
- resistance–reactance–capacitance (RLC) component 244
- roll pressing process 331
- s**
- Sauerbrey equation 258
- scanning electronmicroscope (SEM) 296–300
- cross-sectional 299
  - dry process/wet process 181
  - electron accelerator 296

- energy dispersive spectroscopy (EDS) 300
- equipment, structure of 297, 298
- field-emission 298
- MCMB-25-28 artificial graphite 97
- microporous film 180
- MPCF-3000 artificial graphite 99
- scanning tunnel microscopy (STM) 300
- Schrödinger equation 77, 78
- SEI layer. *See* solid electrolyte interphase (SEI) layer
- selected area electron diffraction (SAED) 295
- SEM. *See* scanning electron microscope (SEM)
- separators 173
  - basic characteristics 174–176
  - cycle performance 178
  - development of materials 179, 180
  - effects on battery assembly 176
  - functions 173, 174
  - manufacturing process 180, 181
  - oxidative stability 176, 177
  - prospects for 181
  - thermal stability 178
- single-walled carbon nanotubes (SWCNTs) 231
- Si/Sb-based alloys 215
- Si/Sn/Sb-based metals 214
- slitting process 330, 332
- slurry storage process 329
- Sn-based anode material
  - *in situ* XRD patterns of 270
- SnO<sub>2</sub> cathode material particle
  - electron diffraction patterns of 296
- Sn–Sb–Cu–graphite alloy anode 215
- solid electrolyte interphase (SEI) layer 200
  - at anode 321
  - anode–electrolyte interface, Randles circuit 218
  - battery performance 217
  - cathode–electrolyte interface, Randles circuit 218
  - charge/discharge of lithium batteries 203
  - collector–electrolyte interface 203
  - disproportionation reactions 222
    - at electrode surface 200–203
  - electrolyte decomposition 210
  - electrolyte/gold electrode, cyclic voltammetry of 211
  - formation 201, 209, 210, 211, 303, 334
    - in metals 124
    - FTIR spectrum of 215
    - Li<sup>+</sup> ion transport 202
    - of LiMn<sub>2</sub>O<sub>4</sub> 219
- solvent reduction, potential values 196
- sulfonyl amide lithium salts 226
- surface–graphite interface 211
- surface modification, surface modification 58–60
  - layered structure compounds 60, 61
  - olivine compounds 64, 65
  - spinel compound 61–64
- t**
- TEM structure 294
  - conventional TEM (CTEM) 294
- tetrahydrofuran (THF) 185, 195, 196
- TGA. *See* thermogravimetric analysis (TGA)
- thermal analysis 301–306
- thermal conductivity 307
- thermal decomposition 302
- thermal stability, cathode materials 65
- thermodynamic equilibrium 231
- thermogravimetric analysis (TGA) 301
  - equipment structure, schematic diagram 304
- THF. *See* tetrahydrofuran (THF)
- THF/LiClO<sub>4</sub> electrolyte 196
- transmission electron microscopy (TEM) 292–296
- transverse acoustic waves 257
  - in quartz crystals 258
- tungsten filament 292, 296
- v**
- vacuum drying process 331
- VC. *See* vinylene carbonate (VC)
- vinylene carbonate (VC) 196, 200
  - oxidation potential 196
  - ring-opening polymers 213
- voltage 12. *See also* current
  - anode 340
  - audio quality 340
  - cathode materials 340
  - effect of current density on 18
  - metal elements, form alloys with lithium 119
- voltage/current behavior, during charging 347
- voltaic pile 2
- w**
- Warburg impedance 249, 250
- wavefunction 78
- welding tip 332
- winding process 331
  - winds electrodes 330, 331
- wireless charging 7

**x**

- XAS measurement cell
  - *in situ* 291
- XPS system 283, 284
- X-ray absorption 284
- X-ray absorption near-edge structure (XANES) 287, 288
  - LiFePO<sub>4</sub> 288
  - physical mechanism of 288
  - P K-edge 289
- X-ray absorption spectroscopy (XAS) 285–287
  - extended x-ray absorption fine structure (EXAFS) 288–292
  - X-ray absorption near-edge structure (XANES) 287, 288
- X-ray beam 263
- X-ray diffraction analysis

- principle of 263–265
- Rietveld refinement 265–267
- *in situ* 267–269
  - LiCoO<sub>2</sub> 269
- X-ray incident radiation 286
- X-ray photoelectron spectroscopy (XPS) 282–285
  - peaks for carbon materials 114
- X-ray transmission 271
- XRD analysis 263
- XRD device 265

**z**

- Zavitsky detected electron paramagnetic resonance 280
- Zeeman interaction 280
- zinc anode 2
- zinc chloride (ZnCl<sub>2</sub>) 2