

Index

A: *see* Conservation laws; Baryon number
 ABC theory, 201–213
 Abelian, 106, 354
 See also Gauge invariance; Groups
 Accelerator, 4
 Adjoint, 223, 228
 Allowed energies, 148
 a: *see* Fine structure constant
 a_{π} , 61, 77, 165, 279, 294
 $a_{\pi\pi}$, 76, 302, 309
 a particle: *see* Particles
 Amplitude, 119, 189, 194–195, 200–201, 229, 231
 Anderson, C. D., 18, 20, 29
 Angular momentum, 103
 addition, 109–113
 eigenfunctions: *see* Spherical harmonics
 eigenvalues, 146
 matrices: *see* Spin matrices
 orbital, 107–109, 153, 252
 spin, 103, 107–109, 116, 252
 Annihilation: *see* Pair annihilation
 Anomalous magnetic moment
 electron, 17, 153, 156, 232
 proton, 156–157
 Anticommutator, 139, 216
 Antielectron: *see* Positron
 Antineutrino, 24, 26–28, 124–125
 Antineutron, 21
 Antiparticle, 3, 18–22, 36–37, 135, 217, 220–221
 Antiproton, 21, 30–31, 96–97
 Antisymmetric state, 112, 118, 174–180
 Antisymmetric tensor, 100, 224
 Antisymmetrization, 231

Associated Laguerre polynomial, 149
 Associated Legendre function, 147
 Associated production, 32–33
 Asymptotic freedom 62–64, 164–165, 209, 279, 292–295
 Axial vector, 126–127, 224, 302–303, 324

B: *see* Beauty
 B meson, 44, 79, 167
 b quark, 44, 122
 Bare: *see* Charge; Coupling constant; Mass
 Barn, 200
 Baryon, 17, 29, 34, 36
 decuplet, 34–36, 38, 111, 179
 magnetic moment, 180–182
 mass, 182–184
 number: *see* Conservation laws
 octet, 33, 39, 111, 179–180
 Beautiful baryon, 44
 Beautiful meson, 44
 Beauty, 44, 47
 Beta decay, 22–24, 27, 46, 52, 56, 301, 309–314
 β particle: *see* Electron
 Bethe, H. A., 155, 159, 208
 Bevatron, 21, 96
 Bhabha scattering, 57–59, 78, 232, 234
 Bilinear covariants, 222–225
 Bispinor: *see* Dirac spinor
 Bjorken, J. D., 42, 269
 Bjorken scaling, 269–273, 294–295
 Bohr, N., 13, 23, 149, 151
 Bohr energies, 148, 186
 Bohr magneton, 153

INDEX

Bohr model, 13
 Bohr radius, 149
 Bohr theory, 149–151
 Boson, 109, 175
 Bottom: *see* Beauty
 Bottomonium, 143–144, 167–168
 See also T meson
 Bound state, 2, 39, 42, 52, 143–188
 Branching ratio, 72, 190, 316
 Brookhaven, 32, 42, 132
 Breit frame, 102
 Brick wall frame: *see* Breit frame
 Broken symmetry, 336
 See also Gauge invariance
 Bubble chamber, 35

C: *see* Charm; Charge, conjugation
 c quark, 42–44, 122
 Cabibbo, N., 70, 317
 Cabibbo angle, 301, 314, 317–321
 Cabibbo theory, 317–322
 Callan–Gross relation, 270–273
 Casimir’s trick, 236–238, 253
 Center of momentum, 96–98
 Central potential, 146
 Centrifugal barrier, 147, 159
 CERN, 6, 40, 44, 46, 67, 323–325, 327
 Chadwick, J., 14
 Charge
 bare, 63, 249
 conjugation, 103, 128–130, 134–135, 162, 222, 252
 conservation: *see* Conservation laws
 effective, 63, 249
 electric, 47, 60, 118
 independence, 117
 renormalization, 246–250
 weak, 65
 See also Coupling constant
 Charged weak interactions, 301–304
 Charm, 42–44, 47, 165
 Charmed baryons, 43–45
 Charmed mesons, 43–44
 Charmonium, 44, 143–144, 162–169
 See also ψ meson
 Chiral states, 330–333
 Chromodynamics, 55–56, 355–357
 See also Quantum chromodynamics
 Clebsch–Gordan coefficients, 111–112
 Cloud chamber, 7, 20
 CM: *see* Center of momentum
 Coleman–Glashow formula, 53
 Colliding beams, 6, 46, 98–99
 Collisions, 91–93
 Color, 41–42, 60–61, 64, 74, 261–262, 279
 factor, 164, 285–289, 291
 octet, 280, 285–286
 sextet, 288
 singlet, 178, 188, 280–281, 284–286, 289, 291, 298

$SU(3)$, 178, 281, 355–356
 triplet, 287–288
 Colorless particle, 41, 64–65, 280–281
 See also Color, singlet
 Commutator, 139
 Completeness, 217, 221, 229, 237
 Compton, A. H., 15
 Compton
 scattering, 15–16, 58, 78, 102, 232, 235–236
 wavelength, 15, 63
 Confinement, 40, 42, 64–65, 286, 289, 295–296
 Conservation laws, 72–76, 79, 103, 105
 angular momentum, 105
 baryon number, 29–31, 72–74, 77, 118
 charge, 32, 72–73, 105, 128, 226, 313
 color, 74
 electron number, 27, 47, 74, 317
 energy, 51–52, 60, 91–92, 105, 203, 230
 flavor, 67, 74–75
 isospin, 117–120
 lepton number, 26–27, 31
 mass, 91–92
 momentum, 91–92, 105, 203, 230
 muon number, 27, 74, 317
 parity, 125–128
 quark number, 74
 strangeness, 32–34, 74–75, 118
 tau number, 47, 74, 317
 Conserved current, 313
 Continuity equation, 226, 347
 Contraction of indices, 87
 Contraction theorems, 239
 Contravariant four-vector, 85, 214
 Cosmic rays, 4, 18–20, 29, 100
 Coulomb force, 57
 Coulomb gauge, 227–229, 281, 302
 Coulomb potential, 148, 164, 194, 285, 287
 Coupling constant, 61, 202
 bare, 249
 dimensions, 230
 effective, 63, 209–210
 electromagnetic, 62–63, 230, 336, 359
 renormalized, 247–248, 292
 running, 62, 77, 209–210, 249, 292, 294–295
 strong, 61, 77, 279, 359
 weak, 77, 302, 309, 324, 335–337
 See also Charge
 Covariant derivative, 349, 352, 356, 365
 Covariant four-vector, 85–86, 214, 251
 Cowan, C. L., 26
 CP violation, 130–134, 321
 Cronin, J. W., 132–133, 135
 Crossing symmetry, 21–22, 58
 Cross section, 119, 189–194, 378
See also Golden rule, for scattering
 $A + A \rightarrow B + B$, 204–206
 hard sphere, 193
 Mott, 241
 nucleon–nucleon, 119

Cross section (*Continued*)
 pair annihilation (QCD), 292
 pair annihilation (QED), 164, 187, 245, 261
 pion-nucleon, 119–120, 140
 Rutherford, 194, 241
 two-body, 199–201
 Current
 charged weak, 332
 color, 357
 conserved, 226, 313
 electromagnetic, 225–227, 333, 335–336, 349
 weak hypercharge, 334–335
 weak isospin, 334–335
 Yang–Mills, 354
 Cutoff, 208, 247
 CVC hypothesis, 313
 Cyclotron formula, 7

D meson, 44, 76, 79, 166
 D_s meson: *see* F meson
 d quark, 37, 122
 D'Alembertian, 227
 Davis, R., 26
 De Broglie wavelength, 6
 Decay rate, 189–190, 195–198, 377
 kaon, 318
 muon, 304–309
 neutron, 311–312
 pion, 316
 positronium, 164, 245–246
 quarkonium, 292
 two-body, 197–198
 Decays, 2, 3, 72–76, 93–94, 241
 Decuplet: *see* Baryon, decuplet
 Deep inelastic scattering, 40, 48, 257–258, 266–273
 Degeneracy, 149
 Delbruck scattering, 78
 A, 31, 34, 69, 120
 Delta function: *see* Dirac delta function
 Density of states, 194
See also Phase space
 DESY, 67
 Detailed balance, 21–22, 134
 Detectors, 7
 Deuteron, 118, 143
 Differential cross section, 192, 200, 245
 Differential decay rate, 195
 Dimensions
 amplitudes, 200–201
 coupling constants, 202, 230
 fields, 347
 Dipole function, 267
 Dipole moments: *see* Electric dipole moment;
 Magnetic moment
 Diquarks, 289
 Dirac, P. A. M., 18, 208–209, 214–215
 Dirac delta function, 157, 195–196, 203, 230–231, 373–376

Dirac equation, 18, 213–222
 momentum space, 218, 228
 Dirac matrices, 215, 380
See also Gamma matrices
 Dirac sea, 18–21, 217
 Dirac spinor, 216, 226
 Disconnected diagram, 207
 Discrete symmetry, 103
 Dot product, 86
 Down quark: *see* d quark
 Downness, 47
 Drell–Yan process, 295
 Dresden, M., 201
 Effective charge: *see* Charge
 Effective mass: *see* Mass
 Eigenfunction, 146
 Eigenvalue, 114, 146
 Eigenvector, 114
 Eight-baryon problem, 121
 Eightfold Way, 33–39, 107, 121–122
 Einstein, A., 14–15, 76
 Einstein summation convention, 64
 Elastic collision, 91–92
 Electric dipole moment, 135
 Electric form factor, 267
 Electrodynamics, 55–56, 225–228
See also Quantum electrodynamics
 Electromagnetic current: *see* Current
 Electromagnetic decay, 241
 Electromagnetic field, 225
 Electromagnetic force, 55–56
 Electromagnetic potential, 226
 Electron, 4, 11–12, 230
 Electron number: *see* Conservation laws
 Electron–deuteron scattering, 278
 Electron–electron scattering: *see* Møller scattering
 Electron–muon scattering, 232–233, 238–240
 Electron–neutron scattering, 276, 278
 Electron–positron scattering
 elastic: *see* Bhabha scattering
 inelastic, 257–262, 327–330
 Electron–positron annihilation: *see* Pair annihilation
 Electron–proton scattering
 elastic, 262–267, 269
 inelastic, 266–269
 Electroweak force, 3, 46, 56, 322, 330–337
See also GWS theory
 Electroweak interference, 326, 330
 Elementary particles, 1
See also Particles
 Energy
 conservation: *see* Conservation laws
 kinetic, 90–92, 152
 operator, 145; *see also* Hamiltonian
 relativistic, 87–91, 152
 rest, 90
 Energy-momentum four-vector, 89
 η meson, 38–39, 170

η' meson, 38–39, 170, 172, 188
 Euler–Lagrange equation, 344–345
 Exchange of particles, 16, 57, 61
See also Mediator
 Exclusion principle: *see* Pauli
 Exotic atom, 159
 Exotic particle, 53
 Expectation value, 151–152, 186
 External line, 58–60, 229–231, 282–283
 F meson, 44 (now called D_s)
 Faddeev–Popov ghost, 282
 Family: *see* Generation
 Fermi, E., 23, 56, 120
 Fermi constant (G_F), 307–309
 Fermi's Golden Rule: *see* Golden Rule
 Fermi theory of beta decay, 23–24, 44, 46, 56, 307–308
 Fermion, 109, 175
 Feynman, R. P., 3, 21, 27, 56, 155, 203, 208
 Feynman calculus, 59, 189–212, 361–362
 Feynman diagram, 55, 57, 59, 189, 194, 201, 203
 Feynman rules, 3, 59, 194, 213, 357–360, 381–384
 ABC theory, 201–204
 GWS, 336–337
 QCD, 279–284
 QED, 213, 228–231, 255
 weak interactions, 302, 317–318, 322
 Feynman–Stueckelberg interpretation, 21
 Field strength tensor, 225
 Fifth force, 296
 Fine structure, 151–155
 Fine structure constant, 9, 59, 148, 152, 230, 249, 294, 309
 Flavor, 41–44, 47, 53, 64, 116–122, 279, 280
 Flavordynamics, 55–56, 67
 Form factor, 266–269, 312, 315
 Four-momentum, 89
 Four-vector, 84–87
 Four-velocity: *see* Proper velocity
 f -value, 312
 Fundamental representation, 121, 171
 G: *see* G-parity
 G_F : *see* Fermi constant
 Gamma matrices, 216, 224, 238–239, 380
 Gamma rays: *see* Photon
 Gauge fields, 348–349, 352, 356
 Gauge invariance, 253, 298
 Gauge quantum number
 abelian, 354
 broken, 362–365
 global, 348, 350, 352, 354
 local, 348–350, 352, 354, 365–367
 nonabelian, 354–355
 Gauge theory, 210, 343–371
 Gauge transformation, 105, 226–227, 348–349
 Gell-Mann, M., 32–34, 36–37, 56, 131–132

Gell-Mann matrices, 282, 355
 Gell-Mann–Nishijima formula, 118, 140, 334
 Gell-Mann–Okubo mass formula, 52
 Generation, 47–48, 317, 321–322
 Ghost particle, 228, 282, 367
 GIM mechanism, 44, 70–71, 301, 319–320, 322
 Glashow, S. L., 42–44, 56, 70, 322–323, 330
 Global gauge transformation, 348, 352, 354
 Glueball, 48, 61
 Gluon, 48, 55–56, 60–61, 260, 275, 279–281
 octet, 280
 Gluon–gluon coupling, 61, 282–284, 291, 299, 359–360
 Golden Rule, 189, 194–201, 305
 for decays, 195, 305
 for scattering, 198–199
 Goldstone boson, 364, 366–367
 Goldstone's theorem, 364, 371
 G-parity, 129–30
 Grand Unification, 31, 76–77
 Gravitational force, 55
 Graviton, 16, 48, 55–56
 Greenberg, O. W., 41
 Ground state
 baryon, 176
 hydrogen, 186
See also Vacuum
 Group theory, 103, 106
 Groups, 106
 abelian, 106
 continuous, 106
 finite, 106
 infinite, 106
 $O(n)$, 106, 137
 $SO(3)$, 107
 $SO(n)$, 106–107, 137
 $SU(2)$, 107, 121, 352
See also Isospin
 $SU(2) \times U(1)$, 334–337, 355
 $SU(3)$, 103, 107, 121
See also Eightfold Way; Color, $SU(3)$
 $SU(6)$, 103, 121
 $SU(n)$, 106, 137
 $U(n)$, 106
 GUTs: *see* Grand Unification
 GWS (Glashow/Weinberg/Salam) theory, 3, 46, 48, 56, 66, 76, 210, 301, 322–325, 330–337
 Gyromagnetic ratio, 153, 156
 Hadron, 28, 33, 143
See also Baryon; Meson
 Hadron production, 257–262
 Half-life, 72, 211, 312
 Hamiltonian, 146, 151–153, 158, 160, 252
 Hard-sphere scattering, 191–193
 Heaviside–Lorentz units, 9, 230, 249, 347
 Heavy lepton, 44
 Heavy quark, 165, 172
 Helicity, 27, 124, 221, 330–333, 339

Heisenberg, W., 116
 See also Uncertainty principle
 Hermitian conjugate, 220, 223
 Hermitian matrix, 351, 355
 Hidden symmetry, 364
 Higgs mechanism, 76, 330, 343, 354, 360, 365–368
 Higgs particle, 48, 367
 Higher-order processes, 58, 63, 202, 206–210, 246–250, 281, 292–294
 Hole theory, 20–21
 t'Hooft, G., 210, 323, 360
 Hydrogen, 143, 148–159
 Hypercharge, 34, 334–335
 See also Weak hypercharge
 Hyperfine splitting
 in baryons, 182–184
 in hydrogen, 156–159
 in mesons, 172
 in positronium, 161
 Identical particles, 1, 41, 175–176
 Impact parameter, 191
 Inclusive cross section, 267–269
 Indistinguishable particles, 1
 Inertial frame, 81
 Infinite momentum frame, 272
 Intermediate vector boson, 46, 56, 335
 See also W^\pm , Z
 Internal line, 58–60, 202, 229
 Internal momenta, 203, 231
 Internal quantum number, 128
 Internal symmetries, 103, 105, 116–120
 Intrinsic angular momentum: see Angular momentum, spin
 Intrinsic parity: see Parity
 Intrinsic strength of weak force, 76, 309
 Intersecting storage rings, 6
 Invariance, 105
 See also Symmetry
 Invariant, 85, 88–89, 94, 97, 281
 Inverse beta decay, 26, 303
 Inversion, 125–126
 Ionization, 7
 Irreducible representation, 107
 Isospin, 103, 116–120, 335
 See also Weak isospin
 J/ψ : see ψ meson
 Jets, 48, 258–260
 Kmeson, 29–38, 128, 131–133, 318
 Kaon: see K meson
 Ket, 3, 109
 Klein–Gordon equation, 213–215, 227
 KM matrix: see Kobayashi–Maskawa matrix
 Kobayashi–Maskawa matrix, 70–71, 133, 301, 321–322, 325
 Kronecker delta, 139

Lagrangian, 343–347
 classical, 343–344
 Dirac, 345–346
 Higgs, 367
 Klein–Gordon, 345
 Maxwell, 347
 Proca, 346–347
 QCD, 357
 QED, 350
 Yang–Mills, 354
 Yukawa, 371
 Lagrangian density, 344, 347
 See also Lagrangian
 Lamb, W. E., 32, 154
 Lamb shift, 17, 154–156, 161, 209, 249, 294
 A (scale parameter in QCD), 295
 A baryon, 29, 32–35, 70
 λ matrices: see Gell-Mann matrices
 Laplacian, 146
 Lederman, L. M., 28, 132
 Lee, T. D., 56, 122, 128
 Left-handed doublet, 334–335
 Left-handed state, 27, 124, 330–334
 Lepton number, 26–27
 See also Conservation laws
 Leptonic decay, 318
 Leptons, 17–18, 28, 65–67
 families, 47
 table, 28, 47
 weak interactions, 301–304, 317
 See also Electron; Muon; Neutrino; Tau
 Levi–Civita symbol, 139, 239, 254, 303
 Lifetime, 42, 52, 72–73, 75–76, 132, 189–190
 A particle, 204
 muon, 307
 neutron, 312–314
 pion, 316
 positronium, 164, 187, 246
 See also Decay rate
 Light quark baryons, 172–184
 Light quark mesons, 143, 168–172
 Lightlike four-vector, 86
 Linear-plus-coulomb potential, 165–167
 Local gauge invariance, 3, 343, 348–350, 352, 360
 Local gauge transformations, 348, 365
 Logarithmic divergence, 208, 247
 Longitudinal polarization, 301
 Loop diagram, 207–210, 231, 246, 255, 281–282, 292–294
 Lorentz condition, 226–229, 281, 301–302
 Lorentz contraction, 83
 Lorentz invariance, 85–86, 97
 Lorentz transformations, 81–84
 Lowering operator, 140
 Luminosity, 194, 245–246
 Magnetic form factor, 267
 Magnetic moment, 153
 anomalous: see Anomalous magnetic moment

baryons, 180–182
 electron, 17, 153, 156
 proton, 156–157
 Mandelstam variables, 102
 Marshak, R. E., 18
 Mass formulas
 baryons, 182–184
 Coleman–Glashow, 53
 Gell-Mann–Okubo, 52
 mesons, 172
 pion, 51
 quarkonium, 165
 Wand Z, 325
 Mass
 bare, 122
 constituent, 122
 current, 122
 effective, 121–122, 209–210
 matrix, 351, 371
 neutral kaon, 132, 135
 origin, 368
 physical, 209
 relativistic, 90, 92
 renormalized, 209, 247
 running, 209
 shell, 60
 term, 360–362
 Massless particle, 90
 Matrix element, 194
 See also Amplitude
 Matter–antimatter asymmetry, 22, 134
 Maximal parity violation, 123, 133, 303
 Maxwell, J. C., 56, 76
 Maxwell Lagrangian, 347
 Maxwell's equations, 225–228
 Mechanics, 2
 Mediator, 16, 47–48, 55–57, 61, 301, 308–309
 See also Gluon; Graviton; Intermediate vector boson; Photon; Pion; W^\pm , Z
 Meson, 17–18, 29, 31, 33–34, 36, 38–39, 128, 168–72
 mass, 171–172
 nonet, 36, 38–39, 128, 169
 octet, 34
 Metric, 85, 216
 Millikan, R. A., 15, 39
 Minkowski metric: see Metric
 Minimal coupling, 350
 Mixing
 Cabibbo, 70–71, 74, 317–322
 Kobayashi–Maskawa, 70–71, 321–322, 325
 neutral kaons, 130–134
 neutral mesons, 170–171
 Möller scattering, 57–58, 232–233
 Momentum
 conservation: see Conservation laws
 four-vector, 89
 operator, 144, 214
 relativistic, 87–91
 space, 218, 228–229, 358
 Mott scattering, 232–233, 240–241, 265, 270, 309, 313

Multiplets, 117–118
 Multiplicative quantum number, 127, 129
 Muon, 4, 18–19, 24–25, 27, 66, 100, 304–309
 Muon number, 27, 47
 See also Conservation laws
 Muonium, 159–160, 168
 N : see Nucleon
 n : see Neutron
 Neddermeyer, S., 18
 Ne'eman, Y., 33
 Negative energy states, 18, 217–218, 221
 Neutral weak interactions, 65–67, 322–324, 326
 Neutrino, 14, 19, 22–28, 124–125
 Neutrino–electron scattering, 303, 323–327
 Neutrino–nucleon scattering, 323–324
 Neutron, 14, 24, 27, 68, 116, 135, 309–315
 Ninth gluon, 280–281, 296, 356
 Noether's theorem, 103, 105, 117, 370
 Nonabelian gauge, 354–355
 Nonet: see Meson, nonet
 Nonleptonic decay, 318–319
 Normalization
 Dirac spinor, 218, 220–221, 225, 229
 Pauli spinor, 113
 polarization vector, 229
 wave function, 145
 November Revolution, 41–45, 166
 Nucleon, 116
 See also Neutron; Proton
 Nucleon–nucleon scattering, 118–119
 Nucleus, 12–14
 $O(n)$: see Groups
 Octet, 35
 See also Baryon, octet; Color, octet; Gluon, octet; Meson, octet
 Ω^- , 34–36, 52–53, 70
 ω , 170, 172
 Orthogonal matrix, 107
 Orthogonal polarization vectors, 229
 Orthogonal spinors, 228, 251
 OZI rule, 75–76, 79, 166–167, 294
 P: see Parity, operator
 Pair annihilation, 58, 161–162, 215, 232, 241–245, 257–262, 289–292
 Pair production, 58, 215, 232
 Pais, A., 32, 131–132
 Parity, 103, 122–128, 130–131, 134, 223–224
 baryon, 127
 conservation, 125, 127–128
 intrinsic, 127
 invariance, 122–123
 meson, 127–128
 operator, 125–127, 224
 particle and antiparticle, 127, 252
 photon, 127

Parity (Continued)

quarks, 127

violation, 123, 131

Particle Data Booklet, 50, 111

Particles

 α , 12–13, 141

antineutrino, 24, 26–28, 124–125

antineutron, 21

antiproton, 21, 30–31, 96–97

B meson, 44, 79, 167

b (beauty or bottom) quark, 44, 122

 β : **see** Electron

c (charm) quark, 42–44, 122

D meson, 44, 76, 79, 166

d (down) quark, 37, 122

A, 31, 34, 69, 120

deuteron, 118, 143

electron, 4, 11–12, 230

 η , 38–39, 170 η' , 38–39, 170, 172, 188F meson, 44 (now called D_s) γ : **see** Photon

gluon, 48, 55–56, 60–61, 260, 275, 279–281

graviton, 16, 48, 55–56

J or J/ψ meson: **see** ψ meson

K meson

charged, 29, 31–38, 128, 318

neutral, 29–30, 32–38, 131–133

kaon: **see** K meson

A, 29, 32–35, 70

 Λ_c , 44–45

muon, 4, 18–19, 24–25, 27, 66, 100, 304–309

neutrino, 14, 19, 22–28, 124–125

neutron, 14, 24, 27, 68, 116, 135, 309–314

nucleon, 116

 Ω^- , 34–36, 52–53, 70 ϕ meson, 170, 172 ϕ meson, 75, 170, 172, 262–263

photon, 14–17, 47, 55–57, 225–230

 π meson: **see** Pion

pion, 18–19, 24–25, 27, 51, 68, 124–125,

211, 314–317

positron, 14, 20–21, 217, 230

proton, 4, 13, 29–34, 39–40, 77, 116, 262–275

 ψ meson, 42, 44, 75, 144, 262–263; **see** also Charmonium ρ meson, 170, 172 s (strange) quark, 37, 122 Σ , 31–33, 182–184 t (top or truth) quark, 44, 47, 122 τ lepton, 44, 47, 261 U (up) quark, 37, 122 Y meson, 44, 79, 144, 167–169, 262–263 W , 44–47, 55–56, 301 Z , 31, 33, 35, 78, 182–184 Z , 6, 46–47, 55–56, 301, 340

Parton model, 269–273

Partons, 42, 270

See also Gluon; Quark

Pauli, W., 23, 125, 208, 215

Pauli matrices, 115, 139, 216, 334, 351, 379

Pauli principle, 1, 3, 18, 41, 174–176

PCAC hypothesis, 313, 319

Perturbation theory, 59

nonrelativistic, 143, 151

relativistic: **see** Feynman calculus

Perturbative QCD, 279, 295

Phase transformation: **see** Gauge transformation

Phase space, 194–195

 ϕ meson, 75, 170, 172, 262–263

Photoelectric effect, 15

Photon, 14–17, 47, 55–57, 225–230

Pion, 18–19, 24–25, 27, 51, 68, 124–125,

211, 314–317

Pion decay constant, 315–316

Planck, M., 14

Planck formula, 14, 90, 149

Planck's constant, 14, 108

Plane waves, 218, 227

Polar vector, 126–127

Polarization, 62–63, 227–229

Polarization vector, 227–229

Positron, 14, 20–21, 217, 230

Positronium, 143, 159–64, 245–246

Potential

Coulomb, 148, 164, 194, 285, 287

four-vector, 226–228

interquark, 165–167, 279, 284–289

linear-plus-coulomb, 165–167

scalar, 226

vector, 226–228

Potential energy term, 361, 363

Powell, C. F., 18–19, 24–25, 29, 31

Primitive vertex: **see** Vertex

Proca equation, 213, 346

Projection matrix, 339

Propagator, 203, 357

electron, 230

gluon, 283

modified, 247

photon, 230

quark, 283

spin zero, 203, 358

spin one-half, 203, 358

spin one, massive, 302, 358

spin one, massless, 230, 359

unstable particle, 329

Wand Z, 302, 325, 329

Proper time, 87

Proper velocity, 88

Proton, 4, 13, 29–34, 39–40, 77, 116, 262–275

Pseudoscalar, 126–127, 223–224

Pseudoscalar mesons, 34, 110, 169–172

Pseudovector: **see** Axial vector ψ meson, 42, 44, 75, 144, 262, 263**See** also Charmonium Q : **see** Charge, electric

Quantum chromodynamics (QCD), 3, 55–56, 60–65, 164, 279–299, 355–357

Quantum electrodynamics (QED), 3, 18, 55–

60, 63, 153, 155, 213–255

Quantum field theory, 2, 3, 10, 16, 21, 135,

175, 189, 213, 343, 357

Quantum mechanics, 2, 3, 143–148, 189

Quark

confinement: **see** Confinement

distribution functions, 273–276

masses, 53, 122

model, 37–44

number, 74

search, 39–40

table, 47, 122

weak interactions, 317–322

See also particles

Quark–quark interaction, 284–289

Quarkonium, 160, 162–169

See also Bottomonium; Charmonium

Quasi-bound state, 162–163, 166

R, 261–263

Rabi, I. I., 29, 149

Radial equation, 147

Radiative corrections, 155

Raising operator, 140

Range, 17, 51–52

Reactor, 4, 26

Real particle, 59–60

Reduced mass, 160

Reflection, 125–126

Regularization, 208

Relativistic correction, 151–152

Relativistic mechanics, 2, 87–99

Relativity, 3, 81–82

Reines, F., 26

Renormalization, 156, 209–210, 246–250, 360

Representation, 107, 116

Resonance, 120, 140, 191, 262–263

 ρ meson, 170, 172

Richter, B., 42

Right-handed state, 27, 124, 331–333

Rochester, G. D., 29–30

Rosenbluth formula, 266, 268–269

Rotation, 105–106

Rotation group, 107

See also Groups

Rotation matrix, 115, 137, 139

Rubbia, C., 46, 327

Running coupling constant: **see** Coupling constant

Rutherford, E., 12–13, 249

Rutherford scattering, 12–13, 40, 193–194,

232–233, 240–241, 309, 313

Rydberg formula, 151

 S : **see** Strangeness s (strange) quark, 37, 122

Salam, A., 56, 323, 330

Scalar, 87, 224

See also Invariant

Scalar product, 86

Scaling: **see** Bjorken scaling

Scattering, 2

See also Bhabha scattering; Collisions;

Compton; Cross sections; Electron–

muon scattering; Electron–positron scat-

tering; Electron–proton scattering;

Golden Rule; Møller scattering; Mott

scattering; Neutrino–electron scattering;

Rutherford scattering

Scattering amplitude, 119

See also Amplitude

Scattering angle, 191–192

Schrodinger equation, 143–148, 213–214,

217

Schwinger, J. S., 56, 153, 155, 208

Screening, 62–64, 249, 294

Sea: **see** Dirac sea

Sea quarks, 275–276

Semileptonic decay, 67, 318–319

Separation of variables, 145–146

Sextet, 288

 Σ , 31–33, 182–184

Simultaneity, 82

Singlet, 112, 118, 158–159

See also Color, singlet

SLAC, 5, 8, 40, 258, 273, 327

Slash notation, 235–236, 238

 $SO(n)$: **see** Groups

Solar neutrinos, 26

Spacelike four-vector, 86

Spectator quark, 68, 70

Spectrum, 148, 150–151, 155, 162–163, 167

Spherical harmonics, 147–148, 186

Spin: **see** Angular momentumSpin $\frac{1}{2}$, 113–116

Spin matrices, 113–115, 139, 221

Spin and statistics, 175

Spin-averaged amplitude, 236

Spin–orbit coupling, 151, 153–154, 157

Spin–spin coupling: **see** Hyperfine structure

Spinor, 113–115

See also Dirac spinor

Spontaneous symmetry-breaking, 323, 343,

360, 362–365

Stable particle, 72–73

Standard Model, 3, 46–48, 121–122, 322,

325, 350, 367–368

State, 3

Statistical factor, 195

Stevenson, E. C., 18

Storage rings, 5

Strange particles, 28–33

Strangeness, 32–34, 37–39, 47, 118

Street, J. C., 18

Strength, 55, 76, 78

Strong force, 17, 32–33, 55–56, 279

Structure constants, 282, 297

Structure functions, 264–276

See also Quark, distribution functions;

Form factor

Stückelberg, E. C. G., 21, 29

Subparticles, 48, 53

- Sum rules, 276, 278
- Supermultiplet, 36, 43, 121, 171–80
 - See** also Baryon, decuplet; Baryon, octet; Meson, nonet
- $Su(n)$: **see** Groups
- Symmetric state, 112, 118, 174
- Symmetric tensor, 100
- Symmetry, 103–141
 - See** also Gauge invariance; Groups; Invariance
- T : **see** Time reversal
- t quark, 44, 47, 122
- τ lepton, 44, 47, 261
- τ number, 47
 - See** also Conservation laws
- τ - θ puzzle, 128
- TCP theorem, 3, 135
- Tensor, 86–87
- θ_C : **see** Cabibbo angle
- θ_w : **see** Weak mixing angle
- Thomas precession, 153
- Thomson, J. J., 11–12
- Three-jet event, 258–260
- Threshold, 22, 96–97, 101, 261–263
- Time dilation, 83
- Time reversal, 103, 134–135
- Timelike four-vector, 86
- Ting, C. C., 42
- Top, 44, 47
- Top quark: **see** t quark
- Toponium, 167
- Total cross section, 193
- Trace, 237–239
- Trace theorems, 238–239, 380
- Transformation
 - Dirac spinor, 222–223
 - four-vector: **see** Lorentz transformations
 - tensor, 86–87
 - See** also Charge, conjugation; Parity; Time reversal
- Transition probability, 3
- Translation, 105
- Transverse gauge: **see** Coulomb gauge
- Transverse polarization, 228
- Tree-level diagram, 206, 249, 282
- Triangle function, 101
- Triplet, 112, 118, 158–159
- Truth, 44, 47
- Two-jet event, 258–259
- Two-neutrino hypothesis, 27–28
- u quark, 37, 122
- $U(n)$: **see** Groups
- Uncertainty principle, 51–52, 73
- Unification, 31, 76–78, 330–337
 - See** also Electroweak force; Grand Unification; GWS theory
- Unitary matrix, 106, 351
- Units, 8, 9, 200–201, 230, 347
- Up quark: **see** u quark
- Upness, 47
- T meson, 44, 79, 144, 167–169, 262–263
- V-A interaction, 303, 324, 330
- V-events, 29
- Vacuum, 362–364
- Vacuum polarization, 63, 156, 246, 293
- Valence quarks, 275–276
- Vector, 224
- Vector interaction, 302–303, 309, 313, 324, 330, 332
- Vector meson, 110, 169–172
- Vector potential, 226–228
- Velocity addition rule, 83, 88
- Vertex, 73
 - ABC, 201
 - QCD, 60–61, 280, 282–283, 353
 - QED, 56–57, 230, 359
 - weak, 65–67, 69–71, 302, 317, 322, 336–337
- Vertex factor: **see** Feynman rules; Vertex
- Virial theorem, 144
- Virtual particle, 58–60, 78, 257–258
- Wboson, 46–47, 48, 55–56, 301
- Ward identity, 250
- Wave function, 3, 145, 176, 214, 347
- Weak force, 32, 55–56, 123, 301–341
- Weak hypercharge, 333–335
- Weak interaction, 65–72
 - charged, 65, 67, 301–304, 317–322
 - neutral, 66, 69, 322–330
- Weak isospin, 333–335
- Weak mixing angle, 324, 336
- Weinberg, S., 56, 323, 330
- Weinberg angle: **see** Weak mixing angle
- Weyl, H., 125, 350, 354, 356
- Work function, 15
- Wu, C. S., 123
- Ξ , 31, 33, 35, 78, 182–184
- Yang, C. N., 56, 122, 128, 350
- Yang–Mills theory, 350–355
- Yukawa, H., 17–18, 47, 56
- Yukawa coupling, 368
- Yukawa meson, 14, 17–18, 47, 51, 65
 - See** also Pion
- Z boson, 6, 46–47, 55–56, 301, 340
- Zweig, G., 37