

Index

- Absorption length 121, 138
 Accelerator driven systems (ADS)
 (see *Nuclear power*)
 Accelerators
 alternating current 112–118
 ATLAS linear accelerator, Argonne, USA
 113
 CEBAF, Jefferson Laboratory, USA
 113–114
 CERN complex 117–118
 Cockcroft-Walton 111
 colliders 110–111, 117–118
 COSY, Jülich, Germany 117
 cyclic 114–118
 cyclotron 114
 direct current 111–112
 fixed-target 109
 International Linear Collider (ILC) 117–118
 LHC, CERN, Switzerland 117–118
 linear (linac) 112–114
 RHIC, BNL, USA 1118
 SLC, Stanford, USA 113
 storage rings 117
 synchrotron 115
 Van de Graaff machine 111–2
 Activation energy in fission 61–62
 Activity 53
 ADS (see *Nuclear power*)
 Allowed transitions in beta decay 242
 α decay 235–238
 Gamow factor 237
 Geiger-Nuttall relation 238, 239
 potential well 236
 tunnelling mechanism 236–238
 α rays, discovery 1
 Amplification factor in gas detectors 128–129
 Amplitude
 invariant 21
 nonrelativistic 20–21
 Anomaly condition 208
- Antiparticles
 discovery 8
 predicted from Dirac equation 7
 Antiscreening 158
 Askaryan effect 327
 Associated production 119
 Asymmetry term in SEMF 48
 Asymptotic freedom 151, 156–158
 ATLAS detector at LHC 142–143
 ATLAS linear accelerator, Argonne, USA, 113
 Atomic mass unit 29, 56, 377
 Atomic number 31
 Axion 303, 329
- BaBar detector 202
 Barn (unit of area) 28
 Barrier penetration
 alpha-decay 236–238
 fission 61
 fusion 263
 quantum theory 339–341
 Baryon-antibaryon asymmetry in universe
 330–331
 Baryon number
 conservation 92
 violation in grand unified theories 317–318
 Baryons
 colour wavefunction 149
 magnetic moments in quark model 102–103
 masses in quark model 103–104
 mass splittings within multiplets 103–104
 multiplets in quark model 96–101
 Beams (see *Particle beams*)
 Beauty quantum number 90
 Becquerel (unit of radioactivity) 53
 Belle detector 202
 Bending magnet 115–116
 β decay
 allowed transitions 242
 comparative half-life (*ft*) 246

444 Index

- β decay (*Continued*)
 condition for stability from SEMF 56
 density of states 241
 double β decay 58
 double electron capture 58
 electron capture 57–58
 electron momentum distribution 240–242
 even-mass nuclei 58–59
 Fermi screening factor 243
 Fermi theory 239–240
 Fermi transitions 239
 forbidden transitions 243
 Gamow-Teller transitions 239–240
 Kurie plot 243–244
 neutrino mass from β decay of tritium 245–246
 neutrinoless double β decay 186, 312–314
 odd-mass nuclei 56–58
 selection rules 242–243
 total decay rate 246
- β rays, discovery 1
- Bethe-Bloch formula 122–124
- Big bang model 327
- Binding energy 45
 experimental data 47
 semi-empirical mass formula 47–51
 theoretical predictions 300–301
- Biological effects of radiation 278–281
 cell damage 279–281
 oxygen effect 281
 production of free radicals 280
 units of radiation 278–279
- $B-L$ quantum number 317
- Born approximation 24
- Bottomium 153–155
 bottom threshold 153
 OZI rule 152–153
 table of states 154
- Bottom quantum number 90
- Bragg curve 123
- Bragg peak 123
- Branching ratio 26
 isospin predictions for 94–96
- Brane 322
- Breit-Wigner formula 26–28
- Bremsstrahlung 124
- Cabibbo allowed/suppressed decays 190
- Cabibbo angle 190
- Cabibbo hypothesis 190
- Callan-Gross relation 168
- Calorimeters 135–138
- Carbon dating 54
- CEBAF accelerator 113–114
- Centre-of-mass system 353
- Čerenkov counter 134–135
- Čerenkov radiation 134
- CERN complex 117–118
- Chandrasekar limit 323
- Charge conjugation
 C parity, definition 10–11
 fermion-antifermion pair 11–12
 violation in weak interactions 180–181
- Charged current weak interactions 177
 W -lepton vertices 189–191
 W -quark vertices 190–192
- Charge distribution of nuclei 40–43
- Charge independence of nuclear force 93, 218
- Charge symmetry of nuclear force 218
- Charm quantum number 98
- Charmed particles 99
- Charmonium 152–155
 charm threshold 152
 OZI rule 152–153
 table of states 154
- Chirality 184–186
- Chromomagnetic interaction 104, 219
- CKM matrix 192, 205–207
- CNO chain 267–268
- Cockcroft-Walton machine 111
- Collective model 234, 235
- Colliders 110–111, 117–118
 advantages and disadvantages 110
 luminosity 111
- Collision length 121
- Colour 147–149
 confinement 148
 evidence from e^+e^- annihilation 163–165
 heavy quark spectroscopy 151–155
 hypercharge and isospin 148
 quantum numbers for gluons 148
 role in QCD 158–159
 singlet 148
 wavefunction 148–49
- Colour confinement 148
 confining potential 154
- Complex nuclear potential 44–45
- Compound nucleus 64
- Compton scattering 125–126
- Computed tomography 286–287
- Confinement (see *Colour*)
- Conservation laws
 angular momentum 8
 baryon number 92
 $B-L$ quantum number 317
 charge conjugation 10
 colour 147–149
 CP 181–183, 197–199
 isospin 93–96

- lepton number 73–74
- linear momentum 8
- parity 9
- quark numbers 91–92
- strangeness, charm, bottom and top 98
- Constituent quarks 90
- Control rods 259–260
- Cosmic baryon asymmetry 330–331
- Cosmic rays 54
- COSY accelerator, Jülich, Germany 117
- Coulomb barrier
 - alpha decay 61–62, 236–238
 - fusion 263
- Coulomb term in SEMF 48
- Coupling constant 19
- C-parity
 - fermion-antifermion pairs 11–12
 - violation in weak interactions 181–182
- CP symmetry
 - consequences for muon decay 181–182
 - violation in B decays 201–203
 - violation in neutral K decays 199–201
- CPT theorem 13
 - experimental tests 305
- CP violation
 - standard model predictions 205–207
 - in B decays 201–203
 - in neutral K decays 199–201
- Cross-sections
 - Born approximation 24
 - deep inelastic scattering 65, 165–167, 195–197
 - definition 23
 - differential 23
 - elastic scattering from nuclei 41
 - flux 23
 - low-energy neutrons 67
 - luminosity 23
 - Mott scattering 39
 - neutron-uranium 254–255
 - partial 23
 - photon scattering 126
 - Rutherford scattering 39
 - spin factors 26
 - total 23
- CT (see *Computed tomography*)
- Curie (unit of radioactivity) 53
- Current quarks 97
- Cyclotron 114
- Cyclotron frequency 34, 143

- Dalitz plot 356–357
- Dark energy 328
- Dark matter 328
 - inflationary big bang model 328
 - MACHOs 328
 - WIMPs 329–330
- Data
 - gauge bosons 378
 - isotopes 384–391
 - leptons 379
 - low-lying baryons 380–381
 - low-lying mesons 382–384
 - periodic table 392
 - physical constants and conversion factors 377
 - quarks 379
- Decay constant 53
- Decay width 26
- Deep inelastic scattering
 - Callan-Gross relation 168
 - charged lepton-nucleon 165–170
 - EMC effect 299–300
 - Gottfried sum rule 175
 - neutrino-nucleon 195–197
 - nuclear 65
 - parton model 167–170
 - sea quarks 169
 - scaling 165–167
 - scaling violations 170–173
 - structure functions 166
- Deformation parameter 60–61, 233
- Degeneracy pressure 323
- Delayed neutron emission 257, 259–260
- Delta resonance 94–96
- Density of states
 - β decay 241
 - cross-section definition 24–25
 - quantum theory 341–343
- Density of the universe 328–329
- $\Delta I = \frac{1}{2}$ rule 194–195
- $\Delta S = \Delta Q$ rule 193
- Detectors (see *Particle detectors*)
- Deuteron 218
- Differential cross-section 23
- Dipole transitions 248
- Diquarks 219
- Dirac equation 7
 - magnetic moment 5
 - parity for fermion-antifermion pairs 10
 - solutions as spinors 7
- Direct nuclear reaction 64
- Double β decay 58, 312–314
- Drift chamber 131
- Drift tube 112

- Effective dose 279
- Elastic scattering, definition 14

446 Index

- Electric dipole moments 303–304
- Electric quadruple moments 231–234
- Electromagnetic interactions 15–16
 - pair production and annihilation 125–126
 - typical lifetimes 102
- Electromagnetic showers 37–138
- Electron
 - discovery 2
 - magnetic moment 5
- Electron capture 57–58
- Electron neutrinos 71–72
- Electron number 73
- Electron-positron annihilation
 - evidence for colour 163–165
 - hadron production 163–165
 - three-jet events 163
 - two-jet events 88–89
- Electron-positron pair production 125–126
- Electron volt (unit of energy) 28
- Electroweak unification 207–210
 - anomaly condition 208
 - confirmation in experiments 211–213
 - manifestation at high energies 211
 - unification condition 208
- Elementarity 4–5
- EMC effect 299–300
- Energy losses by particles in matter
 - ionization losses 122–124
 - photons 125–127
 - radiation losses 124–125
 - short-range interactions with nuclei 120–121
- Equivalent dose 279
- Exotic hadrons 149

- Fast breeder reactor 261
- Fermi (unit of length) 28
- Fermi coupling constant 22
- Fermi gas model 220–222, 235
- Fermi's Golden Rule (see *Golden Rule*)
- Fermi transitions 239, 242
- Feynman diagrams 15–17
 - Feynman rules 20
 - gluon vertices 150, 158
 - multiparticle exchange 22
 - order of 22
 - vertices in electroweak interactions 189–191, 190–192, 210–211
- Feynman rules 20
- Fine structure constant 19
- Fissile nuclei 254–255
- Fission
 - activation energy 61–62
 - chain reactions 255–257
 - condition for stability 60–61
 - delayed neutrons 259–260
 - energy of fragments 60
 - fissile materials 253–255
 - importance of pairing energy 62
 - induced 53, 62
 - prompt neutrons 254
 - reactors 257–262
 - spontaneous 53
- Fixed-target experiment 109–110, 117
- Flavour oscillations 203–205
- Flux 23
- Focusing magnet 115
- Forbidden transitions in beta decay 243
- Form factor 40
- Four-momentum 352
- Four-vector 352–353
- Fragmentation 88, 156, 162
- Fusion
 - Coulomb barrier 262–263
 - Maxwell-Boltzmann distribution 273
 - reaction rates 264–266
 - reactions 265–269
 - reactors 268–271
 - stellar fusion 266–268
 - tunnelling 263
- Fusion reactors
 - deuterium-deuterium reaction 268–269
 - deuterium-tritium reaction 269
 - HiPER 333
 - inertial confinement 276, 333–334
 - ITER 333–334
 - Lawson criterion 270
 - magnetic confinement 270–271
 - tokamak 271

- γ emission 62–63, 247–250
 - multipole radiation 247
 - radiative width 250
 - role of angular momentum 63, 247–248
 - selection rules 247–248
 - transition rates 248–250
 - Weisskopf approximation 249
- γ rays
 - attenuation in matter 125–127
 - use in medical imaging 283–287
- Gammasphere γ ray detector 139–140
- Gamow factor 237, 263
- Gamow-Teller transitions 240, 242–243
- Gas amplification factor 128–129
- Gauge bosons 6
- Gauge bosons: role in standard model 5–6
- Gauge invariance
 - electromagnetism 368–370
 - gauge principle 369
 - Higgs field 372
 - Higgs mechanism 374

- lattice gauge theory 151
- Lorentz condition 369
- spontaneous symmetry breaking 372–375
- standard model 370–372
- unification condition 372
- weak hypercharge 371
- weak isospin 371
- Geiger-Muller counter 132
- Geiger-Muller region 129, 132
- Geiger-Nuttall relation 238–239
- g -factor 228
- Glueballs 151
- Gluino 319
- Gluons
 - determination of spin in electron-positron annihilation 163
 - gluon-gluon scattering 150–151
- Golden Rule 343–345
- Gottfried sum rule 175
- Grand unified theories (GUTs)
 - $B-L$ quantum number 317
 - fundamental vertices 316–317
 - nonconservation of baryon and lepton numbers 316–317
 - proton decay 317–318
 - 'see-saw mechanism' for neutrino masses 318
 - unification mass 315
 - weak mixing angle 317
 - X and Y bosons 316–317
- Gray (unit of radiation dosage) 278–279
- GUTs (see *Grand unified theories*)
- Hadronic showers 138
- Hadrons
 - charge independence of nuclear forces 93, 218
 - charge symmetry 93
 - decays in quark model 100–101
 - excited states in quark model 99–100
 - exotic states 149
 - glueballs 151
 - heavy quark bound states 151–156
 - magnetic moments in quark model 102–103
 - masses in quark model 103–107
 - multiplets 98–100
 - semileptonic weak decays 189–192
- Half-life 54
- Halo nuclei 44, 302
- Heavy quark bound states 151–156
 - bottomium 153–155
 - bottom threshold 153
 - charmonium 152–155
 - charm threshold 152
- OZI rule 152–153
 - table of states 154
- Helicity 182
 - measurement for neutrinos 183–184
 - right-handed and left-handed states 182
 - role in muon decay 185–186
 - role in pion decay 184–185
 - states for particles with mass 184–186
- Higgs boson 6
 - experimental searches 307–311
 - Higgs mechanism 306
 - mass limits from experiment 307–308
 - origin of mass problem 305–307
 - predictions from standard model 306–307
 - predictions in supersymmetry (MSSM) 306
- Higgsino 319
- Hypercharge quantum number 98–99
- Hyperfine interaction 104
- Hypernucleus 299
- Impact parameter 362
- Inelastic scattering, definition 14–15
- Internal conversion 248
- International Linear Collider (ILC), 117–118
- Invariant amplitude (see *Amplitude*)
- Invariant mass 354
- Inverse beta decay 76–77
- Ionization chamber 128–129
- Ion trap 34
- Isobar 31
- Isospin symmetry 93–96
 - branching ratio predictions 94–96
 - formalism 345–349
 - $\Delta S = \Delta Q$ rule 193
 - hadron multiplets 97–101
- Isotone 31
- Isotope 2
- ITER 333
- Jet chamber 131
- Jets 88–89
 - e^+e^- annihilation 161–163
 - evidence for quarks 88–89
 - fragmentation 87
 - gluon spin determination 166
 - 3-jet events 163
 - 2-jet events 88–89
 - QCD 161–153
- Kaons 98
- K-capture 52, 57
- Klein-Gordon equation 7
- Kurie plot 243–244
- Landé g factor 228
- Large Hadron Collider 117–118

448 Index

- Larmor frequency 290
- Lattice gauge theory 151
- Lawson criterion 271
- Lepton number conservation 73
- Leptons 5
 - decays 72
 - lepton numbers 71–74
 - lepton-quark symmetry 189
 - multiplets 71–75
 - number of 75
 - scattering as evidence for quarks 88
 - universal weak interactions 74–75
- Lepton-quark symmetry 189
- Lepton universality 74–75
- LET (see *Linear energy transfer*)
- LHC (see *Large Hadron Collider*)
- Lifetime 26, 54
- Linac (see *Linear accelerator*)
- Linear accelerator 112–114
- Linear energy transfer (LET) 281–282
- Liquid drop model (see *Semi-empirical mass formula*)
- Luminosity 23

- MACHOs 328
- Magic number 224–225
- Magnetic moment
 - Dirac equation prediction 5
 - nuclei 227–229
 - nucleon 6
 - quark model predictions 102–103
- Magnetic resonance imaging (MRI)
 - basic theory 290–292
 - BOLD images 293
 - imaging elements other than hydrogen 292–293
 - Larmor frequency 290
 - nuclear resonance frequency 293
 - recent developments 333
 - relaxation times 291–292
 - spatial encoding 292
 - spin echos 292
- Magnetic deflection spectrometer 32–33
- Mass deficit 46
- Masses in quark model 103–107
- Mass number 32
- Mass spectroscopy
 - deflection spectrometers 32–33
 - kinematic analysis 33
 - Penning trap measurements 34–38
- Matter-antimatter asymmetry 330–331
- Matter distribution in nuclei 44
- Mean life 48
- Medical imaging
 - computed tomography (CT) 286–287
 - CT scanner 287
 - equivalent and effective doses 279
 - functional MRI 292–293
 - γ camera 285
 - magnetic resonance imaging (MRI) 289–293
 - oxygen effect 282
 - positron emission tomography (PET) 288–289
 - projected images 284–286
 - proton beams 282–283
 - single-photon emission CT (SPECT) 287–288
- Mesons
 - bound states of heavy quarks 151–156
 - glueballs 151
 - kaons 99
 - masses in quark model 103–107
 - pions 6, 97–99
 - quark structure 97
- Microstrip detector 133
- Minimum ionization 122–123
- Mirror nuclei 93–94
- Moderator 259
- Mott cross-section 39
- MRI (see *Magnetic resonance imaging*)
- MSSM (see *Supersymmetry*)
- M-theory 322
- Multiplication factor in gas detectors 128–129
- Multipole radiation 247–248
- Multiwire proportional chamber MWPC (see *Particle detectors*)

- Natural units 28
- Nature of the neutrino 311–312
- Neutral current weak interactions 178
 - conservation of quark numbers 210
 - electroweak unification 210–213
 - Z^0 vertices 210–211
- Neutralino 320
- Neutral K decays 197–201
 - CPT theorem 205
 - CP violation 199–201
 - flavour oscillation 203–205
 - strangeness oscillation 203
- Neutrino
 - Dirac or Majorana neutrino? 186, 311–312
 - emitted in supernova explosions 323–325
 - helicity states 182
 - limits of number of neutrinos 75
 - masses 84–96
 - masses from oscillation measurements 80–85
 - mass of ν_e from beta decay of tritium 76
 - mixing 77–79
 - multiplets 71–72
 - oscillations 77–79
 - postulated in β decay 3–4

- scattering from electrons 195–196
- scattering from nucleons 196–197
- solar neutrinos 82–84
- Neutrino astrophysics
 - Amanda experiment 325–326
 - Anita experiment 327
 - Askaryan effect 327
 - Chandrasekhar limit 323
 - detection of supernova neutrinos 324–325
 - IceCube experiment 326
 - neutron star 323
 - supernova mechanism 323–324
 - ultra high-energy neutrinos 325–327
- Neutrino experiments
 - Amanda 325–326
 - Anita 327
 - GALLEX 83
 - IceCube 326
 - Kamiokande II 83
 - NEMO3 314
 - SAGE 83
 - SNO 84
 - SuperKamiokande 80–82
- Neutrinoless double β decay 186, 312–315
- Neutrino masses
 - from cosmological models 86, 329
 - from oscillation measurements 80–85
 - from supernova explosion 324–325
 - mass of ν_e from beta decay of tritium 76
- Neutron
 - capture 65, 67
 - decay 189
 - discovery 3
 - magnetic moment 7, 102–103
 - scattering 65, 67, 254–255
- Neutron number 32
- Neutron star 323
- Nonspherical nuclei
 - collective model 234
 - electric quadrupole moment 231–234
 - shape oscillations 234
- Nuclear chain reaction
 - criticality condition 256
 - critical size for explosive release of energy 256–257
 - use in power production 257–261
- Nuclear charge distribution 40–43
 - form factor 40
 - mean square charge radius 43
- Nuclear density 44
- Nuclear force (see *Strong nuclear force*)
- Nuclear form factor 40–41
- Nuclear fusion (see *Fusion*)
- Nuclear instability 52–53
 - α decay 235–238
 - β decay 56–59, 238–246, 312–315
 - fission 59–62
 - γ emission and internal conversion 47, 247–250
 - one-proton decay 301
- Nuclear matter distribution 43–45
 - density 44
 - optical model 44–45
- Nuclear models
 - collective model 234
 - Fermi gas 220–222
 - liquid drop 45–52
 - shell 222–231
 - summary of properties 234–235
- Nuclear physics
 - data 384–392
 - origins and history 1–3
- Nuclear power
 - accelerator driven system (ADS) 335–338
 - fast breeder reactor 261–262
 - fusion reactors 268–271, 333–334
 - thermal nuclear reactors 257–261
- Nuclear radius 43
- Nuclear reactions 63–67
 - compound nucleus reaction 64
 - deep inelastic scattering 65
 - pickup reaction 64
 - stripping reaction 64
- Nuclear fission reactors (see *Thermal nuclear reactor* and *Fast breeder reactor*)
- Nuclear shape and sizes 38–43
- Nuclear waste disposal problem 261–262, 335–337
- Nuclear weapons
 - fission devices 273–275
 - fission/fusion devices 275–278
 - gun assembly 273
 - implosion assembly 273–274
 - Teller-Ulam technique 276–277
- Nucleon 3
- Nucleon-nucleon force 217–219
 - three-body contribution 300
- Nucleon-nucleon potential 217–220
- Nucleon number 32
- Nucleosynthesis 302
- Nuclide 31
- N-Z* nuclide distribution 52
- Oblate nuclei 232
- Observables
 - amplitudes 21–22
 - cross-sections 22–26
 - decay rates 26–28
- Ω^- particle 147, 194
- Optical model 44–45
- Order of Feynman diagrams 22

450 *Index*

- Oxygen effect 281
- OZI Rule 152
- Pairing term in SEMF 49
- Pair production 125–126
- Parity
 - associated with angular momentum 9–10
 - definition 10
 - fermion-antifermion pair 10
 - gamma emission 248
 - intrinsic 9
 - leptons 11
 - quarks 11
 - violation in weak interactions 178–181
- Partial width 26
- Particle accelerators (see *Accelerators*)
- Particle astrophysics
 - dark matter 327–328
 - matter-antimatter asymmetry 330–331
 - neutrino astrophysics 323–327
- Particle beams
 - neutral and unstable particles 119–120
 - neutron beams 119
 - stability 115–116
- Particle detectors 127–128
 - BaBar 202
 - Belle 202
 - bubble chamber 128
 - calorimeters 135–138
 - Čerenkov counter 134–135
 - cloud chamber 128
 - drift chamber 131
 - emulsion 128
 - Gammasphere 139–140
 - gas detectors 128–132
 - Geiger-Muller counter 132
 - ionization chamber 128–129
 - jet chamber 131
 - microstrip gas chamber 131–132
 - multicomponent detector systems 138–143
 - multiwire proportional chamber 130
 - NEMO3 314
 - pixel detector 133
 - photomultiplier tube 133
 - proportional counter 130
 - scintillation counter 132–133
 - semiconductor detectors 133–134
 - silicon microstrip detector 133
 - spark chamber 132
 - streamer chamber 132
 - Super Kamiokande 80
 - time-projection chamber 131–132
 - track chambers 130
 - vertex detector 134
 - wavelength shifter 133
 - wire chambers 130–132
- Particle interactions with matter 120
 - interaction of photons 125–127
 - ionization energy losses 121–124
 - radiation energy losses 124–125
 - short-range interactions with nuclei 120–121
- Particle physics
 - data 378–384
 - emergence from nuclear physics 3
- Parton model 167–169
- Penning trap 34–38
- Perturbation theory 343–345
- PET (see *Medical imaging*)
- Photino 319
- Photodetector 133
- Photoelectric effect 125–126
- Photomultiplier tube 133
- Photon interactions in matter 125–127
- Physical constants and conversion factors 377
- Pickup reaction 64
- Pions 6
 - decays 101
 - role in nuclear forces 17, 219
- Planetary model of atoms 2
- Planck mass 322
- Plum pudding model of atoms 2
- Positron, discovery of 8
- Positron emission tomography (see *Medical imaging*)
- Principle of detailed balance 13
- Prolate nuclei 232
- Prompt neutron emission 254
- Propagator 21
- Proportional counter 130
- Proton
 - decay 317–318
 - magnetic moment 6
 - quark distributions 170–173
 - 'spin crisis' 298–299
- Proton-proton cycle 266–267
- QCD 149–151
 - asymptotic freedom 151, 156–159
 - colour confinement 151
 - energy dependence of strong coupling 156–159
 - exchange of gluons 17, 150–151
 - jets in QCD 161–163
 - quantum fluctuations 157–158
 - role of gauge invariance 149
 - scaling violations 170–173
 - vacuum polarization 157
- Quadrupole moment 231–234
- Quadrupole transition 247–250

- Quantum chromodynamics (see *QCD*)
- Quark-gluon plasma 160–161
- Quark model
 - excited states 100
 - mass predictions 103–107
 - magnetic moment predictions 102–103
 - postulated by Gell-Mann and Zweig 4
 - proton ‘spin crisis’ 298–299
 - spectroscopy 96–101
- Quarks 96–97
 - constituent quarks 90
 - current quarks 97
 - determination of quark charges 168–170
 - determination of quark spin 168
 - distributions in nuclei 176, 299–300
 - distributions in nucleons 299–300
 - evidence from hadron spectroscopy 88
 - evidence from jet production 88–89
 - evidence from lepton scattering 88
 - flavour independence of interactions 92–93
 - flavours 90
 - generations 90
 - lifetimes 90
 - masses 90
 - mixing of quark states 190–192
 - quark numbers 91–92
 - sea quarks 97, 196–197
 - spectator model 91
 - static properties 4, 90
 - valence quarks 97, 171
- Rad (unit of radiation dosage) 279
- Radiation (see *Biological effects of radiation*)
- Radiation length 125
- Radiation therapy
 - using heavy ions and antiprotons 331–332
 - using photons and protons 281–283
- Radioactive dating 54
- Radioactive decay
 - activity 53
 - chains 54–55
 - decay constant 53
 - discovery 1
 - half-life 54
 - law 53
- Rayleigh scattering 125–126
- Range-energy relation 123
- Range of forces
 - from particle exchange 17–18
 - strong nuclear force 18
 - Yukawa potential 19–20
- Range of particle in matter 123
- Relativistic kinematics
 - centre-of-mass system 353
 - Dalitz plot 356–357
 - four-vectors 352–353
 - frames of reference 353–355
 - invariant mass 354
 - invariants 355–358
 - laboratory system 353
 - Lorentz transformations 351–353
- Relativistic wave equations 7
- Resonances
 - Breit-Wigner formula 26–28
 - quark model predictions 99–100
- RHIC accelerator 118
- Rotational states 234
- Running coupling in QCD 156
- Rutherford scattering
 - classical derivation 361–363
 - quantum mechanical derivation 364–365
- Sargent’s Rule 75, 246
- Scaling 165–167
- Scaling violations 170–173
- Scattering
 - charged lepton-nucleon 165–173
 - elastic 14
 - e^+e^- annihilation 163–165
 - diffraction 44 inelastic 14
 - low-energy neutron scattering 67
 - neutrino-electron 195–196
 - neutrino-nucleon 196–197
 - Mott 39
 - nuclear reactions 63–67
 - optical model 44–45
 - polarized electrons 211–212
 - Rutherford 39
- Schmidt lines 229–230
- Sea quarks 96, 169
- Second Golden Rule 343–345
- ‘See-saw’ mechanism 318
- Segré plot 52
- Selectron 319
- SEMF (see *Semi-empirical mass formula*)
- Semiconductor detectors 133–134
- Semi-empirical mass formula (SEMF)
 - condition for stability against β decay 56
 - correction terms 48–49
 - fit to binding energy data 51
 - mass term 48
 - numerical values of coefficients 49
 - physical basis of formula 48–49
 - size of terms 51
 - use in analysing β decay 55–59
- Scintillation counters 132–133
- Screening 157–158
- Separation energy 51

452 Index

- Shell model
 - applied to atoms 222–223
 - configuration 226–227
 - evidence for 225
 - excited states 229–231
 - magic numbers 224–227
 - magnetic dipole moments 228–229
 - pairing hypothesis 227
 - parities 227–228
 - spin-orbit potential 225–226
 - spins 227
 - summary 235
- Showers 137–138
- Sievert (unit of radiation dosage) 279
- Silicon strip detector 134
- Single-photon emission computed tomography (SPECT) 287–288
- SLC accelerator 113
- Sleptons 319
- Solar neutrinos 82–84
- Solar neutrino problem 83, 268
- Spallation process 119
- Spark chamber 132
- SPECT 287–288
- Spectator quark model 91
- Spin dependence of nuclear forces 218
- Spin-lattice relaxation 291–292
- Spinor 7
- Spin-orbit interaction 225
- Spins of nuclei 227
- Spin-spin interaction 104
- Spin-spin relaxation 292
- Spontaneous symmetry breaking 372–374
- Squarks 319
- Standard model: basic postulates 4–6
- STAR detector 139, 141
- Stellar fusion
 - CNO chain 267–268
 - production of heavy elements 268
 - proton-proton cycle 266–267
 - solar neutrino problem 268
- Storage rings 117
- Strangeness quantum number 97
- Streamer chamber 132
- Strings
 - branes 322
 - M-theory 322
 - Planck mass 322
 - unification point 319
- Stripping reaction 64
- Strong nuclear force 3
 - boson exchange model 219
 - charge independence 93, 218
 - charge symmetry 93, 218
 - isospin symmetry 93
 - quark model interpretation 218–219
 - saturation 48, 218
 - short-range repulsion 217
- Structure functions 166
- Superheavy elements 301
- Supernova 323–324, 316
- Superparticles 318–319
- Supersymmetry (SUSY)
 - branes 322
 - detection of superparticles 319–321
 - electron dipole moments 320
 - Minimal Super symmetric Standard Model (MSSM) 319
 - M-theory 322
 - neutralino 320
 - Planck mass 322
 - proton lifetime 319
 - strings 321–322
 - superparticle quantum numbers 318–319
 - unification point 319
- Surface term in SEMF 48
- SUSY (see *Supersymmetry*)
- Synchrotron 115
- Synchrotron radiation 115
- Tandem van de Graaff 111–112
- Tau lepton 72
- Teller-Ulam configuration 276–277
- Thermal neutron 67
- Thermal nuclear fission reactor
 - control rods 259–260
 - efficiency 260
 - fuel elements 257–259
 - moderator 259–260
 - radioactive waste disposal problem 261–262
 - role of delayed neutrons 259–260
- Time-of-flight method 134
- Time-projection chamber 131–132
- Time reversal
 - definition 12
 - principle of detailed balance 13
- Tokamak 270–271
- Top quantum number 90
- Track chamber 130
- Transmission coefficient 340
- Truth quantum number 90
- Tunnelling (see *Barrier penetration*)
- Unification condition 208, 372
- Unification mass 315
- Units 28–29
- Universality of lepton interactions 74–75
- Universe
 - critical density 328
 - inflationary big bang theory 327–328

- Unstable states
 - branching ratio 26
 - Breit-Wigner formula 26–27
- Vacuum polarization 157
- V-A interaction 184
- Valence quarks 97, 171–173
- Van de Graaff accelerator 111–2
- Van der Waals force 20, 218
- Vibrational states 234
- Virtual process 17
- Volume term in SEMF 48
- W-boson
 - decay 187
 - discovery 187
 - exchange 177
 - vertices 188–191
- Weak hypercharge 371
- Weak interactions
 - charge conjugation violation 180–181
 - charged currents 177
 - chirality states 184–186
 - CP invariance 180–181, 197–199
 - CP violation in B decays 201–203
 - CP violation in K_L^0 decay 199–201
 - Fermi coupling 22
 - hadron decays 189–195
 - lepton decays 72–73
 - lepton-quark symmetry 189
 - low-energy limit 22, 178
 - muon decay 180–181
 - neutral currents 178
 - parity violation 178–181
 - quark mixing 189–192
 - selection rules 192–195
 - semileptonic hadron decays 189–192
 - spin structure 182–186
 - typical lifetimes 102
 - unified theory 207–209
 - V-A interaction 184
- Weak isospin 371
- Weak mixing angle 208–209, 210, 303, 324
- Weinberg angle (see *Weak mixing angle*)
- Weisskopf approximation 249
- WIMPs 329–320
- Wino 305
- Wire chambers 130
- W-lepton vertices 189–191
- Wolfenstein parameterization 206
- Woods-Saxon potential 225
- W-quark vertices 190–191
- X-bosons 316–317
- Y-bosons 316–317
- Yukawa potential 19–20
- Z boson
 - discovery 187
 - exchange 177–178
 - vertices 210–211
- Zino 305

