

Index

- Absorption length 84
Accelerators 77–82
 CEBAF 78
 colliders 76, 80–82
 cyclic 78–80
 fixed-target machines 75, 80
 LHC 81
 linac 77–78
 linear 77–78
 RHIC 82
 storage rings 80
 synchrotron 78
Angular momentum
 classification of particles 124–125
 commutation relations 359–360
 conservation of 121–123
 in quark model 125–127
Anomaly condition 253
Antiparticles 3–9
 discovery of positron 7–8
 predicted from Dirac equation 5
 relation to hole theory 6–7
 relative parity of 129–131
Associated production
 charmed particles 64–65
 strange particles 62–63
Asymptotic freedom 181,
 185–187
ATLAS detector 113–114

Baryon number 55
 conservation 56
 violation in grand unified theories
 311–314
Baryons
 colour wave function of 164, 165–168
 magnetic moments 160–162
 mass splitting within multiplets 153,
 159–160
 quark model 154–159
 table of states 155, 158–159,
 397–398
Beauty quantum number 54
 β decay processes 29–30, 56–57, 224,
 329–332
Bethe–Bloch formula 85–86
Big bang model 320
Bjorken scaling 203–205
 deviations from 207–210
 in parton model 205–207
 B -mesons 65
 $B_H^0 - B_L^0$ mass difference 302
 CP violation 296–299, 304
 factories 297
 flavour oscillations 302–303
 lifetimes 237–238, 246–247
Born approximation 20, 200,
 349
Bottomium 64, 169, 172–176
Bragg curve 87
Branching ratio 32
 isospin predictions of 366–367
 tables of values 395–401
Breit–Wigner formula 68, 259–260,
 351–357
 decay distributions 352–355
 resonant cross-sections 355–357
Bremsstrahlung 88–89
Bubble chamber 62–65, 94

Cabibbo allowed/suppressed decays 229
Cabibbo angle 227–228
Cabibbo hypothesis 227
Callan–Gross relation 207

- Calorimeters 103–106
 electromagnetic showers 104–105
 hadronic showers 105–106
- Cascade baryon 156–159, 233
- CDF detector 112–113
- CEBAF accelerator 78
- Centre-of-mass energy 76, 115, 337–338
- Čerenkov counters 101–103
 properties of radiators 102
 ring-image mode 102–103
 threshold mode 102
- Charge conjugation 134–142
 nonconservation in muon decay 281–283
 of π^0 and η^0 mesons 136–138
 positronium analysis 138–142
- Charged weak currents 218–220, 386–388
- Charmed particles 63–64, 229
- Charmonium 41, 127–130, 169–172
 energy levels 173
 experimental discovery 63, 169–170
 table of states 169
- Charm quantum number 53–54
- Charm threshold 170
- CKM matrix 236
- Cloud chamber 7, 61
- Colliders 76, 80–82
- Colliding beam experiments 76
- Collision length 84
- Colour 162–168
 charges 162–165, 380–381
 confinement 162–165
 evidence for in e^+e^- annihilation 195–196
 hypercharge and isospin 163
 role in QCD 179–181
 wavefunction 164–168
- Commutation relations for angular momentum 359–360
- Compton scattering 24
- Confinement 162–165, 167–168, 181
- Confinement condition 163, 181
- Conservation laws
 angular momentum 120–123
 baryon number 55
 $B-L$ 311
 charge conjugation 134–136, 281–285
 colour 162
 CP 288–299, 303–305, 315–317
 isospin 148–150
 lepton numbers 28, 33
 linear momentum 119
 parity 127–129, 279–285
 strangeness, charm and beauty 54–55
- Cosmic rays 31–32, 42, 51, 53, 57, 60, 327
- C-parity 134–136
 fermion–antifermion pairs 136, 168
 positronium 138–142
 violation in weak interactions 281–285
- CP conservation 281–283, 288–291
- CP nonconservation
 in B decays 296–299
 in K decays 291–296
 in neutrino sector 305
 and standard model 303–305
- CPT theorem 299, 302
- Cross-sections
 Born approximation 20, 200, 349
 definitions 343–344
 differential 346–348
 elastic electron–proton 200–201
 Rutherford formula 197, 200–201
 total 84, 345
- Dark energy 320
- Dark matter 320–323
 search for cold dark matter 322–323
- $\Delta S = \Delta Q$ rule 233, 294
- Decay width 67
- Deep inelastic scattering
 Callan–Gross relation 206–207
 charged lepton–proton 202–210
 neutrino–proton 201–215
- Detailed balance 144–145
- Detectors, *see* Particle detectors
- Differential cross-section 346–348
- Dipole fit to proton form factors 199–200
- Dirac equation 4–6, 375–376, 391
- Dirac magnetic moment 5, 32, 140–141, 160
- D -mesons 64
- Double-beta decay 329–332
- Drift chamber 96–97
- Elastic scattering 83, 346
 electron–proton 196–202
 neutrino–electron 24, 33, 34, 45, 49
- Electromagnetic interactions
 basic vertices 9–12
 gauge invariance of 371–372
 typical lifetimes 56–57
- Electromagnetic showers 104–105
- Electron–electron scattering
 one-photon exchange 13
 two-photon exchange 14
- Electron neutrinos 28–31
 discovery of 30–31
 mass from tritium decay 29
 oscillations 44–46

- Electron number 28
 Electron–positron annihilation
 evidence for colour in 195–196
 to hadrons 169–172, 190–196,
 256–258
 in hole theory 10
 to muon pairs 169, 199, 248–250
 to photons 14–17, 130, 141–142
 three-jet events 193–194
 total cross-section 194–196
 two-jet events 190–192
 Electron–positron pair production 10,
 16–17, 90–92
 Electron–proton scattering
 elastic 196–202
 form factors 198–200
 inelastic 202–210
 Electroweak interactions 256–258
 gauge theory of 263–269, 384–392
 Electroweak unification 249, 253–258,
 384–392
 Elementarity, test for 5
 Emulsions 57–58, 94
 Energy losses by particles in matter
 ionization losses 85–88
 radiation losses 88–90
 short-range interactions with nuclei
 83–85
 η -meson 136–138, 154–155
 Exotic states 72–73

 Fermi coupling constant 22, 35–36
 Feynman diagrams
 electromagnetic vertices 9–10, 220
 electron–positron annihilation 14–16
 energy–momentum conservation in
 12–13
 higher-order diagrams 13–15,
 35–36
 order of 13–14
 QCD vertices 180–181
 real processes 10–13
 relation to hole theory 10–12
 weak and strong processes 17
 weak vertices 220–223, 225–228,
 250–253
 Feynman rules 14
 Fixed-target accelerators 75, 80
 Fixed-target experiments 75
 Flavour independence 180
 Flavour oscillation 299–303
 Flux 344
 Form factors of proton 198–200,
 202–203
 Fragmentation 190–191

 Gas detectors 93–99
 Gauge bosons 12, 179, 217
 table of properties 395–396
 Gauge invariance 179, 263–265, 369–392,
 395–396
 Gauge theories 179, 369–392
 electromagnetic interaction 179, 263,
 370–376
 electroweak interactions 256–258,
 264–265, 384–392
 gauge principle 264–265, 369,
 374–376
 photon mass 372–374
 quantum chromodynamics 179–187,
 380–384
 unification condition 253, 388–391
 Gauge transformation 263
 electroweak 264–265, 387, 388
 QCD 381–383
 QED 263, 371–372
 Georgi–Glashow model 309–314
 proton decay in 311–314
 quark and lepton charges in 310
 weak mixing angle in 311
 Glueballs 181, 182–183
 Gluino 314
 Gluons 2, 180–182, 416
 spin determination in e^+e^- annihilation
 193–194
 Grand unified theories 308–314
 Georgi–Glashow model 309–314
 proton decay in 311–314
 unification mass 308
 X and Y gauge bosons 309

 Hadronic showers 105–106
 Hadrons
 allowed quantum numbers 71–73
 decays 56–57, 201–205
 exotic quantum numbers 72, 413
 general properties 53–57
 internal quantum numbers 54–55
 light baryons 156–159
 light mesons 154–156
 resonances 66–67
 tables of properties 57, 158, 159,
 395–401
 typical lifetimes 57
 weight diagrams 154–157
 Helicity
 definition 283
 implication for pion and muon decay
 286–288
 of neutrino 283–285

- Higgs boson 263, 265, 268
 decays 269–273
 searches for 273–276
 width 270
 Higgs field and particle masses 265–269
 Higgsino 314
 Higgs mechanism 265–269, 376–380
 Hole theory 6–12
 Hypercharge 148
- Inelastic electron and muon scattering
 202–210
 Bjorken scaling 203–205
 Callan–Gross relation 206–207
 parton model 205–207
 structure functions 204–205
 Inelastic neutrino scattering 210–215
 Interaction lengths 85
 Interactions of photons in matter 90–92
 Internal quantum numbers 55–71
 Intrinsic parity 128
 Invariant mass 337–339
 Inverse β decay 30
 Inverse muon decay 33, 34–35, 37
 Ionization energy losses 85–87
 Isospin 148–153, 359–367
 branching ratio predictions 366–367
 conservation 148–151
 formal theory of 359–367
 hadron multiplets 148, 364–365
 operators 360–362
 quantum numbers 148–150
 in quark model 150–151, 153
 states 362–363
 u, d quark mass splitting 153
- Jet chamber 97
 Jets in e^+e^- annihilation 190–194
 gluon spin determination 193–194
 J/ψ meson 63, 169–173
- Kaons 60–63, 148, 150, 154–155, 226–228
 see also Neutral kaons
 Klein–Gordon equation 3–4, 19–20,
 377–379
- Lattice gauge theory 182–183, 188
 Lepton number conservation 33, 48–49
 Lepton–quark symmetry 224–229,
 251–253
 Leptons 27–33
 lepton numbers 28
 multiplets 27–28, 31–33
 parity 129–131
 table of properties 396
 universality 36–38
- LHC accelerator 81
 Lifetimes of hadrons 57
 Light baryons
 magnetic moments 160–162
 mass splittings 159–160
 quark model predictions 157–159
 table of states 158–159
 weight diagrams 157
 Light mesons
 quark model predictions 155
 table of states 155
 weight diagrams 154
 Linear accelerators (linacs) 77–78
 Lorentz condition 373
 Lorentz gauge 373
 Lorentz transformations 335–341
 Luminosity 76, 344
- MACHOs 321
 Magnet designs 78–80
 bending magnets 78–79
 focusing magnets 78–80
 Magnetic moments
 baryons 5, 9, 160–162
 Dirac form 5
 electron and positron 5, 140
 muon 32
 quark 160–162
 Majorana neutrinos 327–328
 Matter–antimatter asymmetry in universe
 323–324
 Mesons
 charmonium and bottomium 168–176
 pseudoscalar mesons 154–156
 quark model 53–54, 72, 125–127,
 131–132, 154–156
 table of properties 54, 399–401
 vector mesons 154–156
 weight diagrams 154
 Minimal ionizing particles 87, 88
 Multiwire proportional chambers 96
 Muon 27–28, 31–32
 decay 32, 35, 37–38, 281–283, 287–288
 magnetic moment 32
 number 28
 Muon neutrino oscillation 42–44
- Natural units 22–24
 Neutral currents 218–219, 250–253,
 388–390
 Neutralino 317
 Neutral kaons 288, 291, 299

- Neutral K mesons 62–63, 288–299
 CP violation 291–296
 K_1^0 and K_2^0 states 289–290
 K^0 and \bar{K}^0 mixing 288–290, 288–296
 K_L^0 and K_S^0 mass difference 302
 K_L^0 and K_S^0 state 291, 288
 strangeness oscillation 299–303
- Neutrino astronomy 324–327
- Neutrino–electron scattering 24, 33, 34, 45, 48
- Neutrino masses 29, 46–48
 from double-beta decay experiments 329–332
 seesaw mechanism 328–329
- Neutrino–nucleon scattering 30, 210–215, 218–219
- Neutrino oscillation experiments 42–46
 GALEX 45
 Kamiokande II 44
 KamLAND 46
 Minos 44
 SAGE 45
 SNO 45
 SuperKamiokande 42–43
- Neutrinos
 detection 30–31, 85, 325–327
 Dirac or Majorana 327–332
 electron 28–30
 helicity 283–284
 limit on number of 258–263
 masses 46–48, 321–322, 328–329, 330
 mixing 39–41
 oscillations 41–46
 seesaw mechanism 328–329
 solar neutrinos 44–46, 265–267
 from supernova 1987A 325
- Neutron
 decay 29, 56–57, 224
 magnetic moment 5, 160–162
 quark distributions 215
 scattering cross-sections 84–85
- Nuclear cross sections 84–85
- Omega-minus particle 156–160, 233–234
- Order of Feynman diagram 13
- OZI rule 171
- Pair production cross-section 90–91
- Parity
 of charged pion 132–133
 conservation 127–129
 intrinsic 128
 lepton–antilepton pairs 129–131
 nonconservation in ^{60}Co decay 279–283
 nonconservation in muon decay 281–283
- of photon 133–134
 of quarks and hadrons 131–132
 tau-theta puzzle 280
 violation 279–288, 391–392
- Particle beams 76, 82–83
- Particle detectors 92–106
 AMANDA 326–327
 ANITA 327
 ATLAS 113–114
 BaBar 298
 bubble chamber 62–65, 94
 calorimeter 103–106
 CDF 112–113
 Čerenkov counter 101–103
 cloud chamber 7, 61
 drift chamber 96–97
 gas detectors 93–99
 Geiger–Müller counter 98
 IceCube 327
 ionization chamber 95
 jet chamber 97
 multiwire proportional chamber 96
 NEMO3, 331–332
 neutrino detectors 30–31, 42–43, 212–213, 326–327
 photographic emulsion 57–58
 scintillation counter 100–101
 semiconductor detector 99
 silicon vertex detector 99
 spark chamber 99
 spectrometer 93
 STAR 113–114
 streamer chamber 99
 SuperKamiokande 42–43
 time projection chamber 97–98
 UA1, 107–109
 WA1, 212–213
 WIMP detector 322–323
 wire chambers 95
- Particle exchange forces 18–19
 range of force 18–19
 W and Z exchange 34–36
 Yukawa potential 19–20
 zero-range approximation 20–22
- Particle interactions with matter 83–92
 ionization energy losses 85–88
 radiation energy losses 88–92
 short-range interactions with nuclei 83–85
- Parton
 charge determination 213–215
 distributions 207–210
 model 205–207
 neutrino scattering 210–213
 spin determination 206–207

- Pauli spin matrices 122
 Photino 314
 Photographic emulsion 57–58
 Photomultiplier tube 100–101
 Photon
 C-parity 136–137
 cross-sections 91
 interactions with matter 90–92
 mass and gauge invariance 372–374
 parity 133–134
 physical constants 435
 Pion–proton scattering 83–84
 Pions 57
 C-parity of neutral pions 136
 decays 57–58, 136–137, 286–287
 discovery 57–58
 isospin 150, 155–156
 parity of charged pion 132–133
 role in nuclear forces 59–60
 spin of charged pion 144–145
 Planck mass 319
 Positron 5–7
 magnetic moment 140
 Positronium 138–142
 C-parity 141–142
 e^+e^- annihilation 141–142
 energy levels 138–139
 fine structure 139–140
 ortho and para 139
 Principle of detailed balance 144
 Proca equations 373
 Proportional chambers 95–96
 Proton
 charge distributions 197–198
 decay in grand unified theories 311–313
 form factors 198–200
 magnetic moment 5, 160–162
 rms radius 198, 199
 structure functions 204–209
 Pseudoscalar mesons 154–156

 Quantum chromodynamics 179–190
 e^+e^- total cross-section prediction 194–196
 gauge theory of 380–384
 scaling violations 207–210
 screening and antiscreening in 185–187
 strong coupling constant in 182–185
 Quantum electrodynamics 14–16
 Quantum fluctuations 185–187
 Quark–antiquark potential 172–176
 Quark confinement 163–165, 181–182
 Quark–gluon plasma 187–190
 Quark mixing 227–229, 235–238, 303–305, 393, 430–431

 Quark model 51–53
 allowed quantum numbers in 71–72
 angular momentum in 125–127
 charmonium and bottomium 168–175
 isospin in 148–153
 light baryons 156–159
 light mesons 154–156
 magnetic moments 160–162
 parity in 131–132
 Quarks
 colour charges 163
 distributions 207–210
 electric charges 53, 214–215
 flavours 52–53
 masses 53
 numbers 54–56
 parity 131–132
 quantum numbers 54–56, 150, 396
 sea quarks 207–210
 search for free quarks 52–53
 table of properties 396
 third generation 234–238
 valence quarks 207
 Q -value 57

 Radiation energy losses 88–90
 Radiation length 89
 Range 88, 92
 of particle exchange force 18
 Reines and Cowan experiment 30–31
 Relativistic kinematics 335–341
 Relativistic wave equations 3–4
 Dirac equation 4
 Klein–Gordon equation 3
 Resonances 66–70
 Breit–Wigner formula 68, 351–356
 decay width 67–68
 exotic resonances 72
 formation and production 66–67
 kaon resonances 69–70
 RHIC accelerator 82
 Rotational invariance 120–123
 Running coupling constant of QCD 183–184
 Rutherford cross-section formula 197, 200–202

 Scale invariance 204
 Scaling 204–205
 Scaling variable 203
 Scaling violations in QCD 204–205
 Scattering amplitude 20, 348–351
 Born approximation 20, 200–202, 349
 Scintillation counters 100–101
 Sea quarks 208–209
 Secondary particle beams 82

- Selection rules in weak interactions 231–234, 292
 Selectron 314, 317–318
 Semiconductor detectors 99
 Shower counters 103–106
 Sigma baryons 151–154, 156–158, 231–233
 Smuon 314
 Solar neutrinos 44–46
 Spark chamber 99
 Spectrometers 93
 Spectroscopic notation 124–125
 Spin matrices 123
 Spinors 5
 Spontaneous symmetry breaking 265–267, 379–380
 Squark 314
 Standard model, overview of 1–2
 STAR detector 113–114
 Stauon 314
 Storage rings 80
 Strangeness oscillations 299–301
 Strangeness quantum number 54
 Strange particles 60–63
 Streamer chamber 99
 String theories 318–319
 Strong coupling constant 182–185
 Structure functions 204–209
 Superparticles 314–315
 detection of 317–318
 Supersymmetry 314–318
 CP violation in 315
 electric dipole moments in 315–317
 superparticles 314–315
 Symmetries
 charge conjugation 134–138, 281–285
 CP invariance 281–283, 288–291, 303–305, 315–317
 gauge invariance 179, 263–269, 369–392
 parity 127–134, 279–288, 391–392
 rotational invariance 120–123
 time reversal 142–145
 translational invariance 118–120
 Synchrotron radiation 79
 Synchrotrons 78

 Tauon 27–29, 32–33, 36–39
 Time projection chamber 97–98
 Time reversal 142–145, 304, 315
 principle of detailed balance 144
 spin of charged pion 144–145
 Top quantum number 54
 Top quark
 discovery 240–245
 properties 238–240

 Total cross-section 83–84, 345–346
 Translational invariance 118–120

 Unification condition 253–255, 388–390
 Unified electroweak interaction 249, 253–258, 384–392
 Units and dimensions 22–24
 Universality of lepton interactions 36–38

 Vacuum polarization effects 186
 V–A interaction 286
 Valence quarks 208–209
 Vector mesons 154–156
 Virtual processes 13

 W bosons
 decays 222–224, 229–231
 discovery 106–109, 110–112
 exchange and Fermi coupling 22, 35–37
 mass 111, 254–255
 Weak hypercharge 388
 Weak interactions
 charge conjugation violation in 279, 281–285
 charged currents 218, 219–220
 CP violation 288–299, 303–305, 315–317
 $\Delta S = \Delta Q$ rule 233, 294
 Fermi coupling constant 22, 35–37
 hadron decays 56–57, 201–205
 higher order corrections 218, 249–250
 lepton decays 31–32, 36–38
 lepton–quark symmetry 224–229, 250–253
 low-energy limit 22, 35–37
 mixing angle 253–255
 neutral currents 218–219, 250–252
 parity violation in 279–288, 391–392
 quark mixing 227–229, 235–238, 303–305, 393, 430–431
 selection rules 231–234, 292
 universality 36–38
 V–A interaction 286
 W boson decays 222–224, 229–231
 W and Z exchange 34–36
 see also Leptons; Neutrinos; Unified electroweak interaction; W bosons; Z bosons
 Weak isospin 385–386
 Weak mixing angle 253–255, 311, 314, 315
 Weak neutral current vertices 250–252
 Weight diagrams 154–158
 Weinberg angle, *see* Weak mixing angle
 WIMPs 322–323
 Wino 314

-
- Wire chambers 95
W-lepton interactions 220–224
Wolfenstein parameterization 304
- X-bosons 310, 311–313
- Y-bosons 310, 311–313
Yukawa potential 19–20
Yukawa theory of nuclear forces 59–60
- Z bosons
 decays 260–263
 discovery 106–110
 formation in e^+e^- annihilation 258–260
 mass 110, 254–255, 260
 unification condition 264–265, 388–391
Zero-range approximation 20–22
Zino 314
Z-lepton vertices 250–251
Z-quark vertices 251–252