

## Index

### **a**

Abrikosov, Alexei 187  
 acceptor 111, 113  
 acoustic metamaterials 150–153  
 acoustic waves 51–53, 69–72  
 actinoids 101  
 Akasaki, Isamu 170  
 Alferov, Zhores 164  
 alkaline earth metals 101  
 alkaline metals 101  
 allotropes 33  
 Alnico V 210  
 alpha-chitin 149  
 aluminum gallium arsenide (AlGaAs) 169  
 aluminum gallium indium phosphide (AlGaInP) 169  
 aluminum gallium phosphide (AlGaP) 169  
 amorphous halo 2  
 amorphous materials 1, 100  
 amorphous silica 2  
 Anderson localization 174  
 Anderson, Philip 69, 191, 206  
 angle-resolved photoemission spectroscopy (APRES) 43, 126–128, 250  
 angular frequency 13, 24, 45, 70, 116, 137, 175, 243  
 anhydrous guanine crystals 149

anisotropic crystals 67, 150  
 anisotropy energy constant 218  
 antenna radome 147  
 antiferromagnetic material 206  
 antimony telluride 250  
 antiparallel magnetizations 213  
 APRES measurements 127  
 Atalla, Mohammed 118  
 atomic magnetic moments 197, 198, 199  
 atomic networks 4, 9, 35  
 axis of easy magnetization 208  
 Azbel-Kaner cyclotron resonance 43, 47  
 Azbel, Mark 46

### **b**

Ba-doped LaCuO<sub>3</sub> 189  
 ballistic electron transport 79  
 band-gap engineering 105, 164  
 band gaps 32–34, 35, 106  
 band-pass filters 147  
 band structure 23, 31–35, 40, 98, 126, 237, 241, 248  
 Bardeen, John 109, 117, 178  
 barium titanate (BaTiO<sub>3</sub>) 22, 221, 222, 225, 227, 228, 229, 231, 232  
 Basov, Nicolay 172  
 BCS theory 178, 179, 180, 190

- Be ( $2s^2$ ) 33  
beam steerers 147  
Bednorz, J. Georg 189, 190  
Berezinskii-Kosterlitz-Thouless (BKT) phase transition 249  
Berezinskii, Vadium 248, 249  
biaxial in-plane strains 166  
biaxial Young modules 166  
Biot-Savart law 10  
bipolar junction transistor (BJT) 116, 117  
bismuth antimonide 250  
bismuth selenide ( $Bi_2Se_3$ ) 250  
bismuth telluride ( $Bi_2Te_3$ ) 250  
Bloch domain wall 217  
Bloch, Felix 81, 208  
Bloch functions 238  
Bloch–Grüneisen law 82  
Bloch theorem 24  
Bloch waves 24  
body-centered cubic (bcc) 7, 29  
body-centered lattices 7  
Bohr magneton 198  
Bohr model 120, 250–251  
Bohr quantization condition 120, 250  
Boltzmann assumption 56  
Boltzmann constant 53, 94, 158  
Boltzmann distribution 57, 78  
Boltzmann energy distribution 77  
Boltzmann probabilities 73  
Boltzmann statistics 199, 238  
Born-von Karman cyclic boundary conditions 53  
Bose-condensate 179, 184  
Bose-Einstein statistics 57, 80, 99, 179  
Bose's derivation of the Planck distribution function 73–74  
Boyle, Willard S. 168  
Bragg angle 16, 61, 62, 64, 65, 173  
Bragg diffraction 16, 65  
Bragg law 16, 63  
Bragg peak intensity 65  
Bragg peaks 3  
Bragg reflection 67, 173, 174  
Bragg reflectors 233, 234  
Bragg scattering 62, 65, 79  
Brattain, Walter 117  
Bravais, Auguste 3  
Bravais lattice 3, 4, 7, 8, 9, 28, 29, 34, 102, 207  
Brewster, David 220  
Brillouin, Leon 13  
Brillouin zone 8, 17, 26–31, 34, 36, 37, 40–43, 53, 128, 169, 249  
Brockhouse, Bertram 64  
bulk acoustic waves, velocities of 69  
bulk modulus 68, 150, 152  
bulk plasmons 149
- C**
- cadmium telluride/mercury telluride ( $CdTe/HgTe/CdTe$ ) quantum well structure 250  
Ca-doped lanthanum manganite 240  
carbon crystalline polymorphs 33  
Cartesian (Descartes) coordinate system 10  
 $CaTiO_3$  221  
centered (non-primitive) Bravais lattices 8  
centro-symmetric crystals 8, 9, 231  
cerium-doped yttrium-aluminium garnet (YAG) crystals 170  
cesium (Cs) 125, 126  
charge-coupled devices (CCD) 155, 167–168  
Chu, Paul 190  
circular current 214

- classical and quantum Hall effects 241–247  
 classical 3D perovskites ( $\text{ABX}_3$ ) 161  
 classical Drude theory 76–77  
 classical ferromagnetics 206  
 classical Hall measurements 242  
 classical oscillator 56  
 classical (simple) perovskite structure 161  
 Cochran, William 69  
 coercivity 210  
 conduction band 27, 32, 33, 38, 39, 79, 98, 105–107, 109, 110, 111, 124, 131  
 constant wavevector 24  
 constructive interference 148, 149  
 contact potential 96, 131, 132  
 convex lens 144  
 cooperative phenomena in electron systems  
   classical and quantum Hall effects 241–247  
   electron energies and orbit radii in the simplified Bohr model 250–251  
 Mott metal-insulator transition 237–241  
 topological insulators 247–250  
 Cooper, Leon 178  
 Cooper pairs 179, 180, 182, 184, 191–193, 244  
 Coulomb attraction 112  
 Coulomb field 112, 238–240  
 Coulomb interaction 246  
 Coulomb law 231  
 Coulomb potential 179, 192–193, 238  
 Coulomb repulsion 179, 198, 237, 240, 246  
 critical magnetic field in type I superconductors 195  
 crystalline GaSb 2  
 crystalline quartz 2  
 crystal melting 60, 220  
 crystal-monochromator 63, 64  
 crystal symmetry 9  
   in real space 3–9  
 cubic  $\text{BaTiO}_3$  221, 228  
 cubic symmetry system 7, 20  
 cubic system 4  
 $\text{Cu}_2\text{MnSn}$  101, 102  
 Curie constant 200  
 Curie, Jacques 230  
 Curie, Pierre 230  
 Curie temperature 201, 202, 213, 221–223  
 Curie–Weiss constant 225  
 Curie–Weiss law 202, 223, 225  
 current density 10, 75, 76, 94, 97, 136, 156, 180, 181, 186, 187, 195, 214, 241  
 current ( $I$ )-voltage (in units of  $eU$ )  
   characteristic 183, 184  
 cyclotron frequency 44–46, 243  
 cyclotron resonance 43  
 Czochralski method 169
- d**  
 Darwin, Charles Galton 173  
 dc Josephson effect 184  
 de Boer, Jan 237  
 de Broglie equation 64  
 de Broglie wavelength 13  
 Debye approximation 60  
 Debye frequency 53, 58  
 Debye–Hückel screening radius 238  
 Debye, Peter 58  
 Debye temperature 53, 59, 60, 77, 80, 81, 179, 180  
 Debye–Waller factor 51, 65–67, 79  
 Debye wavevector 81

- defects contributions to metal resistivity 82–84
- deformation vector 11
- deformed crystal 11
- degeneration of states 222
- de Haas-van Alphen effect 43, 47, 48
- de Haas-van Alphen oscillations 48
- de Haas-van Alphen resonance 48
- diamagnetism 199, 200
- diamond structure 9, 33, 106
- dielectric constant 112, 113, 120, 121, 136, 140, 141, 147, 174, 175, 222
- dielectric permittivity 10, 11, 113, 123, 132, 136, 146
- of a vacuum 224, 251
- diffracted waves 17, 25, 66
- diffraction phenomena 3, 149
- Dirac cones 39
- Dirac fermions 38, 39
- Dirac, Paul 38
- Dirac points 39
- Dirac semimetal 39
- direct measurements of the superconductor energy gap 182–184
- dislocation formation 165
- dispersion curve 27, 62, 63
- dispersion laws 52, 61, 137, 157
- divalent elements 33
- divalent Mg metal 33
- dodecahedron 5, 6, 31, 42
- domain walls 205, 207–210, 216–219, 228–230
- donor-type semiconductor 110
- doped semiconductors 110, 184
- Doppler effect 143
- Doppler frequency 143
- double C resonator 152, 153
- Drude formula 79
- Drude, Paul 76
- Drude theory 77, 109, 211
- Dulong–Petit law 57–59, 87
- Dumke, William 172
- dye-sensitized solar cells 159
- dynamic random-access memories (DRAMs) 225
- e**
- effective mass 27, 46, 55, 107, 120, 151
- Einstein, Albert 57, 100, 126, 170, 179
- Einstein convention 11
- Einstein equation 126
- Einstein model 59, 80
- Einstein temperature 100
- Einstein theory 58
- elastic constants 150
- elastic wave frequencies 56
- electrical conductivity 109
- in semiconductors
- extrinsic semiconductors 110–111
  - intrinsic semiconductors 105–109
  - p-n*-junction 111–117
- tensor 11
- electrical resistivity 75, 76, 80–82
- electric field 10–12, 32, 34, 39, 46, 76, 106, 109, 111, 112, 114, 119, 125, 133, 136, 159, 168, 180, 186, 219, 220
- electrochemical potential 96, 160, 161
- electroluminescence 168
- electron density 31, 40, 76, 77, 79, 91, 132, 141, 205, 238, 239, 241
- electron diffraction 2
- electron energies and orbit radii in the simplified Bohr model 250–251

- electron energy loss spectroscopy (EELS) 141
- electron kinetic energy 24
- electron mass 23, 43, 46, 191
- electron transfer 106, 160
- electron wave function 23, 36
- electron waves in crystals
- band structure 31–35
  - Brillouin zone 28–31
- cyclotron resonance and related phenomena 43–49
- electron behavior in a periodic potential and energy gap formation 23–28
- Fermi surface 40–43
- graphene 35–40
- elementary magnetic moment 214
- Emmy Noether theorem 13
- energy density 11, 52, 53, 157, 215, 216
- energy diagrams 84
- energy dispersive spectroscopy (EDS) 163
- energy gap 17, 23–28, 26, 27, 108, 165
- energy-momentum conservation law 126, 134
- energy profiles 27, 38, 107
- energy resolution 63–65, 162, 163
- energy scheme 107, 110, 111, 183
- equilibrium flux 170
- Esaki calculations 165
- Esaki diodes 184
- Esaki, Leo 164, 184
- Euler angles 217–218
- Ewald, Paul 173
- exciton radius and binding energy 121
- extended zone scheme 27, 28
- extrinsic semiconductors 110
- f**
- face-centered cubic (fcc) 7, 29, 41
- face-centered lattices 7
- F-centered Bravais lattice 7
- Fermi-Dirac distribution 78, 84, 90, 107, 216
- Fermi-Dirac function 87
- Fermi-Dirac probabilities 215
- Fermi-Dirac statistics 77, 87, 89, 238
- Fermi energy 31, 40, 78, 87, 94, 96, 108, 111, 115, 124, 128, 155, 172, 179, 215, 239
- Fermi level 31, 40, 109–112, 124, 131, 160, 161, 179, 182, 216, 239, 248
- Fermi sphere 41, 80, 180
- Fermi surface 40, 45, 126, 128, 181
- Fermi temperature 98
- Fermi velocity 38, 79, 93, 180
- Fermi wavevector 31, 40, 78, 169
- ferroelectric domains 20, 22, 223, 227–230
- ferroelectric field-effect transistor (FeFET) 235, 236
- ferroelectricity 8
- application fields 233–236
  - domain structure 227
  - piezoelectric effect 230–233
  - theory of ferroelectric phase transition 223–227
- ferroelectric  $\text{LiNbO}_3$  234
- ferroelectric material potassium dihydrogen phosphate,  $\text{KH}_2\text{PO}_4$  (KDP) 222
- ferroelectric materials 219, 222, 225, 234, 235
- ferroelectric random-access memory (FRAM) 236
- ferroelectrics-based photovoltaics 235

- ferromagnetic material 202, 204, 206, 207, 211, 221, 224  
 ferromagnetism 177, 219  
   elementary magnetic moment 214  
 giant magnetoresistance 211–214  
   Ising model 204–205  
 magnetic domains 207–210  
 magnetic domain walls 216–218  
 magnetic materials 210–211  
 magnetic structures 205–207  
 paramagnetism 198–204  
   paramagnetism Pauli 214–216  
 Fert, Albert 212  
 Feynman, Richard 38  
 field-effect transistor (FET) 117, 163  
   working principle 118  
 field-emission gun 130  
 field tensors 10, 11  
 figure of merit 97, 103  
 five-valent bcc V 41  
 five-valent P 110  
 flexible elastic membrane 152  
 fluorescent X-rays 163  
 forwardly biased *p-n* junction 156  
 forward voltage 114, 132  
 Fourier coefficients 24  
 Fourier component 27, 79, 127, 145, 179  
 Fourier law 92  
 Fourier series 24, 145  
 Fourier transform 179  
   of Coulomb potential 192  
 four-valent Si 110, 111  
 Fowler–Nordheim tunneling 130  
 fractional quantum Hall effect (FQHE) 242, 245, 246  
 Franz, Rudolph 93  
 Frenkel exciton 112  
 Frenkel-type excitons 112  
 Frenkel, Yakov 112  
 Fröhlich, Herbert 178, 180  
 full Heusler alloys 102
- g**
- GaAs-AlGaAs heterostructures 245  
 gallium arsenide phosphide (GaAsP) 169  
 gallium phosphide (GaP) 169  
 GaP/InAs superlattices 164  
 Geim, Andre K. 35  
 germanium 33  
 Giaever, Ivar 182  
 Giaever phenomenon 184  
 giant magnetoresistance 197, 211–214  
 Gibbs free energy 204  
 Ginzburg–Landau theory of superconductivity 187  
 Ginzburg, Vitaly 187, 223  
 golden ratio 5, 17  
 graphene 35–40, 249  
 Grätzel cell 159–161  
 Grätzel, Michael 159  
 Grünberg, Peter 212  
 Grüneisen, Eduard 68  
 Grüneisen law 68  
 Grüneisen parameter 68  
 guanine nanocrystals 149
- h**
- Haldane, Duncan 249  
 half-Heusler alloy 99, 101, 102  
 halide perovskite solar cells 161–162  
 Hall coefficient 241, 242  
 Hall conductivity 241, 242, 244  
 Hall current 241, 244, 246  
 Hall, Edwin 212  
 Hall effect 39, 212, 241, 243, 244

- Hall measurements 242, 244, 245  
 Hall potential 241, 244  
 Hall resistance 242, 244  
 Hall resistivity 242, 243  
     measurements 245  
 Hall, Robert 172  
 Hall voltage 242, 243  
 hard magnetic materials 210  
 Harrison, Walter 182  
 heat flux 92, 94, 95  
 Heisenberg, Werner 203  
 Helmholtz oscillator 152  
 Helmholtz resonator 152  
 hematite 206, 207  
 Hertz, Heinrich 126  
 Heusler alloy 101, 102  
 Heusler intermetallics 100  
 hexagonal boron nitride (*h*-BN) 40  
 hexagonal graphite 34  
 hexagonal system 4  
 hexagonal wurtzite structure 106  
 HgBaCaCuO 192  
 HgTlBaCaCuO 192  
 high-energy resolution 163  
 highest occupied molecular orbital  
     (HOMO) 159  
 high-frequency electromagnetic  
     wave 135, 140  
 high-orbit satellites 141  
 high-order symmetry elements 8  
 high-symmetry elements 5  
 high-temperature superconductivity  
     (HTSC) 189–192  
 high-temperature superconductors  
     190  
 Holonyak, Nick 168  
 honeycomb-like graphene lattice  
     35  
 hopping integral 37, 38  
 Hubbard model 191, 240  
 Hund’s rules 197, 198, 201  
     hydrogen-like atom 120, 121, 238,  
         250–251  
     hysteresis loops 210, 211, 220  
  
*i*  
 icosahedron 5, 6  
 ideal diamagnetics 199  
 image charge method 124,  
     133–134  
 imaginary refractive index 141  
 improper ferroelectrics 223  
 InAs/GaP superlattice 165  
 InAs/GaSb superlattice 165, 166  
 incident waves 17  
 individual electron orbit 46  
 induced polarization vector 230  
 infra-red detectors 164  
     arrays 165  
 insulators 27, 32, 33, 38, 87, 93,  
     103, 192, 225, 237, 240  
 integer quantum Hall effect 242  
 inter-atomic distances 11, 240  
 interface strains 165  
 intrinsic semiconductor 105,  
     107–110  
 inverse process 155  
 inversion-center symmetry 39  
 invisible cloak 146, 147  
 iron crystal 209  
 Ising, Ernst 204  
 Ising model 204–205  
 isomorphous III-V solid solutions  
     164  
 isotope effect in superconductivity  
     181  
  
*j*  
 Jahn-Teller effect 190, 191  
 Jahn-Teller theorem 190  
 John, Sajeev 174  
 Josephson, Brian 184

- Josephson constant 188  
 Josephson current 188, 189, 194  
 Josephson effect 43, 184, 193–195,  
     244  
 Josephson equation 185  
 Josephson junctions 189  
 Joule heat 94, 95  
 junction field-effect transistor  
     (JFET) 118
- k**
- Kahng, Dawoon 118  
 Kamerlingh-Onnes, Heike 177  
 Kamerlingh-Onnes' original data  
     178  
 Kaner, Emanuil 46  
 Kelvin, Lord 94, 212  
 Kelvin probe method 125  
 Kilby, Jack 117  
 Kohn, Walter 241  
 Kosevich, Arnold 48  
 Kosterlitz, Michael 249, 250  
*K*-points 34, 36, 38, 39  
 Kroemer, Herbert 164  
 Kronecker symbol 15, 70  
*k*-space 31
- l**
- Lamb, Horace 138  
 Lamé coefficients 150  
 Landau approach 249  
 Landau diamagnetism 200  
 Landau energy level 44, 47, 245  
 Landau energy states 245  
 Landau gauge 43  
 Landau, Lev 43, 204, 223, 248  
 Landau levels 44, 45, 47, 48, 242,  
     243, 244–246  
 Lande factor 201, 203  
 Langevin function 199, 200  
 Langevin paramagnetism 216  
 lanthanoids 101  
 Laplace operator 24, 136  
 Larmor frequency 199  
 LaSrCuO 189  
 lattice anharmonicity 67–69  
 lattice heat capacity 56, 57  
 lattice heat conductivity 92, 93,  
     98, 101, 103  
 lattice inversion 4  
 lattice potential 26, 27, 40, 42, 110,  
     127  
 Laughlin quasi-particles 247  
 Laughlin, Robert B. 246  
 Laughlin state 246  
 lead halide perovskites 235  
 lead titanate ( $\text{PbTiO}_3$ ) 222  
 lead zirconate titanate (PZT) 222,  
     225, 231, 232  
 left-handed (LH) materials 142,  
     143  
 Lifshitz, Ilya 48  
 light 126, 135, 138, 149, 150, 155,  
     160, 169, 234  
 Light Amplification by Stimulated  
     Emission of Radiation  
     (LASER) 170  
 light-emitting diodes (LED)  
     168–170  
 light-induced charge generation  
     156  
 light-induced current density 156  
 light-induced electrons 156  
 light interaction with metals and  
     dielectrics  
     acoustic metamaterials 150–153  
     light reflection from metal  
     138–139  
 Maxwell equation 135, 139  
 metamaterials 141–147  
 plasma frequency 140–141  
 skin effect in metals 137–138  
 structural colors 148–150

- light interaction with  
semiconductors  
charge-coupled devices 167–168  
light-emitting diodes 168–170  
photonic materials 173–175  
semiconductor lasers 170–173  
solar cells 155–162  
solid state radiation detectors  
162–166
- light interference 148
- light irradiation 126, 155, 156, 234
- light reflection coefficient 138
- light reflection from metal  
138–139
- light-stimulated emission 171
- light wavevector 142
- Li-interstitials 163
- Lilienfeld, Julius 117
- Lindemann, Frederick 60
- linear chain of the periodically  
positioned atoms 51–56
- linear defects 82
- linear electro-optical effect 12, 234
- linear expansion coefficient 11, 67
- local (point) symmetry 4, 9
- London equation 186
- London, Fritz 179, 186, 244
- London, Heinz 186
- London penetration length 187,  
195
- long-range atomic diffusion 1
- Lorentz force 44, 45, 211, 241, 243
- Lorentz number 93, 94
- Losev, Oleg 168
- lowest unoccupied molecular  
orbital (LUMO) 159–161
- m**
- magnetic dipole moment 10, 198
- magnetic domains 204, 207–210  
walls 208, 216–218
- magnetic hysteresis 210
- magnetic loops 210
- magnetic materials 210–211
- magnetic moments 9, 10, 189, 197,  
198, 199, 200, 201, 203,  
205–208, 214–219, 229
- magnetic permeability 136, 141,  
146, 199
- magnetic resonance imaging (MRI)  
187
- magnetic structures 205–207
- magnetic susceptibility 47, 200,  
202, 216
- magnetic symmetries 205
- magnetic tunnel junctions (MTJs)  
213
- magnetite 206–207
- magnetization curves 208, 209
- magnetization directions 208, 210,  
212, 213
- magnetization vector 209, 212,  
213, 218, 229
- magnetoresistive random access  
memories (MRAM) 213
- magnetostriction 209
- magnitude of vector 127
- Mandelstam, Leonid 143
- Matthiessen rule 83
- maximum magnetization 202, 210
- Maxwell equations 135, 139, 141,  
186, 195, 216
- Meißner, Walther 185
- Meissner effect 185–188
- membrane resonators 152, 153
- metal bulk 124, 138
- metallic thermocouples 97
- metal-oxide-semiconductor (MOS)  
capacitor 118, 167
- metal-oxide-semiconductor  
field-effect transistor  
(MOSFET), 118, 119, 242, 243
- metals 27, 32, 75–85, 123–126

- metal-semiconductor junction 131–133  
 metal/vacuum contact 131  
 metamaterials 141–147, 149–153  
 methylammonium lead trihalide 162  
 $Mg(3s^2)$  33  
 microwave couplers 147  
 Miller indices 15, 65  
 momentum (wavevector)  
     conservation law 233  
 monoclinic symmetry systems 4  
 monovalent fcc Cu 41, 42  
 monovalent metal 33, 41  
 Moore’s law 119  
 MOSFET 118, 119, 242, 243  
 Mössbauer effect 65  
 MOS transistor 118, 119  
 Mott calculations 98  
 Mott insulators 192, 240  
 Mott metal–insulator transition 237–241  
 Mott, Nevill 112, 212, 237, 238, 240  
 Mott theory 213  
 Mott–Wannier-type excitons 112  
 Müller, K. Alex 189
- n**
- Nakamura, Shuji 169, 170  
 nano-disk 150  
 nano-hole arrays 150  
 nano-patches 150  
 nano-structured materials 83, 100  
 NbTi alloy 187  
 $n$ -doped semiconductor 110  
 Néel domain walls 218  
 Néel, Louis 206  
 Neel temperature 206  
 negative magnetic permeability 146  
 negative materials 143, 145, 146, 147  
 Neumann’s principle 9, 10, 13  
 Newton’s law 51, 151  
 nickel-oxide (NiO) 237, 238  
 90°-domains 228, 229  
 Noether, Emmy 13  
 non-centro-symmetric crystals 9, 165  
 non-coplanar vectors 3, 15  
 non-stationary Schrödinger equation 23  
 non-trivial elements 18  
 non-trivial (non-zero) solution 26  
 Nordheim, Lothar 83  
 normalization constant 80  
 normalized spontaneous magnetization 203  
 Novoselov, Konstantin S. 35  
 Noyce, Robert 117  
 $n$ -type semiconductor 110, 111, 131  
 nuclear magnetic resonance (NMR) 187
- o**
- Ochsenfeld, Robert 185  
 Ohm, Georg Simon 75  
 Ohm’s law 75, 77, 182  
 Ohm standard 244  
 one-dimensional electron movement 140  
 one-dimensional Ising model 204  
 180°-domains 227  
 Onsager, Lars 48, 205  
 Onsager–Lifshitz quantization rule 47  
 open circuit voltages 234  
 optical metamaterials 147, 150, 153  
 optical phonons 55, 61, 120  
 order-disorder type ferroelectrics 223  
 orthorhombic crystals 21

- orthorhombic system 4  
 orthorhombic  $\text{YBa}_2\text{Cu}_3\text{O}_7$  (YBCO) 191  
 oxidized photosensitizer 160
- p**  
 parabolic dispersion law 24  
 paraelectric/ferroelectric phase transition 221  
 parallel magnetizations 213  
 paramagnetic/ferromagnetic phase transition 201, 205, 223, 225  
 paramagnetism 198–204  
 paramagnetism Pauli 214, 215  
 particle momentum vector 134  
 Pauli exclusion principle 31, 84, 179, 197, 198, 203, 214  
 Pauli principle 203, 245  
 Pauli susceptibility 216  
 Pauli, Wolfgang 203  
 $p$ -doped semiconductor 111  
 Peierls, Rudolf 84, 237, 238, 248  
 Peltier coefficient 95  
 Peltier cooling 163  
 Peltier effect 94, 95  
 Pendry, John 145, 146  
 Penrose tiles 2, 3  
 periodic lattice potential 17, 23, 24, 27  
 Permalloy 210  
 Perovski, Lev 221  
 perovskite structure ( $\text{ABO}_3$ ) 22, 161, 190, 221, 222, 235  
 phonon contribution to electrical resistivity 80–82  
 phonon-glass electron crystals 100  
 phonon-mediated Cooper pairing mechanism 178–182  
 phonons and heat capacity 56–59  
 phonon scattering 99, 100  
 phonon wavevector 61, 70, 79, 249  
 photoelectric effect 126–128, 134, 232  
 photoferroelectrics 234  
 photon-electron interaction 134  
 photon flux 158, 170, 171  
 photonic crystal (PC)-based optical devices 175  
 photonic materials 147, 173–175  
 photonics 174  
 photosensitizer 160, 161  
 photovoltages 234  
 photovoltaics 155, 235  
 piezoelectric crystal 231, 233  
 piezoelectric effect 9, 12, 165, 222, 230–233  
 piezoelectricity 8, 230  
 planar defects 82  
 planar solar cell 157  
 Planck blackbody radiation 175  
 Planck constant 13, 23, 188, 198, 244, 250  
 Planck's distribution function 74  
 Planck's formula 57, 157  
 Planck's hypothesis 57, 73  
 Planck's quantization of energy states 57  
 Planck's quantum theory 170  
 plasma frequency 140–141  
 plasmonic nano-structures 149  
 plasmons 140, 141, 149  
 Platonic bodies 5  
 $p$ - $n$  junction 111–117, 112, 113  
 functioning as diode 116  
 $I$ - $U$  characteristics 115  
 transistor effect 116  
 Pockels effect 12, 234  
 point defects 82  
 point groups 6, 205  
 Poisson equation 112, 132, 239  
 polarons 191  
 Popper, P. 161  
 positive electrons 38

- potassium sodium tartrate tetrahydrate 219  
 potential barriers 123, 130, 131, 156, 238  
 potential energy function 114  
 Poynting vector 142  
 pressure wave 150  
 primitive lattices 7, 8  
 principal quantum number 238, 250, 251  
 Prokhorov, Alexander 172  
 proportionality factor 52, 62, 75, 158, 170, 201  
 proportionality parameter 68  
 pseudo-spin 40  
*p*-type semiconductor 111  
 pure antimony 250  
 pure diamagnetics 199  
 pure elemental metals 75  
 pyroelectric materials 219
- q**
- quadratic electro-optical effect 234  
 quantum-mechanical approach 77–80  
 quantum-mechanical characteristics 26  
 quantum-mechanical density functional theory (DFT) 241  
 quantum spin Hall topological state 250  
 quarter-wavelength plate 148  
 quasicrystal diffraction conditions 6  
 quasicrystals 1–3, 5, 16  
 quasi-momentum (quasi-wavevector) conservation law 16, 61  
 in 3D 1  
 quaternary alloy 169
- r**
- radar antenna 147  
 rare-earth-based Nd or Sm-Co magnets 210  
 Rayleigh, Lord 72  
 Rayleigh waves 72, 73, 233  
 real refractive index 141  
 reciprocal lattice 13–17, 24, 25, 28, 29, 30, 35–37, 41, 79  
 rectifying effect 115  
 red light 169  
 reduced zone scheme 27, 28  
 reflectivity coefficient 139  
 refractive index 12, 25, 137, 139, 141–143, 148, 149, 174, 234  
 regular crystals 1–4, 6, 8, 17, 149  
 regular dodecahedron 5  
 regular icosahedron 5  
 regular pentagon 3, 5, 6  
 remnant magnetization 210  
 resonant frequency 45, 146, 149, 151, 152, 153, 233  
 resonating valence bond theory (RVB) 191  
 reverse voltage 114  
 rf-SQUID 189  
 rhombohedral Bravais lattice 207  
 rhombohedral system 4  
 Richardson, Owen Willans 129  
 Richardson/Richardson–Dushman law 129  
 Riemann functions 82  
 right-handed materials (RH-materials) 142, 143  
 Rochelle salt 219–221  
 room-temperature dielectric constant 225  
 room-temperature electrical resistivities 75  
 rotation axes 4, 5, 8, 18–21, 30  
 Ruddlesden–Popper (RP) phase 161

- Ruddlesden, S.N. 161  
 Russell–Saunders coupling 198, 201  
 Rydberg constant 121, 251
- s**  
 SAW-based Bragg reflectors 233, 234  
 Sb-based skutterudites 101  
 Schottky diodes 132, 133  
 Schottky effect 124  
 Schottky, Walter 124, 247  
 Schrieffer, John 178  
 Schrödinger equations 23, 24, 43, 44, 193  
 Scotch tape method 35  
 Seebeck coefficients 94, 97, 98, 100  
 Seebeck effect 94, 97  
 semiconductor lasers 170–174  
 semiconductors 27, 32, 33, 87, 98  
 semiconductor/vacuum contact 131  
 semimetal 32, 35, 164  
 Shall, Clifford 64  
 Shechtman, Dan 2, 3  
 Shockley–Queisser radiative efficiency limit 162  
 Shockley–Read–Hall recombination 168  
 Shockley, William 109, 117  
 short-wavelength quantum beams 1  
 shot noise 247  
 Shubnikov–de Haas effect 47  
 Si-based detectors 162  
 side-centered Bravais lattices 7  
 Si(Li)-detectors 163  
 silicon 33  
 silicon dioxide ( $\text{SiO}_2$ ) 2  
 silicon drift detectors (SDDs) 163  
 silicon solar cells 157  
 simplified Bohr model 120, 238, 250–251  
 Si wafers 117  
 skin-effect calculations 138  
 skin effect in metals 137–138  
 skutterudite 99–101, 100  
 Smith, George E. 168  
 Snell’s law 143, 144, 148  
 soft ferromagnetic materials 211  
 soft magnetic materials 210  
 solar cells 155–162  
 solidified Al–Mn alloys 2  
 solid state radiation detectors 162–166  
 Sommerfeld approach 89  
 Sommerfeld, Arnold 89  
 Sommerfeld calculation approach 216  
 sound velocity 52, 53, 70, 71, 72, 93, 100, 150, 152, 180  
 specific electrical conductivity 75, 136  
 specific wavevector 26  
 $\text{sp}^2$ -hybridization 33, 34, 99  
 $\text{sp}^3$ -hybridization 33  
 split-ring resonators 146  
 spontaneous dielectric polarization 219  
 spontaneous emission 170, 171, 174  
 spontaneous magnetization 202, 203, 208, 212, 213, 227  
 spontaneous polarization 10, 219, 221, 222, 223, 225, 227, 232  
 state of superconductivity 177  
 static deformation fields 79  
 Stefan–Boltzmann constant 158  
 Stefan–Boltzmann law 158  
 stimulated light emission 172  
 Stirling formula 205  
 Störmer, Horst L. 245, 246  
 strain tensor 11, 12, 67, 69  
 stress tensor 11, 69, 71, 231  
 strong covalent atomic bonds 105

- strontium titanate (BST) 222  
 structural colors 148–150  
 sub-wavelength gratings 150  
 superconducting quantum interference device (SQUID) 188–189  
 superconductivity 177–195  
     critical magnetic field in type I superconductors 195  
     direct measurements of the superconductor energy gap 182–184  
     Fourier transform of Coulomb potential 192–193  
     high-temperature superconductivity 189–192  
     Josephson effect 184–185  
     Meissner effect 185–188  
     phonon-mediated Cooper pairing mechanism 178–182  
     superconducting quantum interference device (SQUID) 188–189  
     theory of the Josephson effect 193–195  
 super-exchange in MnO 207  
 superlenses 146, 153  
 surface acoustic waves (SAW) 72–73, 233  
 surface charge density 133  
 surface plasmons 149  
 symmetry and physical properties in crystals 9–13  
 symmetry constraints on rotation axes 18–20
- t**
- Taylor series 37, 58  
 tensor of linear expansion coefficients 11  
 tensor rank 10  
 tetragonal BaTiO<sub>3</sub> 228  
 tetragonal distortion 191, 221, 222  
 tetragonal system 4  
 theory of ferroelectric phase transition 223–227  
 theory of the Josephson effect 193–195  
 thermal diffuse scattering 61, 62, 65  
 thermal vibrations 1  
     of atoms in crystals 59–60  
 thermionic emission 128–130  
 thermocouple 95–97  
 thermodynamical potential 223, 224, 226  
 thermoelectric materials 97, 98–103, 248  
 thermoelectric phenomena 94–98  
 thermo-electron emission 128  
 Thompson, William 95  
 Thomson coefficient 95  
 Thomson effect 94, 95  
 Thomson extra heat 95  
 Thomson, William 94, 212  
 Thouless, David 249, 250  
 three-dimensional isotropic crystal 60  
 three-dimensional photonic superlattices 175  
 3D lattices of cubic diamond 34  
 3D-structure of energy bands 39  
 tight-binding approximation 36  
 time-of-flight (TOF)  
     neutron spectrometer 63  
     technique 63, 64  
 time-reversal (TR) symmetry 38, 39, 248, 250  
 time-varying magnetic field 146  
 titanium dioxide (TiO<sub>2</sub>) 159  
     nanoparticles 160  
 TlBaCaCuO 192  
 topological insulators 38, 103, 247–250

- Townes, Charles 172  
 transistor base 116  
 transistor effect 116  
 translational symmetry 1–22, 24,  
   25, 27, 53, 54, 61, 79, 100, 173,  
   249  
 translation vectors 3, 4, 7, 18, 21,  
   29, 30, 31, 35, 228  
 transparent conducting oxide (TCO)  
   160  
 trap-assisted recombination 168  
 triclinic symmetry systems 4  
 triple-axis neutron diffractometer  
   63  
 trivalent orthorhombic Ga 41  
 trivial symmetry element 4, 18  
 Tsui, Daniel C. 245, 246  
 tunneling coefficient 130  
 tunneling conditions between two  
   superconductors 184  
 twin boundaries 22  
 twinning in crystals 20–22  
 two-dimensional Ising model 205  
 two-dimensional material graphene  
   35  
 type-II superconductors 187  
 type-I superconductors 187, 195
- u**  
 ultimate efficiency hypothesis  
   (UEH) 158, 159  
 ultrathin ferroelectric domain walls  
   230  
 undoped semiconductors 105–109  
 unit cell 1, 4, 7, 8, 15, 21, 24, 29,  
   30, 31, 34, 35, 36, 55, 66, 100,  
   101, 112, 162, 173, 205–208,  
   217, 218, 221, 222, 227, 228,  
   229, 235  
 unusual acoustic wave propagation  
   150
- v**  
 Valasek, Joseph 219, 220  
 valence band 28, 32, 34, 37, 38, 39,  
   105–107, 110, 111, 112, 164,  
   169, 172, 235  
 van-der-Waals forces 34  
 van Hove singularities 48  
 vector potential 43  
 Vegard law 164  
 velocities of bulk acoustic waves  
   69–72  
 Verwey, Evert 237  
 Vesselago publication 145  
 Vesselago, Victor 141  
 virtual ferroelectric 222  
 visible light 135, 159, 169  
 Volt 185  
 Volt standard 185, 244  
 von Klitzing experiments 242, 245  
 von Klitzing, Klaus 242, 245
- w**  
 Wannier excitons 112  
 Wannier functions 238  
 Wannier, Gregory 112  
 wavelength dispersive spectroscopy  
   (WDS) 163  
 wave propagation in periodic media  
   and construction of reciprocal  
   lattice 13–17  
 wave scattering 14, 25  
 wavevector projections 126, 127  
 wavevectors 13–17, 24–27, 37–40,  
   45, 46, 48, 49, 52, 53, 54, 56,  
   58, 61, 62, 63, 70, 72, 78, 79,  
   107, 127, 137, 142, 143, 168,  
   169, 173, 179, 181, 233, 249  
 Weiss, Pierre-Ernest 201, 207  
 Weiss theory 203  
 wide-zone semiconductor 32  
 Wiedemann–Franz law 92–94, 93,  
   94, 97, 98

- Wiedemann, Gustav 93  
Wigner–Seitz cell 28, 29  
Wigner–Seitz construction 29, 36  
work function  
defined 125  
energy scheme 125  
graphical presentation of function 125  
image charge method 124, 133–134  
in metals 123–126  
metal-semiconductor junction 131–133  
photoelectric effect 126–128  
photon-electron interaction 134  
thermionic emission 128–131  
values of 125
- Wu, M.K. 190  
wurtzite structure 106, 170
- x**  
X-ray and neutron interaction with phonons 61–67  
X-ray spectrometers 65
- y**  
Yablonovitch, Eli 174  
Yukawa potential 192
- z**  
zero-gap 37  
zero strain 166  
zinc blende/sphalerite structure 9  
zinc blende structure 9, 106, 164  
 $\text{Zn} (3\text{d}^{10} 4\text{s}^2)$  33



















