

# Subject Index

- A15 superconductor, 2  
 accelerators, 492  
 Ag/Bi-2212 magnets, 346–347  
 Ag/Bi-2212 tapes (*see* first generation HTS wire)  
 Ag/Bi-2212 wires (*see* first generation HTS wire)  
 Ag/Bi-2223 tapes (*see* first generation HTS wire)  
 $\text{AlSr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$ (Al-12( $n-1$ ) $n$ ), 89  
 angle-resolved photemission spectroscopy (ARPES), 158, 160, 426, 473, 475, 490  
 angular magnetoresistivity (AMR), 160  
 anisotropic superconductors, 83–84  
     anisotropy parameter, 84  
     anisotropic superconducting properties (cuprates), 165  
 $B_c$ ,  $B_{c2,ab}$ ,  $B_{c2,c}$ , 84  
     definition of anisotropic material properties, 83–84  
 $\lambda_{ab}$ ,  $\lambda_c$ , 83  
 $\kappa_{ab}$ ,  $\kappa_c$ , 84  
 antiferromagnetic domains, 160  
 antiferromagnetic ordering ( $\text{La}_2\text{CuO}_4$ ), 152–153  
 antiferromagnetism, 87  
 Arrhenius law, 207  
 Arrhenius plots of resistance, 213–215  
 artificial bicrystal grain boundaries, 189–190  
 atomic form factor, 106  
 attempt frequency (flux line hopping), 207  
  
 Ba-122, 459–461, 463, 467, 469, 473, 475, 477, 480–482, 490  
     coherence length, 475  
  
     critical current density (IBAD tape), 480  
     critical current density (PIT tape), 481  
     doping, 461, 464  
     energy gap, 473  
     lattice parameters, 470  
     layering scheme, 460  
     penetration depth, 475  
     phase diagram, 467  
     resistivity, 476  
     synthesis, 479  
     upper critical field, 474  
 band insulator, 21  
 band structures, 17–18  
     insulator, 17–18  
     metal, 17–18  
     semiconductor, 17–19  
 $B_c$ , 76  
 $B_{c1}$ , 76  
 $B_{c2}$ , 76  
     table, 76  
 BCS theory, 4, 40, 45–52, 71, 424, 426, 473  
 Bi-2212  
     bulk superconductors, 317–320  
     copper oxide blocks, 112, 116  
     crystal structure, 111–114  
         atom positions, 114  
     dependence of  $T_c$  on charge carrier density, 132–133  
     in-plane resistivity anisotropy, 233, 239–240  
     lattice parameters, 111  
     powder synthesis, 298–299  
     specific heat, 281–282, 284–285  
     tunneling spectra, 158  
     XRD pattern, 112

502 *Subject Index*

- Bi-22(n – 1)n  
 $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+4}$  family, 89  
 crystal structure, 111–114  
 effect of number of  $\text{CuO}_2$  planes/ $\text{CuO}_2$  block on  $T_c$ , 135  
(Bi,Pb)-2223  
 bulk superconductors, 317–320  
 copper oxide blocks, 112  
 crystal structure, 111–114  
 lattice parameters, 111  
 powder synthesis, 299–303, (*see also*  
     synthesis of cuprate superconductor  
     powders)  
 pressure dependence of  $T_c$ , 140  
 specific heat, 281–285  
 thermal conductivity, 251–252  
 XRD pattern, 112  
Bitter technique, 204  
Bloch functions, 17  
Bloch theory, 22  
body centering, 108, 113, 116  
Bose–Einstein distribution law, 47  
Bragg condition, 102, 105  
Bragg scattering, 17  
Bravais lattices, 103–104  
Bravais lattice symbols, 103–104  
Brillouin zones, 17–18  
BSr<sub>2</sub>Ca<sub>n-1</sub>Cu<sub>n</sub>O<sub>2n+3</sub> (B-12(n-1)n), 89  
bulk cuprate superconductors, 293,  
     317–326  
     Bi-2212, 317–320  
     (Bi,Pb)-2223, 318–320  
     cold isostatic pressing, 318  
     manufacture, 293  
     melt cast process, 317–318  
     properties, 293  
     RE-123, 320–326  
         melt powder melt growth, 323  
         melt processing without thermal  
             gradient, 322  
         melt texture growth, 321  
         seed crystals, 323  
         trapped magnetic flux, 325–326  
Ca-122 (CaFe<sub>2</sub>As<sub>2</sub>), 462, 465, 471, 472, 474,  
     476  
 critical temperature, 462  
     under pressure, 465  
 crystal structure, 472  
 lattice parameters, 472  
 resistivity, 476  
 upper critical field, 473  
Carnot efficiency, 6–7  
carrier concentration (*see* charge carrier  
 density)  
Ce-1111, 461–463, 466, 468, 474  
 coherence length, 475  
 critical temperature, 462–463, 465  
 lattice parameters, 469  
 phase diagram, 466  
 synthesis, 479  
 upper critical field, 474  
characteristic length scales, 165–169, 473,  
     475  
cuprate superconductors, 165–169  
 coherence length, 165–166  
 penetration depth, 165–166, 169  
 table, 167–168  
Fe-based superconductors, 473, 475  
charge carrier density ( $\text{CuO}_2$  planes), 93–96,  
     151, 166  
 cuprates, 166  
charge carrier reservoirs, 88–91, 93, 94, 114,  
     119, 122, 203, 205, 219  
charge stripes, 160–161  
 fluctuating charge stripes, 160  
      $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+x}$ , 160  
      $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$ , 214  
 compounds, 160  
 citrate pyrolysis, 294, 296  
 coated conductors (*see* second generation  
     HTS wire)  
coherence length, 71, 73, 165–166, 188,  
     432–433, 475  
cuprate superconductors, 165–168  
Fe-based superconductors, 475  
 MgB<sub>2</sub>, 432, 433  
collective pinning theories, 209  
 effective pinning potential, 209  
conduction band, 17–18  
conduction electrons, 13  
conduction planes (*see*  $\text{CuO}_2$  planes)  
Cooper pairs, 2, 4, 31, 45–47, 50–51, 71,  
     160  
 condensation energy, 71  
 wave function, 31, 50  
     phase of wave function, 50–51  
 phase coherence, 160  
 preformed, 160  
Cooper-pair tunneling, 45

*Subject Index 503*

- copper oxide blocks, 88–89, 110–112, 114, 116, 118–119, 124, 127, 131–133, 135–138, 145–146, 165, 187, 205, 206, 219, 220, 224, 293, 303, 313, 408  
 Bi-2212, 112  
 (Bi,Pb)-2223, 112  
 $\text{HgBa}_2\text{CuO}_4$ , 89  
 $\text{La}_2\text{CuO}_4$ , 88  
 Tl-1223, 119, 121  
 Tl-2201, 114–115  
 Tl-2212, 116–117  
 Tl-2223, 118  
 Tl-2234, 118  
 $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ , 89  
 $\text{YBa}_2\text{Cu}_3\text{O}_7$ , 88, 110–111  
 corner junction, 155–157  
 Josephson current, 155–157  
 cost of cooling, 7  
 Coulomb interaction, 49  
 Coulomb repulsion, 21, 87  
 creep effects, 83  
 critical current, 174, 176–182  
     definitions, 174, 176–178  
     electric field criterion, 174, 176–177  
     offset criterion, 176–177  
     resistivity criterion, 178  
 history effect (granular  
     superconductors), 180–181  
 polycrystalline cuprate  
     superconductors, 178–182  
 critical current density ( $j_c$ ), 7, 47  
     required for applications, 6  
 critical current density (cuprates), 182–191, 193, 319–320, 323–325  
     across artificial grain boundaries, 191  
     angle dependence of  $j_c$ , 187–188  
     anisotropy of  $j_c$ , 185, 186  
     bulk cuprate superconductors, 182–183  
          $j_c$  (Bi-based  
             superconductors), 319–320  
          $j_c$  (RE-123 bulk  
             superconductors), 323–325  
     superconducting films  
         (cuprates), 183–188  
          $j_c$  at zero applied field, 184  
 critical current density (Fe-based  
     superconductors), 477–482  
 critical current density ( $\text{MgB}_2$  wires and  
     tapes), 441–444  
 critical magnetic field ( $B_c$ ), 27–28  
 critical temperature ( $T_c$ )  
 Al, 4  
 BCS formula, 48  
 $\text{Cs}_3\text{C}_6$ , 6  
 cuprate superconductors, 90–93,  
     131–143  
     dependence on formal Cu valence,  
         132  
     Bi-2212, 132–133  
     La-214, 132–133  
     Hg-1201, 134  
     Hg-1212, 134  
     Hg-1223, 134  
     Y-123, 132–133  
     Y,Ca-123, 132–133  
     dependence on number of  $\text{CuO}_2$   
         planes/CuO block, 131  
     table, 92–93  
     effect of pressure on  $T_c$ , 138–146  
     effect of number of  $\text{CuO}_2$  planes/CuO  
         block, 135–138  
     Bi-22( $n-1$ ) $n$ , 135  
     (Cu,C)-12( $n-1$ ) $n$ , 136  
     (Cu,Cr)-12( $n-1$ ) $n$ , 136  
     Hg-12( $n-1$ ) $n$ , 136  
     (Hg,Cr)-12( $n-1$ ) $n$ , 136  
     (Hg,Tl)-22( $n-1$ ) $n$ , 135  
     Tl-22( $n-1$ ) $n$ , 135  
     definitions of  $T_c$ , 23–24  
 Hg, 3  
 $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+\delta}$ , 2, 5  
 $\text{Hg}_{0.8}\text{Ti}_{0.2}\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+x}$ , 5  
 high-temperature superconductors, 23  
 In (under pressure), 41  
 iron-based superconductors, 461–467  
     dependence on anion height, 463  
     dependence on Fe-As-Fe bond  
         angle, 462, 464  
     effect of chemical pressure, 463, 465  
     pressure dependence, 465  
     table, 462  
 $\text{K}_3\text{C}_6$ , 2, 6  
 $(\text{La},\text{Ba})_2\text{CuO}_{4+\delta}$  (under pressure), 41  
 $\text{La}(\text{O}_{1-x}\text{F}_x)\text{FeAs}$ , 2  
 $\text{LiTi}_2\text{O}_4$ , 6  
 low-temperature superconductors, 22, 29,  
     30  
 $\text{MgB}_2$ , 2, 6  
 $\text{Nb}_3\text{Ge}$ , 2, 4  
 $\text{NbN}$ , 2, 3

504 *Subject Index*

critical temperature ( $T_c$ ) (*continued*)

Pb, 3

$\text{SmO}_{0.85}\text{FeAs}$ , 6

Sn, 3

$\text{SrTiO}_3$ , 6

superconducting elements, 29

under high pressure, 30

$\text{V}_3\text{Si}$ , 2

$\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ , 2, 4, 87

crystal structure

Bi-22(n-1)n, 111–114

Bi-2212, 111–114

atom positions, 114

(Bi,Pb)-2223, 111–114

atom positions, 114

$\text{HgBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+2}$ , 121–125

Hg-1201, 121–123

atom positions, 123

Hg-1212, 124–125

atom positions, 125

Hg-1223, 124–125

atom positions, 125

Hg-1234, 124–125

atom positions, 125

Hg-1245, 124–125

iron-based superconductors, 459–460, 467–472

$\text{CaFe}_2\text{As}_2$  (Ca-122), 472

$\text{LaOFeAs}$  (La-1111), 472

lattice parameters, 459–460, 469

(1 1 1 1) family, 468, 469

Ba-122, 469

FeSe, 469

LiFeAs, 469

layering schemes, 459–460

(1 1) family, 459–460

(1 1 1 1) family, 459–460

(1 2 2) family, 459–460

$\text{La}_2\text{CuO}_4$ , 107–109

atom positions, 109

$\text{MgB}_2$ , 424

Tl-1223, 119–121

atom positions, 121

Tl-2201, 114–116

atom positions, 116

Tl-2212, 116–117

atom positions, 117

Tl-2223, 116, 118–120

atom positions, 120

Tl-2234, 118–120

atom positions, 120

$\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ , 108–111

atom positions, 111

$\text{CuBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+2}$  (Cu-12(n-1)n), 90

(Cu,C) $\text{Ba}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$

((Cu,C)-12(n-1)n), 90

$\text{CuO}$  chains ( $\text{REBa}_2\text{Cu}_3\text{O}_7$ ), 89, 109–110

$\text{CuO}_2$  layers (*see CuO<sub>2</sub> planes*)

$\text{CuO}_2$  planes, 87–91, 93–94, 96–97, 108,

110–112, 135, 138

inner  $\text{CuO}_2$  planes, 135

outer  $\text{CuO}_2$  planes, 135

nonuniform hole distribution among planes, 138

$\text{CuO}_2$  sheets (*see CuO<sub>2</sub> planes*)

cuprate superconductor films, 393–416

deposition techniques

Bi-based HTS films, 394

table, 395–397

Hg-based HTS films, 397, 400–404

table, 401–403

RE-123 HTS films, 404–407

table, 405–407

Tl-based HTS films, 394, 397

table, 398–400

multilayers (ultrathin films), 407–412

critical temperature, 410

$\text{MgO}/\text{Pr}-123/\text{Y}-123$ , 407–408

$\text{SrTiO}_3/\text{Pr}-123/\text{Y}-123/\text{Pr}-123$ ,

408–409

superlattices ( $\text{La},\text{Sr})_2\text{CuO}_4/\text{La}_2\text{CuO}_4$ ),

410–412

critical temperature, 411–412

strain effects, 412–416

Tl-Hg cation exchange, 400

cuprate superconductors

$\text{AlSr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$  (Al-12(n-1)n), 89

$\text{BSr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$  (B-12(n-1)n), 89

$\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+4}$  (Bi-22(n-1)n), 89

cation disorder, 94

$\text{CuBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+2}$  (Cu-12(n-1)n),

90

(Cu,C) $\text{Ba}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$

((Cu,C)-12(n-1)n), 90

doping (*see also* charge carrier density), 93–96

electron-doped cuprate superconductors, 95

$\text{Nd}_{2-x}\text{Ce}_x\text{CuO}_4$ , 95

## Subject Index 505

- $\Pr_{2-x}\Ce_x\text{CuO}_{4-\delta}$ , 95  
 $\Sm_{2-x}\Ce_x\text{CuO}_4$ , 95  
 $\text{GaSr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$  ( $\text{Ga-12}(n-1)n$ ), 90  
 $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+\delta}$  (*see also Hg-1223*), 2, 5  
 $\text{HgBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+2}$  ( $\text{Hg-12}(n-1)n$ ), 89  
 La-214, 89  
 $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$ , 6, 87  
 oxygen content, 94  
 RE-123, 89  
 self-doping, 94  
 $\text{Tl-12}(n-1)n$  ( $\text{TlM}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$ ) ( $\text{M} = \text{Ba or Sr}$ ), 89  
 Tl-2201 ( $\text{Tl}_2\text{Ba}_2\text{CuO}_6$ ), 89  
 Tl-2212 ( $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ ), 89  
 Tl-2223 ( $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ ), 89  
 $\text{Tl-22}(n-1)n$  ( $\text{Tl}_2\text{Ba}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+4}$ ), 89  
 Y-123 ( $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ ), 2, 4, 87  
 current leads, 249, 293, 317, 320, 492  
 current-voltage characteristic (NIN junction), 54  
 current-voltage characteristic (NIS junction), 58  
 current-voltage characteristic (SIS junction), 59  
 current-voltage characteristic (vortex glass), 217–218  
  
 de Broglie relation, 101  
 de Broglie relationship, 52  
 Debye frequency, 35, 48–50, 279  
 Debye model, 279  
 Debye temperature, 35, 40, 279, 434  
 density of energy states, 15, 40, 47–48, 159  
     density of states (superconducting energy gap), 47  
     *d*-wave superconductor, 159  
     *s*-wave superconductor, 159  
 differential thermal analysis (DTA), 341  
 Dimos experiment, 189  
 doping, 93–96, 461, 463, 464  
     cuprates, 93–96  
     Fe-based, 461, 463, 464  
 drift velocity (electrons), 19  
 Dulong–Petit value (specific heat), 434  
*d*-wave superconductor, 159, 162  
  
 effective mass (electrons), 19–20  
 Ehrenfest relationship, 144  
  
     Einstein specific heat, 283  
     electrical conductivity, 19–20  
     electrical resistance, 13–21  
     gold, 1  
     metals, 1  
     mercury, 1–3  
     platinum, 1  
     electron concentration, 16  
     electron-doped cuprate superconductors, 95  
          $\text{Nd}_{2-x}\Ce_x\text{CuO}_4$ , 95  
          $\Pr_{2-x}\Ce_x\text{CuO}_{4-\delta}$ , 95  
          $\Sm_{2-x}\Ce_x\text{CuO}_4$ , 95  
     electron-electron interaction, 87  
     electron-phonon coupling, 49, 490  
     electron-phonon coupling constant, 49  
         intermediate coupling, 49  
         strong coupling, 49  
         weak coupling, 49  
     electron-phonon interaction, 20–21, 45–48, 50, 424, 450  
     energy gap (semiconductors), 17–18  
     energy gap (superconductor), 47  
         antinodal gap, 160  
         BCS theory, 47–49  
         cuprates, 153  
             maximum gap, 169–171  
             table, 170  
             spatial variation, 170  
         density of states close to  $E_F$ , 47  
         Fe-based superconductors, 471, 473  
             ARPES, 473  
             point-contact Andreev-reflection spectroscopy (PCAR), 473  
             table, 473  
         nodal gap, 160  
         nodes, 154  
             relation with  $T_c$  (BCS theory), 48  
             symmetry, 153–154  
     engineering critical current density, 340, 370  
     extended *s*-wave gap, 490  
  
     fault current limiters, 293, 317, 339, 493  
     Fermi-Dirac distribution function, 15, 265  
     Fermi energy, 15  
     Fermi gas, 20  
     Fermi liquid, 20–21  
     Fermi liquid behavior (overdoped cuprates), 162  
     Fermi liquid theory, 20, 151  
     Fermi surface ( $\text{CuO}_2$  planes), 159

506 *Subject Index*

- Fermi wave number, 15  
 FeSe, 469–471  
 FeTe, 471  
 flux creep resistance, 212  
     activation energy, 216, 217  
 flux flow resistivity, 81–82, 203  
 flux-line lattice, 204  
      $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+x}$ , 204  
      $\text{YBa}_2\text{Cu}_3\text{O}_7$ , 204, 205  
 flux-line lattice melting, 171–172  
 flux lines, 83, 203  
 flux pinning, 79, 83, 203–226, 371  
      $\text{BaZrO}_3$  nanorods, 371  
 flux quantization, 2, 4, 50–52  
 flux quantum, 52, 77  
 field penetration (thin superconducting slab), 32–34  
 formal valence (Cu in cuprate superconductors), 94, 96, 97  
 formal valence at maximum  $T_c$ , 132, 135  
 free electrons (see also conduction electrons), 13–14  
 density of states, 16  
 energy eigen values, 14  
 momentum, 14  
 wave function, 14  
 wave vector, 14
- $\text{GaSr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$  ( $\text{Ga-12}(n-1)n$ ), 90  
 generators, 492  
 generic phase diagram (hole-doped cuprates), 151–153, 161  
 carrier concentration, 152  
 optimum carrier concentration (maximum  $T_c$ ), 161  
 overdoped, 162  
 generic phase diagram (iron-based superconductors), 459, 465–467  
 parent compounds, 459  
 phase diagram ((1 1 1 1) family), 465–466  
 phase diagram ((1 2 2) family), 467  
 Gibbs free energy, 36  
 Ginzburg–Landau equations, 71  
 Ginzburg–Landau (GL) parameter, 73  
 cuprates, 166, 194  
     table, 167–168  
 $\text{MgB}_2$ , 433  
     table, 74  
 Ginzburg–Landau (GL) theory, 4, 70–73  
 grain alignment, 344  
 grain-boundary weak links, 180, 188–191, 423  
 granular cuprate superconductor, 180  
 granularity, 180
- Hall coefficient, 95  
 Hall effect, 94–95  
 Hall voltage, 94–95  
 helium liquefaction, 1, 2  
 Hg-1201  
     crystal structure, 121–123  
     atom positions, 123  
     dependence of  $T_c$  on charge carrier density, 134  
     lattice parameters, 123  
     powder synthesis, 311–313  
     pressure dependence of  $T_c$ , 142  
     specific heat, 283  
     XRD pattern, 122
- Hg-1212  
     crystal structure, 124–125  
     atom positions, 125  
     dependence of  $T_c$  on charge carrier density, 134  
     lattice parameters, 125  
     powder synthesis, 313–314  
     pressure dependence of  $T_c$ , 142  
     XRD pattern, 123
- Hg-1223  
     crystal structure, 124–125  
     atom positions, 125  
     dependence of  $T_c$  on charge carrier density, 134  
     lattice parameters, 125  
     powder synthesis, 313, 315–317  
     pressure dependence of  $T_c$ , 142  
     record  $T_c$  value, 5  
 high-angle grain boundaries, 190  
 high-temperature superconductivity, 4  
 high-temperature superconductor (HTS)  
     wires  
 first-generation HTS wire, 340–361  
     Ag/Bi-2212-coated conductors, 347  
     Ag/Bi-2212 wires and tapes, 341–353  
         bubble formation, 346  
         critical current densities, 349–353  
         dip-coating, 347, 348  
         electrophoretic deposition, 347  
         heat treatment schedules, 343–345,  
             348

*Subject Index 507*

- melt processing, 346  
 overpressure processing, 346  
 partial melting, 341, 344  
 partial melting temperature, 344  
 phase assembly, 346  
 residual carbon content, 346  
 round wire, 341  
 step solidification, 344  
 tape casting, 347–348  
 void swelling, 345  
**Ag/Bi-2223 tapes**, 341, 351–361  
 average particle size, 356–357  
*c*-axis texture, 354, 356, 361  
 colony structure, 356  
 critical current, 358–359  
 critical current normalized to  $j_c(77\text{ K}, \text{sf})$ , 360  
 deformation studies, 357  
 heat treatment atmosphere, 354  
 high pressure processing, 357, 358  
 lead substitution, 354  
 powder-in-tube method, 352  
 residual carbon content, 356  
 rolling, 353  
**powder-in-tube (PIT)**  
 method, 341–342, 352  
**second-generation HTS wire (coated conductors)**, 339–340, 361–381  
 biaxial texture, 361  
 buffer layer architectures, 365–369  
 buffer layers, 364  
 chemical vapor deposition, 362  
 critical current densities, 370–377  
     angle dependence, 373, 375–377  
         77 K, 1 T, 375  
         20–50 K, 3 T, 376  
         4.2 K, 60 K at high fields  
             anisotropy, 371, 377  
     field dependence at 77 K, 370–372  
     field dependence (4.2–65 K), 371, 373  
     temperature-dependence, 371, 374  
 electron beam evaporation, 362, 364  
 flux pinning, 371  
      $\text{BaZrO}_3$  nanorods, 371  
 inclined substrate deposition (ISD), 363  
 ion-beam-assisted deposition (IBAD), 362  
 buffer layer sequences, 370  
 lengthy coated conductors, 379–381  
 microstructure, 377–379  
 pulsed laser deposition (PLD), 362, 363  
**RABiTS (Rolling Assisted Biaxially Textured Substrates)**, 363–364  
 film sequences, 370  
 yield strength of Ni, 369  
 yield strength of Ni-W, 369  
**RE-123**, 347  
 weak-link problem, 361  
 X-ray  $\phi$  scans, 362  
**holes (in cuprate superconductors)**, 94  
 hopping rate (flux lines), 207  
**HTS insert coil**, 340  
 inclined substrate deposition (ISD), 363  
 intrinsic pinning (cuprates), 203, 205–207  
 iodometric titration, 96  
 ion-beam-assisted deposition (IBAD), 362  
     buffer layer sequences, 370  
 iron-based superconductors, 459–482  
     critical current densities, 477, 480–482  
     critical temperatures, 461–467  
         dependence on anion height, 463  
         dependence on Fe-As-Fe bond angle, 462, 464  
         effect of chemical pressure, 463, 465  
         pressure dependence, 465  
         table, 462  
     crystal structures, 459, 467–471  
          $\text{CaFe}_2\text{As}_2$  (Ca-122), 472  
          $\text{LaOFeAs}$  (La-1111), 472  
         layering schemes, 459–460  
             (1 1) family, 459–460  
             (1 1 1) family, 459–460  
             (1 1 1 1) family, 459–460  
             (1 2 2) family, 459–460  
         lattice parameters, 459–460  
             (1 1 1 1) family, 469  
         Ba-122, 469  
         FeSe, 469  
         LiFeAs, 469  
     dependence of  $T_c$  on doping, 461, 463, 464  
     doping, 461  
     FeAs layer, 460  
     iron-chalcogenide (FeCh) layers, 460  
     iron-pnictides, 6, 459–460  
      $\text{La}(\text{O}_{1-x}\text{F}_x)\text{FeAs}$  (La-1111), 2, 6

508 *Subject Index*

iron-based superconductors (*continued*)  
 lower critical field, 473–474  
   table 474  
 magnetic instability, 459  
 parent compounds, 459  
 phase diagram ((1 1 1) family), 465–466  
 phase diagram ((1 2 2) family), 467  
 physical properties, 471–477  
   characteristic length scales, 473, 475  
   table (penetration depth, coherence length), 475  
 energy gap, 471, 473  
   ARPES, 473  
   point-contact Andreev-reflection spectroscopy (PCAR), 473  
   table, 473  
 resistivity, 475–477  
 $\text{Sm(O}_{1-x}\text{F}_x\text{)FeAs}$  (*see* Sm-1111)  
 $\text{SmO}_{0.85}\text{FeAs}$  (*see* Sm-1111)  
 spin density wave (antiferromagnetic ordering), 465–467  
 structural instability, 459  
 synthesis, 477  
   table, 478–480  
 upper critical field, 473–474  
   table, 474  
 irreversibility field ( $B_{irr}$ ), 171, 218–221  
   anisotropy, 219, 221  
 irreversibility line, 171–174, 194, 203, 216–226  
   after irradiation, 222, 225, 226  
 irreversibility temperature, 172–173  
 isotope effect ( $T_c$ ), 50–51, 424–425  
   isotope effect exponent, 50–51  
 $\text{MgB}_2$ , 424–425  
  
 Josephson AC current, 61–62  
 Josephson DC current, 59–61  
 Josephson–Fraunhofer diffraction pattern, 64  
 Josephson–Fraunhofer interference, 64  
  
 Knight shift, 137  
  
 $\text{La-1111 (LaO}_{1-x}\text{F}_x\text{FeAs)}$ , 2, 6, 459–463, 469, 472, 474–476, 478  
   coherence length, 475  
   critical temperature, 461–463  
   crystal structure, 472  
   doping, 461  
   energy gap, 473

lattice parameters, 469  
 layering scheme, 459–460  
 parent compound ( $\text{LaOFeAs}$ ), 465–466, 469, 472, 475–476  
 penetration depth, 475  
 phase diagram, 466  
 resistivity, 476  
 synthesis, 478  
 upper critical field, 474  
 Landau theory, 70  
 $\text{LaOFeAs}$  (*see* La-1111)  
 Laue method, 104–105  
 lattice parameters  
   Bi-2212, 111  
   (Bi,Pb)-2223, 111  
 cuprate superconductors (table), 126–127  
 Fe-based superconductors, 459–460  
   (1 1 1) family, 469  
   Ba-122, 469  
   FeSe, 469  
   LiFeAs, 469  
   Hg-1201, 123  
   Hg-1212, 125  
   Hg-1223, 125  
   Hg-1234, 125  
   Hg-12( $n-1$ ) $n$ , 127  
    $\text{La}_2\text{CuO}_4$ , 89, 107  
    $\text{MgB}_2$ , 424  
   Tl-2201, 114  
   Tl-2212, 116  
   Tl-2223, 116, 118  
   Tl-2234, 118  
   Tl-12( $n-1$ ) $n$ , 127  
    $\text{YBa}_2\text{Cu}_3\text{O}_7$ , 89  
 lattice vibrations (see phonons)  
 layering schemes (cuprate superconductors), 88–91  
 $\text{HgBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+2}$   
   (Hg-12( $n-1$ ) $n$ ), 89, 91  
 $\text{La}_2\text{CuO}_4$ , 88  
 $\text{Tl}_2\text{Ba}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+4}$   
   (Tl-22( $n-1$ ) $n$ ), 89–90  
 $\text{YBa}_2\text{Cu}_3\text{O}_7$ , 88  
 layering schemes (Fe-based superconductors), 459–460  
   (1 1) family, 459–460  
   (1 1 1) family, 459–460  
   (1 1 1 1) family, 459–460  
   (1 2 2) family, 459–460

*Subject Index 509*

- LiFeAs (Li-111), 459–460, 462, 470, 473, 475, 479  
 coherence length, 475  
 critical temperature, 462  
 energy gap, 473  
 lattice parameters, 470  
 layering scheme, 459–460  
 penetration depth, 475  
 synthesis, 479  
 London equations, 3, 31–32  
 London penetration depth, 3, 26, 27, 32  
 London theory, 2, 4, 26, 32  
 loop currents (*see* orbital currents)  
 Lorentz force, 203, 205, 208, 268, 339  
 low-angle gain boundaries, 188  
 lower critical field ( $B_{c1}$ ), 69, 75  
     cuprates, 165, 174–176  
     table, 175  
 Fe-based superconductors, 473–474  
     table, 474  
  
 magnet applications, 317, 339  
 magnetic bearings, 293, 317  
 magnetic phase diagram, 171–174  
     cuprates, 171–172  
     Type I, 28, 78  
     Type II, 78, 171  
 magnetic relaxation effects, 207  
     logarithmic relaxation, 208  
     nonlogarithmic relaxation, 208  
     relaxation of remanent  
         magnetization, 209–210  
 magnetic resonance imaging (MRI), 345, 492  
 magnetic shielding, 293  
 magnetic susceptibility, 38  
 map of highest critical temperatures, 5  
 Matthieson's rule, 20  
 Mauguin–Hermann symbols, 104  
 Maxwell equations, 31–32  
 mean free path of electrons, 73  
 Meissner effect, 3, 25, 27, 30, 31, 69  
 melt-cast process, 317–318  
 metal-insulator transition, 152  
 $MgB_2$ , 423–450, 489–490  
     coherence length, 432, 433  
     conventional superconductor, 425, 492  
     critical temperature, 423  
     crystal structure, 424  
     electron-phonon interaction, 424  
     energy gap  
  
 band coupling, 427  
 $\pi$ -band gap, 425–427  
 $\sigma$ -band gap, 425–427  
 Ginzburg–Landau parameter, 432, 433  
 grain-boundary weak links, 423  
 irreversibility field, 430–432  
 irreversibility line, 429–432  
 isotope effect, 424–426  
     partial B isotope effect exponent, 425  
     partial Mg isotope effect exponent, 425  
 lattice parameters, 424  
 penetration depth, 432, 433  
 physical properties (table), 433  
 resistivity, 434–435  
     residual resistivity ratio, 434  
 specific heat, 434, 436–437  
 thermal conductivity, 434, 436  
 two gap superconductor, 425, 426  
 two gaps, 425–427, 490  
 two-gap scenario, 426–428  
     angle-resolved photo electron  
         spectroscopy (ARPES), 426  
     electronic specific heat, 427  
     point-contact Andreev-reflection  
         spectroscopy, 426  
     scanning tunneling spectroscopy, 426  
     specific heat jump, 427–428  
 upper critical field, 428–432  
     angular dependence, 429  
     anisotropy factor, 429  
     evidence for two-gap scenario, 428  
     table, 430  
 XRD pattern, 424–425  
 $\pi$ -band, 425  
 $\sigma$ -band, 425  
 $\sigma$ -band holes, 425  
 $MgB_2$  bulk material, 444–446  
 $MgB_2$  films, 446–450  
     critical current densities, 449  
     multilayers, 448–450  
     preparation, 446–448  
         table, 447–448  
     ultrathin films, 448–449  
 $MgB_2$  wires and tapes, 437–444  
     critical current densities, 441–444  
     *ex situ* route, 437–440  
     high-pressure deformation, 442  
     *in situ* route, 437–440  
     mono-core wires, 437–439, 442  
     multifilament wires, 437–439, 442

510 *Subject Index*

- MgB<sub>2</sub>** wires and tapes (*continued*)  
 powder, 440, 442  
 powder-in-tube (PIT) method, 437–442  
 sheath materials, 439–440
- Miller–Bravais indices**, 102
- Miller indices**, 102–103, 106
- mixed state**, 75, 79–80
- molecular superconductors**, 6
- Mott insulator**, 21, 87, 151–152, 161
- Mott transition**, 21
- muon spin rotation**, 137, 158
- Nd-1111 (NdO<sub>1-x</sub>F<sub>x</sub>FeAs)**, 462, 464, 474, 476, 478–479  
 critical temperature, 462  
 energy gap, 473  
 irreversibility field, 474  
 resistivity, 476  
 synthesis, 478–479  
 upper critical field, 474
- Néel temperature**, 152
- Nernst coefficient**, 268
- Nernst effect**, 158, 160, 265, 268, 273–276  
 vortex Nernst effect, 268
- neutron diffraction**, 106–107
- neutron scattering**, 158
- NMR spectrometers**, 492
- Nobel prize winners**, 2
- nuclear magnetic resonance (NMR)**, 137, 158  
 chemical shift, 137  
 Knight shift, 137
- Ohm's law**, 31
- optimum hole concentration (cuprates) (*see* formal valence)**
- orbital currents**, 161–162
- organic superconductor**, 6
- oxalate co-precipitation**, 294–295, 297, 299, 303–304,
- pancake vortices**, 205
- paramagnetic susceptibility**, 77
- partial melting process**, 341
- Pauli limiting field**, 77
- Pauli's exclusion principle**, 15, 20, 21, 35, 47
- Pauli spin susceptibility**, 77, 137
- Peltier coefficient**, 266
- Peltier effect**, 265–266
- penetration depth**, 32, 72–73, 165–169, 432–433, 475
- cuprates**, 165–169
- Fe-based superconductors**, 475
- MgB<sub>2</sub>**, 432, 433
- perfect diamagnetism**, 2, 24, 38
- phonons**, 19
- pinning potential**, 207–209
- powder-in-tube (PIT) method**, 341–342, 352, 437–442
- power applications**, 339
- power transmission cables**, 339, 492
- pressure dependence of *T<sub>c</sub>***  
 (cuprates), 139–145
- Bi-2212**, 140
- (Bi,Pb)-2223**, 140
- Hg-1201**, 142
- Hg-1212**, 142
- Hg-1223**, 142
- initial pressure derivatives**  
 Hg-based cuprate  
 superconductors, 143
- table**, 144
- Tl-1223**, 141
- Tl-2201**, 141
- Tl-2212**, 141
- Tl-2223**, 141
- uniaxial pressure**, 143–145
- probability density**, 17
- processing (cuprate superconductor powders)**, 293–317 (see also synthesis)
- pseudogap**, 151, 158–162  
 pseudogap temperature, 160
- pyrolysis**, 299
- quantum interference effects**, 45  
 single SIS contact, 62–64  
 double SIS contact, 64–66
- RABiTS (Rolling Assisted Biaxially Textured Substrates)**, 363–364
- film sequences**, 370
- yield strength of Ni**, 369
- yield strength of Ni-W**, 369
- relative permeability**, 38
- relaxation rate (magnetization)**, 211
- relaxation time**, 19
- residual resistivity**, 1, 20
- residual resistivity ratio RRR (definition)**, 20
- resistivity**, 20–21  
 intrinsic (metals), 20

*Subject Index 511*

- upper limit in superconducting state, 23–24
- resistivity (normal state)
  - cuprate superconductors, 232–249
    - anisotropy of resistivity, 239–241
    - anisotropy ratios, 239, 241
  - Bi-based cuprates, 233–234
    - in-plane anisotropy (Bi-2212), 233, 239–240
  - effect of heat treatments, 234, 236–237
  - Hg-based cuprates, 234–235
  - irradiation effects on  $T_c$ , 238–239
  - $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$  (sintered), 232–233
  - RE-123, 234, 236
  - relation with pseudogap temperature, 241, 248–249
  - table, 242–247
  - Tl-based cuprates, 234–235
- Fe-based superconductors, 475–477
- $\text{MgB}_2$ , 434–435
- Rutger's formula, 40
- Rutherford cables (Ag/Bi-2212), 351
  
- Scanning tunneling microscopy (STM), 170
- scanning tunneling spectroscopy (STS), 158, 159
- Schottky anomaly, 279
- Schottky barrier, 191–193
- Schottky contribution (see Schottky specific heat)
- Schottky specific heat, 280, 289
- Schrödinger equation, 14, 17
- screening currents, 24
  - thin superconducting slab, 34–35
- Seebeck coefficient, 265–266, 269–273
- Seebeck effect, 265
- Shubnikov phase (see mixed state)
- Sm-1111 ( $\text{SmO}_{1-x}\text{F}_x\text{FeAs}$ ), 6, 459, 461–463, 466, 468, 473, 474
  - critical temperature, 459, 461–463
  - energy gap, 473
  - lattice parameters, 469
  - penetration depth, 475
  - phase diagram, 466
  - resistivity, 476
  - upper critical field, 474
- small-angle grain boundaries, 355
- solid-state reaction, 294–295, 298–300, 302, 305, 311
  
- space charge region, 191–193
- space charge effects, 192
- space group, 104
- space group symbol, 104
- specific heat
  - cuprates
    - low temperature specific heat, 280–283
    - Bi-2212, 281, 282
    - (Bi,Pb)-2223, 281, 283
    - Hg-1201, 283
    - $\text{La}_2\text{CuO}_4$ , 283
    - Y-123, 280, 281
    - Y-124, 283
    - Y-247, 283
  - specific heat jump at  $T_c$ , 284–286
    - Bi-2212, 284, 285
    - (Bi,Pb)-2223, 284, 285
    - Dy-123, 284
    - Gd-123, 284, 285
    - in-field data, 284
    - Tl-2223, 284, 285
    - Y-124, 284, 285
    - Y-123, 284, 285
  - specific heat data up to room temperature, 287–288
- Debye approximation, 34–35, 279
- electron contribution (electron-specific heat), 35–36
- jump in specific heat at  $T_c$ , 40–41, 280
- normal state, 35–36
  - at low temperatures, 37
- phonon contribution (phonon-specific heat), 34–36, 279
- Sr-122, 462, 481
  - critical current density, 481
  - critical temperature, 462
- standard enthalpies of formation (Bi-Sr-Ca-Cu-O system), 298
- strong links, 180, 355
- structure factor, 106
- superconducting elements, 29, 30
  - $T_c$  under high pressure, 30
- superconducting order parameter, 151–152
  - antinodal direction, 159, 162
  - d*-wave symmetry, 151–154, 162
  - extended *s*-wave, 490
  - nodal direction, 152, 159, 162
  - s*-wave symmetry, 151–154

512 *Subject Index*

- superconductivity  
discovery, 1–4  
macroscopic quantum phenomenon, 3, 45–66  
milestones in history of  
superconductivity, 2  
superconductor thermodynamics, 34–42  
entropy, 38–40  
Gibbs free energy, 34, 36  
Gibbs free energy of normal state, 37, 39  
Gibbs free energy of superconducting state, 38, 39  
internal energy, 36  
normal state entropy, 37  
specific heat, 39–41  
surface energy, 72, 73  
synthesis (cuprate superconductor powders), 293–317  
Bi-based superconductors, 296–303  
Bi-2212, 296–299  
oxalate co-precipitation, 299  
pyrolysis, 299  
solid-state reaction, 298–299  
table, 299  
(Bi,Pb)-2223, 296, 298–303  
freeze-dried nitrate solutions, 302  
heat treatment atmosphere, 300  
oxalate co-precipitation, 303, 304  
partial lead substitution, 300  
solid-state reaction, 300, 302  
two-powder process, 300, 302  
Hg-based superconductors, 311–317  
Hg-1201, 311–313  
Hg-1212, 313, 314  
Hg-1223, 313, 315, 316  
Hg-1234, 313  
solid-state reaction, 311  
Tl-based superconductors, 303–311  
Tl-1212, 305, 306, 308  
Tl-1223, 305, 306, 309, 310  
Tl-2201, 304, 305  
Tl-2212, 305, 306  
Tl-2223, 305, 307, 308  
Tl-2234, 305  
two-step synthesis routes, 303–304  
Y-based superconductors, 294–296  
citrate pyrolysis, 294, 296  
oxalate co-precipitation, 294–295, 297  
solid-state reaction, 294–295  
thermal conductivity (cuprates), 249–256  
anisotropy, 253, 255  
bulk cuprate superconductors, 253, 254  
effect of applied magnetic field, 255, 256  
electronic contribution, 250, 251  
measurement, 251, 253  
melt-textured Y-123, 253  
phonon contribution, 249, 250  
polycrystalline cuprate  
superconductors, 251–252  
aligned (Bi,Pb)-2223, 252  
single crystals, 253–255  
thermally activated flux creep, 203, 207–216  
thermocouple, 266, 267  
thermopower (thermoelectric power), 265  
cuprates, 269–273  
Thomas–Fermi screening length, 191  
Thomson coefficient, 266  
Thomson effect, 265, 266  
Thomson relations, 268  
tilt grain boundaries, 190  
Tl-1212, 305, 306, 308  
Tl-1223, 119–121, 141, 304–306, 309, 310  
copper oxide blocks, 119  
crystal structure, 119–121  
atom positions, 121  
initial  $dT_c/dp$ , 141  
powder synthesis, 304–306, 309, 310  
XRD pattern, 120  
Tl-2201, 89, 114–116, 140, 141, 304, 305  
copper oxide blocks, 114, 115  
crystal structure, 114–116  
atom positions, 116  
initial  $dT_c/dp$ , 141  
lattice parameters, 114  
powder synthesis, 304, 305  
XRD pattern, 115  
Tl-2212, 116–118, 140, 141, 305, 306  
copper oxide blocks, 116, 117  
crystal structure, 116, 117  
atom positions, 117  
initial  $dT_c/dp$ , 141  
lattice parameters, 116  
powder synthesis, 305, 306  
XRD pattern, 116  
Tl-2223, 116, 118–120, 140, 141, 284, 285, 305, 307, 308  
crystal structure, 116, 118–120  
atom positions, 120

## Subject Index 513

- initial  $dT_c/dp$ , 141
- lattice parameters, 116, 118
- powder synthesis, 305, 307–308
- specific heat, 284, 285
- XRD pattern, 118
- transformers, 339, 492
- transition temperature, see critical temperature
- tri-crystal superconducting rings, 154, 155
  - zero ring, 155
  - $\pi$ -ring, 154, 155
- tunneling, 52–66
  - single electron tunneling (NIN), 54–56
  - single electron tunneling (NIS), 56–58
  - single electron tunneling (SIS), 56, 57, 59, 60, 62, 64, 65
- tunneling experiments, 4
- tunneling spectra of Bi-2212, 158
- two-gap scenario (see  $MgB_2$ )
- two-gap superconductor (see  $MgB_2$ )
- Type I superconductors, 69, 72–81
  - critical current, 81–83
- Type II superconductors, 69–84
  - critical current, 81–83
- upper critical field ( $B_{c2}$ ), 69, 75
  - cuprate superconductors, 165, 173–175
    - table, 175
  - Fe-based superconductors, 473, 474
    - table, 474
- $MgB_2$ , 428–434
  - angular dependence, 429
  - anisotropy factor, 429
  - evidence for two-gap scenario, 427, 428
  - table, 430
- valence band, 17, 18
- Vickers micro hardness, 346
- vortex–vortex interaction, 79, 204
- vortices, 79, 81–83, 160, 205, 206, 268, 274
- weak-link behavior, 191
- weak-link problem, 317, 361, 489, 491
- weak links (grain boundaries), 180, 188–193
- Werthamer-Helfand-Hohenberg (WHH) theory, 173, 473
- Wiedemann–Franz law, 250, 251
- X-ray diffraction, 104–106
  - rocking curve, 354, 355
- X-ray powder diffraction, 105–106
- X-ray powder diffraction pattern (XRD pattern)
  - $BaFe_{1.87}Co_{0.13}As_2$ , 470
  - $Ba_{0.6}K_{0.4}Fe_2As_2$ , 470
  - Bi-2212, 112
  - (Bi,Pb)-2223, 112
  - $CeO_{0.84}F_{0.16}FeAs$ , 469
  - FeSe, 471
  - FeTe, 471
  - Hg-1201, 122
  - Hg-1212, 123
  - Hg-1223, 123
  - $LaO_{0.8}F_{0.2}FeAs$ , 468
  - $La_{2-x}Sr_xCuO_4$ , 107
  - LiFeAs, 470
  - $MgB_2$ , 424
  - $Sm_{0.85}F_{0.15}FeAs$ , 468
  - Tl-1223, 120
  - Tl-2201, 115
  - Tl-2212, 116
  - Tl-2223, 118
  - Tl-2234, 118
  - $YBa_2Cu_3O_{7-\delta}$ , 110
- Y-123
  - crystal structure, 108–111
    - atom positions, 111
  - CuO chains, 110
  - dependence of  $T_c$  on formal Cu valence, 132, 133
  - multilayers (Pr-123-Y-123), 407, 408
  - specific heat, 280, 281, 284, 285
  - thermal conductivity, 253
  - tri-layers (Pr-123-Y-123-Pr-123), 408, 409
  - XRD pattern, 110

