

## Index

### **a**

Abrikosov's vortex 278, 336  
 absolute magnitude of star brightness 426  
 accelerating universe 513  
 achromaticity 494  
 acoustic oscillation 459, 461, 462  
 ADD model, *see also* LED 270  
 adiabatic 430, 435, 447, 461  
 – approximation 104  
 – condition 103, 104  
 – fluctuation 443, 459, 461  
 – index 432, 547  
 adjoint representation 164, 165  
 Adler-Bell-Jackiew anomaly, *see* chiral anomaly 158  
 $AdS_5$ : anti-de Sitter space 298  
 AGB: asymptotic giant branch 364, 518  
 age crisis 516, 518  
 Aharonov-Bohm effect 291, 336  
 Aharonov-Bohm phase 290  
 ALP: axion-like particle 362, 373  
 $\alpha_T$  analysis 256, 257  
 AMSB *see* SUSY models  
 – AMSB  
 angular diameter distance 398  
 angular momentum operator 199  
 annihilation catastrophe 402  
 anomalous dimension 246  
 anomaly, *see* chiral anomaly 350  
 anomaly mediated symmetry breaking *see* supersymmetry AMSB 232  
 anthropic principle 522  
 anti-deSitter space 296  
 apparent magnitude of star brightness 425–427  
 apparent luminosity 515  
 asymptotic freedom 161  
 ATLAS 2, 31, 48

### **auxiliary field** 215, 217, 219

axial charge 352, 355  
 axial current 350, 353, 355  
 axion 329, 356  
 – ADMX 374–376  
 – bremsstrahlung 363  
 – CAST 373  
 – cold dark matter 363  
 – coolant 363  
 – dark matter 329, 363, 376  
 – decay constant 357  
 – DFSZ – 361, 363, 376  
 – hadronic, *see* KSVZ – 361  
 – helioscope 373  
 – hot dark matter 363  
 – invisible – 357, 360, 363  
 – KSVZ – 361, 363, 373, 376  
 – microwave cavity detector 374  
 – misalignment – 494  
 – PQ  
 – – charge 358, 360, 362  
 – – symmetry 356, 357  
 – – transformation 358  
 – Primakoff effect 363, 365, 374  
 – standard – 357  
 – telescope search 373  
 – thermal – 373

### **b**

B-L, *see also*  $\Delta$  (B-L) 171, 172  
 B-L conservation 229  
 Baker-Campbell-Hausdorff formula 201  
 BAO *see also* baryon acoustic oscillation 63, 441, 443  
 baryogenesis 395, 401  
 baryon  
 – – photon fluid 460  
 – acoustic oscillation 63

- baryon (*contd.*)
  - asymmetry 400, 401, 404, 406–408
  - density 388, 401, 464, 465
  - number 158, 171
  - – non-conservation 348, 349
- BB, *see* neutrino beta beam 124
- Bessel function 304, 337
- $\beta$  function 160
- $\beta$  function 160, 170, 185, 246, 283, 284
- big bang 377
  - cosmology 377, 396, 400, 401, 412, 413, 418, 420
  - nucleosynthesis 377, 395, 410, 413
- Big Crunch 528
- big hierarchy 16, 244, 267, 283
  - problem 182
- big hierarchy problem 18, 283, 285, 299
- Big Rip 533
- bimaximal 120
- black hole 141, 325, 327
  - classical – 326
  - Hawking radiation 326, 327
  - Hawking temperature 325
  - production 326, 327
  - quantum – 327, 328
  - Schwarzschild radius 325
- Bolometer 505
- Boltzmann equation 394, 406, 429, 447
- Bose condensate 5, 420
- brane 232, 245
- bulk 232, 245
- bullet cluster 485
  
- c**
- Cabibbo-Kobayashi-Maskawa matrix 114, 120
- carbon deflagration 514
- Casimir
  - effect 191
  - operator 243
- D: charge coupled deviceI 514
- CDM, *see* cold dark matter 437
- Chandrasekhar mass 140, 548
- charged current interaction 81, 85, 86, 99, 101
- chemical potential 384, 385, 389, 406, 407, 410, 411, 416
- Chern-Simons number 339, 342, 349
- chiral
  - anomaly 329, 348, 350, 352, 356, 359, 361
  - charge 357
  - current 355, 358
- fermion in the brane 281
- symmetry 159, 351, 353
- transformation 351–353, 356, 357
- Christoffel symbol 560
- CKM, *see* Cabibbo-Kobayashi-Maskawa 3
- CKM matrix 3, 20, 354
- CKM mechanism 231
- Clifford algebra 274
- cluster counts 537, 539, 540
- CMB 63, 377, 379, 387, 389, 395, 413, 414, 417, 422, 454 *see also* cosmic microwave background
  - anisotropy 455, 456, 458, 460
  - B-mode 452, 468, 470, 471, 473
  - – measurement 474
  - – spectrum 452, 455
  - dipole component 455
  - E-mode 452, 468, 470, 471
  - Planck 450, 453, 456, 457, 519
  - power spectrum 452, 454, *see also* CMB anisotropy 456, 457, 461
  - quadrupole component 467, 468, 471
  - T-E cross-correlation 452, 472
  - tensor to scalar ratio 474
  - WMAP 311, 450, 455, 519
- CMS 2, 48, 49
- CMSSM *see* SUSY models
- CMSSM
- coincidence problem 418, 523
- cold dark matter 388, 437, 491
- collective symmetry breaking, *see* little Higgs model 33
- color anomaly 358, 359, 362
- color magnitude diagram, *see* Hertzsprung-Russel diagram 364
- comoving
- coordinate 379, 380, 384–386, 396–398
- distance 379–381, 396–398, 482
- frame 483
- volume 490
- compact group 551
- compactification 274, 276, 296, 302
- completeness relation 192, 197
- complex mass 354
- composite
  - model 156, 184
  - particle 19
  - scalar 183
- Concordance Model 377, 388, 466, 519, 520
- conformal Newtonian gauge, *see* Newtonian gauge 562
- connected
  - infinitely – 552
  - simply –, *see* simply connected 553

- connectedness 552
- connection 559
- constrained MSSM *see* SUSY models CMSSM 231
- continuity equation 429, 462
- convective equilibrium 545
- convergence 482, 484, 488
- Cooper pair 28, 184, 336, 351
- core collapse 141, 146
- coset group 557
- cosmic
  - budget 475
  - destiny 539, 567
  - equation 378, 385
  - parameter 386–388
  - phase transition 378
  - variance 457, 465
- cosmic destiny 396
- cosmic ray background 90
- cosmological constant 293, 297–299, 383, 384, 387, 392, 418, 435, 464, 520, 532
- problem 418
- cosmological parameter 441, 451, 454, 464, 466, 467, 516
- cosmological principle 378, 379, 384, 396, 454
- Coulomb barrier 412
- coupling strength
  - fermion *see* flavor hierarchy in ED 282
  - gauge field in 5D 288
  - KK graviton in RS model 306
  - scalar field in 5D 272
- covering group 554
- CP
  - asymmetry 123
  - eigenstate 128
  - invariance 20, 24
  - phase 121, 128, 129
  - violating term 115, 117
  - violation 115, 116, 121, 126
- CPT theorem 403
- critical density 383, 387
- curvature 378, 379, 385, 387, 398, 423, 424
  - of the universe 464, 520
  - parameter 387, 388
  - perturbation 427, 459
  - spatial- 563
  - term 392
- custodial  $SU(2)$  symmetry 20
- d**
- D-brane 269
- dark age 417, 466
- dark energy 377, 384, 388, 396, 464, 513
  - component 465
  - models 532
- dark matter 229, 244, 308, 377, 388, 413, 415, 435–437, 440, 448, 454, 458, 475
  - candidates 493
  - axion 494
  - MACHO 494
  - neutrino 494
  - WIMPs 494
  - component 466
  - detection method 495
  - large scale structure 488
  - searches
    - accelerators 497
    - astrophysical 495
    - underground 496
    - WIMPs, *see* WIMPs wind 505
  - Daya Bay 119
- de Sitter space 297
- deceleration parameter 387
- decoupling, *see* photon decoupling 435
- degeneracy condition 230, 237, 241
- degeneracy problem 537
- degenerate state 514
- degenerate vacua 554
- delayed decay mechanism 404
- $\Delta$  (B-L) 350, 404, 407
- $\delta$  function 195, 211
- $\Delta m_{21}^2$  120
- $\Delta m_{31}^2$  120
- $\Delta m_{32}^2$  87, 120
- Derrick's theorem 339, 341
- DGLAP evolution equation 41
- diffusion length 436, 462, 463, 465
- Dirac
  - equation 66
  - field 66, 114
  - mass 65, 68
  - neutrino 63, 66, 67, 71
  - particle 65, 68, 72, 128
  - phase 114
- Dirichlet condition 269
- distance modulus 427, 515, 516, 537
- Doppler effect 455, 457, 461, 462, 474
- double beta decay 126
  - $0\nu$  mode 127
  - $2\nu$  mode 127
  - EXO200 134, 136
  - KamLAND-Zen 134, 136, 137
- doubly connected 553
- Dp-brane, *see* D-brane 269
- Drell-Yan process 178

**e**

- e-like event 80, 81, 90
- $E_6$  174, 177, 178, 180
- ECC, *see* emulsion cloud chamber 85, 125
- ED, *see* extra dimension 270
  - searches for ED
  - astrophysical 314
  - collider experiments 316
  - - graviton exchange 321
  - - graviton production 316, 318, 319
  - cosmic diffuse gamma rays 316
  - early universe 315
  - neutron star 315
  - SN1987A 314
  - $\text{TeV}^{-1}$  ED
    - - ADD model 322, 323
    - - RS model 322, 323
    - - UED model 324
    - split fermion 285
    - TeV brane 298, 299, 305
    - UED 270, 308, 313
  - Einstein equation 293, 378
  - in ED 293
  - Einstein ring 481
  - Einstein tensor 293
  - Einstein's stationary solution 568
  - elastic ribbon model 333
  - electroweak
    - mixing 4
    - phase transition 348
    - precision data 17
    - scale 168, 182
  - ellipticity 484–487
  - emulsion 85, 86
    - cloud chamber 85
  - entropy 390, 391, 404, 409, 430, 435, 459, 489, 490
  - equation of state 385, 389, 390, 431, 533, 536, 545
  - parameter 524, 529, 530, 532–534, 536
  - equipartition 529
  - equivalence principle 193, 559
  - equivalence theorem 39
  - equivalent W approximation 40
  - escape velocity of Milky Way 499
  - eternal expansion 568
  - Euclidean action 346
  - Euler equation 429
  - event horizon 399
  - EXO200 *see* double beta decay
    - EXO200–200 136
  - extra dimension 19, 180, 182, 184, 267
    - ADD model 270, 313
    - anti-domain configuration 282, 283

- anti-kink 279, 280
- brane 269, 279
  - - tension 298
  - bulk 269, 279, 305
  - bulk action 293
  - chiral fermion 273
  - domain 279, 281, 282
    - - configuration 278, 280, 281
    - - coupled fermion 279, 285
    - - wall 278
  - fat brane 279, 285
  - gauge field 287
  - gauge-Higgs unification 288, 289, 292
  - gravitational field 292
  - decomposition of 294
  - gravity 292
  - KK graviton 549
  - KK tower 270, 283
    - - gauge field 288
    - - graviton in warped ED 302
    - - scalar field 272
  - LKP 308, 310, 312, 313, 323
  - $M_5$ : Planck mass in 5D 245, 297
  - orbifold *see* orbifold
  - Planck brane 298, 299, 302
  - Planck mass in D dimension, *see*  $M_D$  293
  - $R^{(5)}$ : Ricci curvature in 5D 297, 301, 307
  - radion 296, 299, 300
  - Randall-Sundrum model 297, 307, 313
    - - RS1 scenario 299
    - - RS2 scenario 300
    - $S^1/Z_2$  275
      - scalar field 270
    - searches, *see* searches for ED 313
      - - KK conservation rule 308
      - - KK parity 310
      - - split - 324
      - - with gravity 312
      - - without gravity 312
    - volcano potential 303
    - warp factor 297, 298, 305
    - warped - 270, 296
    - $Z_2$  275
      - - operation 291
      - - parity 275, 279, 282, 310
      - - symmetry 275, 276, 281, 285, 291, 292
    - $Z'_2$  operator 277

**f**

- family
  - family problem 64, 156
  - family structure 158, 160
- Fayet-Iliopoulos model, *see* D-term breaking 221

- FCNC 19, 30, 175, 246  
Fermat's principle 479  
field strength 209  
fifth force 300  
fine tuning 17, 18, 30, 182–184, 225, 245,  
  265  
– problem 530  
first law of thermodynamics 384, 390  
flat direction 223  
flatness problem 418, 423  
flavor changing neutral current, *see* FCNC 19  
flavor eigenstate 73, 75, 76, 120  
flavor hierarchy 268, 282, 285, 286, 314  
– in ED 282, 283, 285, 286, 318  
form factor 19, 71, 184  
formula 41  
freeze out 489–491  
– temperature 490–492  
Friedmann equation 386, 387, 389, 393, 394,  
  396, 518  
fundamental representation 162–164, 177
- g**  
galaxy formation theory 436  
Gamow 412  
Gamow's criteria 394  
gauge  
– – Higgs unification, *see* extra dimension 289  
– freedom in GR 294  
– hierarchy, *see* big hierarchy 244  
– sector 4, 22  
– transformation  
– – in GR 427, 562  
– unification 185  
gauged away 5, 34  
Gauss's law 268  
Gell-Mann matrix 34  
general gauge mediation *see* supersymmetry  
  GGM 231  
general relativity 294, 559  
generation puzzle *see* family problem 64  
geodesic equation 559  
geodesic line 381  
GIM mechanism 185  
Ginzburg-Landau free energy 335  
globular cluster 364, 365, 434, 437, 517  
– age of 517  
gluon 166  
gluon fusion 39, 43, 45, 46, 53  
– *see* SUSY models  
– GMSB 231  
Goldstino 222, 223  
Goldstone bosons 24
- GPS:global positioning system 82  
GR, *see* general relativity 294  
graded algebra 199  
grand unification 14, 18  
Grand Unified Theory 18, 155, 161  
Grassmann number 191, 194–196,  
  198–200, 203, 210  
– Jacobian 195  
gravitational lens 440, 452, 455, 468, 473  
gravitational lensing, *see* lensing 476  
gravitational wave 427, 467, 470, 471, 474,  
  562, 563  
– primordial – 451, 474  
graviton 267, 269, 292  
– in extra dimension 292  
graviton *see also* extra dimension graviton 267  
GRB: gamma ray bursts 537, 539  
GUT, *see* Grand Unified Theory 155  
GUT scale 18, 182, 183
- h**  
Hamilton's principle 340  
harmonic gauge 294  
harmonic oscillator 280  
Harrison-Zeldovich isocurvature Spectrum 444  
HDM, *see* hot dark matter 437  
helium flash 367  
helium ignition 365  
Hertzsprung-Russel diagram 364, 517  
HI 477  
hidden sector 224, 231, 232, 236, 241, 245,  
  246  
hierarchy 268  
hierarchy problem 19, 155, 182, 184, 225,  
  241, 267, 268, 299, 305  
Higgs 1  
– charged – 56  
– colored – 403  
– coupling strength 53  
– decay branching ratio 8  
– decay width 7, 8, 44, 53  
– detection method 48  
– discovery of 51  
– in MSSM 22, 55  
– mass 26, 27, 36  
– mass spectrum 24  
– quadratic coupling 19, 32  
– quartic coupling 10, 15, 17, 19, 20, 32  
– sector 1, 2, 4, 6, 16, 22, 25, 40  
– spin-parity 52  
Higgsstrahlung 39  
homomorphic 558

- homotopy 551  
 homotopy class 337–339, 341, 343, 551, 552,  
   555  
 horizon 421, 422  
 horizon problem 418, 421  
 horizontal branch 364, 373, 518  
 horizontal symmetry 64  
 Hosotani mechanism 289, 291  
 hot dark matter 437, 490  
 Hubble  
   – constant 398, 427, 449  
   – damping 531  
   – diagram 515, 516  
   – distance 535  
   – expansion 530  
   – parameter 534  
   – time 393, 421, 519, 526  
 hypercharge 176–178, 406
- i**  
 I,Q,U,V, *see* Stokes parameter 468  
 IGM: intergalactic medium 401, 417  
 imaginary time 346  
 inequivalent 194  
 inflation 394, 400, 522, 529  
 inflation model 387, 418, 435, 448, 450, 453,  
   454, 457, 513  
 inflaton 418–421, 428, 435, 448–450  
   – mass 420  
   – potential 450, 451  
 infrared cutoff 283  
 initial condition  
   – acoustic oscillation 461  
   – density fluctuation 462  
 instanton 329, 340, 345, 348–350, 354, 355,  
   406  
 Integrated Sachs-Wolf effect, *see* ISW 459  
 internal background 92  
 ionization cooling 126  
 IR brane: infrared brane, *see* TeV brane 299,  
   302  
 irreducible representation 205  
 ISM: interstellar medium 475  
 isocurvature fluctuation 461  
 isomorphic 558  
 isothermal fluctuation 461  
 ISW 459, 461, 465  
   – early 459  
   – late 459
- j**  
 Jacobi identity 200  
 Jacobian 338  
 Jacobian peak 50, 181  
 Jarlskog factor 116  
 Jeans length 432, 433, 436, 448  
   – neutrino 436, 447  
 Jeans mass 433, 434  
   – baryon 434, 437  
   – neutrino 436
- k**  
 Kähler potential 226  
 Kaluza-Klein theory 267  
 KamLAND-Zen 137  
 kink 278, 332, 334  
 KK: Kaluza-Klein *see* extra dimension KK 270
- l**  
 L to B conversion 406  
 L-R mixing 240, 248, 251  
 $\Lambda$ CDM model 388, 417, 436, 442, 447, 448,  
   451, 452, 454, 457, 466, 519, 533, 537  
 $\Lambda$  dominated universe 392, 393, 399, 418  
 Landau pole 14  
 Landau-Zener formula 106  
 Lane-Emden equation 546  
 large scale structure 436, 437, 443, 448, 459  
 last scattering 395, 414, 417, 454, 458, 465,  
   467, 468  
 latent heat 418  
 lattice QCD 15  
 LED:large extra dimension 270  
 left-right symmetric model 69  
 left-right symmetry 174, 175, 178, 179  
 lens equation 480, 481  
 lensing 476, 479  
   – effect 494  
   – strong 481  
   – transfer matrix 482, 483, 488  
   – weak 477, 481, 484–486  
 leptogenesis 121, 404, 407  
 lepton asymmetry 400  
 lepton number 158, 171  
 leptoquarks 166  
 LHC 2  
 Lie algebra 191, 198, 199, 553  
 Lie group 551  
 lightest KK particle *see* extra dimension LKP  
   308  
 lightest supersymmetric particle *see* SUSY  
   models LSP 229  
 little hierarchy 16, 308  
 little hierarchy problem 18, 32, 59  
 little Higgs model 19, 31, 179  
   – collective symmetry breaking 33  
   – littlest Higgs model 38  
   – simplest model 38

longitudinal polarization 8, 13  
 Low Scale Techni-Color model 30  
 luminosity distance 398  
 luminosity function 43  
 luminosity of WW collision 41  
 Lyman  $\alpha$  417, 466

**m**

M/L: mass to luminosity ratio 436, 479  
 magnetic flux soliton 335  
 main sequence 62, 364, 517, 518, 545  
 Majorana
 

- condition 66, 194, 197
- fermion 228, 238
- field 65, 66, 194, 196
- heavy –neutrino 404, 405, 407
- mass 407
- Lagrangian 196
- magnetic moment 72
- mass 65, 128, 134, 135
- neutrino 61, 63, 67, 68, 72, 126
- – test of 126
- particle 62, 65, 128
- phase 76, 114
- spinor 192, 199, 200

 Majoron 67  
 manifold 551  
 mass eigenstate 73, 74, 76, 101–105, 107, 115, 120, 130  
 mass hierarchy 69, 121, 126, 127, 267  
 – problem 64  
 matter density 464  
 matter dominated 392, 393, 399, 414  
 matter eigenstate 105  
 matter oscillation 100  
 matter-antimatter asymmetry, *see* baryon asymmetry 400  
 matter-radiation equality 395, 414, 428, 435, 436, 444–446, 448, 513, 523  
 Maxwell distribution 498  
 Maxwell-Boltzmann factor 411  
 $M_D$ : Planck mass in D dimension 232, 268, 293  
 messenger 242, 243  
 metastable vacuum 15  
 metric tensor 427  
 Michel parameter 69  
 Mikheyev-Smirnov-Wolfenstein effect, *see* MSW effect 103  
 minimum SUGRA *see* SUSY models  
 – mSUGRA 231  
 minimum supersymmetric extension of the Standard Model, *see* MSSM 20  
 modulus field 300

mono jet 263, 319, 320, 497  
 monopole 340  
 monopole probelm 418, 424  
 MSSM 20, 25, 223, 224, 226, 236, 237, 239, 241, 249, 283  
 – brane 245, 246  
 – particles 241  
 MSW effect 100, 103  
 MT2 analysis 257  
 $\mu$ -like event 80, 90

**n**

Nambu-Goldstone Boson 29, 32, 33, 35, 355–357  
 Nambu-Goldstone vacuum 351  
 natural isotope 92  
 naturalness 27, 263, 265  
 Neumann condition 269, 302  
 neutral current interaction 99, 101  
 neutrino 61
 

- active – 99
- beta beam 124
- charge distribution 70
- CNGS 82, 85, 86
- decoupling 395, 408, 412
- electromagnetic interaction 70
- heavy – 74
- magnetic moment 71
- mass 62, 409
- – inverted hierarchy 121, 129, 130
- – normal hierarchy 121, 129
- – quasi degenerate 121, 129, 130
- – seesaw mechanism *see* seesaw mechanism 68
- mass hierarchy 120, 121
- mass matrix 65, 66
- mixing 73, 75
- neutrino factory 124, 125
- NUMI 84
- right-handed 62
- sterile – 63, 81
- super-beam 124
- supernova 136
- telescope 97
- temperature 409

 neutrino oscillation 61, 76
 

- accelerator experiments 82
- atmospheric – 79
- Borexino 109, 110
- bronze channel 124
- CP term 122, 123
- evidence 80, 100
- golden channel 101
- IMB 79, 97, 136

- neutrino oscillation (*contd.*)
  - K2K 82, 86, 87
  - Kamiokande 87
  - long baseline experiment 76, 123, 126
  - matter effect, *see* MSW effect 101
  - MINOS 82, 84, 86, 87
  - mixing angle 120
    - $\theta_{13}$  122
    - $\sin^2 \theta_{12}$  109
    - $\sin^2 \theta_{13}$  119
    - $\sin^2 \theta_{32}$  87
    - $\sin^2 \theta_{atm}$ , *see*  $\sin^2 \theta_{32}$  87
    - $\theta_{13}$  118
  - NOvA 123
  - OPERA 85
  - oscillation curve 81, 109
  - reactor, *see* reactor experiment 111
  - Schrödinger equation 101
  - short baseline experiment 76, 116, 117, 121
  - silver channel 125
  - solar, *see* solar neutrino 93
  - SuperK 80, 86–88, 92
  - T2K 82, 123
  - three-flavor – 114
  - two-flavor – 76
- neutron electric dipole moment 354
- Newtonian gauge 427, 446, 562, 563
- Newtonian limit 430
- NF, *see* neutrino factory 124
- NGB, *see* Nambu-Goldstone Boson 32
- no big bang 520, 568
- Noether current 334, 352, 353
- non-linear  $\sigma$  model 32
- non-SUSY GUTs 174
- normalcy temperature 316
- nuclear form factor 503
- nuclear matrix element 128, 131, 135
- nucleosynthesis 526
  
- o**
- O’Raifeartaigh model, *see* F-term breaking 221
- old standard model in cosmology 519
- onion structure 145
- onion structure of pre-supernova 145
- optical depth 466
- orbifold 275–278, 281, 291, 292, 298, 302, 303, 308
- order parameter 5, 336
  
- p**
- parallel transport 559
- particle horizon 394, 399
- path integral formalism 346, 348
- Peccei-Quinn symmetry, *see* axion PQ 356
- peculiar velocity 386
- penetration depth 337
- perfect fluid 384, 427, 429, 430, 446
- Peskin-Takeuchi S, T parameter 311
- phantom energy 533
- phase field 32
- phase rotation 126
- phase transition 17, 18, 418
  - first order 404, 418, 420
  - second order 418
- photo-disintegration 411
- photon decoupling 395, 417, 435
  - time 416
- photon temperature 409
- pion decay constant 29, 360
- Planck energy 267
- Planck satellite *see* CMB Planck 519
- Planck’s formula 389, 395, 455
- plasma frequency 373
- plasmon 73, 145
- PMNS matrix 73, 116, 120
- pNGB: pseudo-Nambu-Goldstone Boson 29
- Poincaré group 194
- Poisson equation 429, 430, 484
- polytrope gas 545
- Pontecorvo-Maki-Nakagawa-Sakata matrix, *see* PMNS matrix 73
- Pontryagin charge 338, 557
- power spectrum 438, 442, 447, 448, 462
  - CMB, *see also* CMB anisotropy 454
  - large scale structure 437
- Primakov effect 494
- proper distance 380, 396, 399
- proton decay 171, 172, 175, 185, 187, 285, 286
- pseudo Nambu-Goldstone Bosons 24
  
- q**
- quadrupole
  - component 470
  - matrix 487
  - moment 485, 487
- quantum anomaly, *see* chiral anomaly 158
- quantum tunneling 350
- quark confinement phase 395
- quark mass
  - scale dependence 173
- quark number, *see* baryon number 158
- quartic coupling
  - *see* Higgs 32
- quasar 417, 466

- quintessence  
 – attractor 530  
 – energy density 529  
 – freezing model 524, 529–531  
 – model 523  
 – scaling solution 525  
 – slow rolling 524  
 – slow rolling field 531  
 – thawing model 530, 531  
 – tracker 523, 528–530  
 – tracker solution 526  
 – tracking condition 526, 529  
 – tracking potential 528
- r**  
 R-parity, 229, *see* SUSY models 308  
 r-process 516  
 radiation dominated 392, 393, 397, 399, 414  
 radiative correction 17  
 radioisotope 516, 518  
 radion 296, 300  
 21 cm radiwave 476  
 razor analysis 258  
 reactor experiment 111  
 – Daya Bay 118, 119  
 – energy spectrum 147  
 – KamLAND 87, 109, 111, 117, 119  
 – – data 113  
 recombination 395, 414, 415, 417, 454, 464, 466, 468  
 red giant 365, 518  
 Red Out 533  
 red shift 385, 386  
 – of particles 386  
 reduced Planck mass 292, 421  
 refraction 101  
 – index 101  
 reheating 418–420  
 reionization 417, 466, 468  
 relics of big bang 489  
 renormalization group equation 11, 14, 160, 170, 171, 173, 185, 233–235, 244, 247, 283, 284  
 resonant density 103  
 resonant mixing 102, 104  
 RGB: red giant branch 364, 365, 367  
 RGE, *see* renormalization group equation 11  
 $\rho$ : neutral to charged current ratio 9, 20  
 Ricci scalar curvature 293, 378, 561  
 Ricci tensor 378, 561  
 Riemann tensor 561  
 right-handed gauge boson *see*  $W_R$  69  
 Robertson-Walker metric 379, 396, 427, 446  
 rotation curve  
 – Milky Way 499  
 – spiral galaxy 476, 477  
 RSD: Redshift Space Distortion 539  
 Rydberg-atom 374
- s**  
 Sachs-Wolfe effect 458  
 Saha's equation 416  
 Sakharov's three conditions 402, 404  
 SB, *see* neutrino super-beam 124  
 Scherk-Schwartz mechanism, *see* symmetry  
 – breaking by boundary condition 277  
 Schwarzschild radius 400  
 SD: spin dependent cross section 500  
 SDSS 426  
 seesaw mechanism 61, 63, 67–69, 76, 121, 126, 407  
 shear 479, 486, 487  
 – field 482, 488  
 – matrix 482, 484, 487  
 – measurement 479  
 – pattern 486  
 – – B-mode 486  
 – – E-mode 486  
 – reduced complex – 488  
 shift transformation 32  
 SI: spin independent cross section 500  
 Silk damping 435, 462  
 – length 463  
 Silk mass 463  
 simplified model 249  
 simply connected 553  
 – Lie group 424  
 Sine-Gordon equation 332  
 SL(2,C) 194  
 slow rolling 418–420  
 slow rolling parameter 525  
 SM: Standard Model 2  
 SN1987A 73, 87, 97, 136, 149–151  
 sneutrino 229  
 SO(10) 69, 174  
 solar neutrino 93  
 –  $^7\text{Be}$  109  
 –  $^8\text{B}$  92, 107, 108  
 – CNO cycle 95, 99  
 – energy spectrum 96, 98  
 – Ga experiment 98  
 – GALLEX/GNO 98  
 – Homestake experiment 94  
 – LMA:large mixing angle solution 106  
 – pp-chain 94, 95  
 – puzzle 79, 94, 100  
 – SAGE 98  
 – SMA:small mixing angle solution 106, 109

- solar neutrino (*contd.*)
  - SNO 99, 100
  - SNU 96
  - SSM, *see* Standard Solar Model 93
  - SuperK 97
  - survival probability 107
- solar term 122
- solitary wave, *see* soliton 329
- soliton 329, 551
  - sound horizon 432, 443, 444, 461, 464
  - sound velocity 431–433, 436, 460
- spallation 91, 113, 119
- specific heat 507
- sphaleron 349, 350, 404, 406, 407
- splitting function 42
- SQUID 374
- M: sequential Standard ModelI
  - 30, 180, 181, 324
- M:standard solar modelI
  - 93, 94, 97–100
- standard candle 513–515, 539
- stellar
  - cooling 73, 152
  - cycle 149, 150
  - evolution 62, 138, 363
  - evolution model 73, 97, 137, 141
- Stokes parameter 468, 469
- strong CP problem 329, 350, 355–357
- structure formation 395, 414, 425
- SU(2) 2
- SU(5) 160
- SUGRA, *see* supergravity 193, 234
- SUGRA GUT 231
- SUGRA scale 233
- super algebra, *see* graded algebra 199
- super particle *see* supersymmetry sparticle 225
- super Poincaré algebra 201
- Super-Kamiokande 88
- super-Weyl scale invariance 232
- superconductivity 28
- supergravity 157, 193
- SuperKamiokande *see* neutrino oscillation
  - SuperK 80, 88
- supernova, *see also* SN1987A 73
  - type Ia 138, 143, 513, 537
  - type II 138, 146
- superspace 200
- supersymmetry 14, 18, 19, 59, 155, 157, 174, 184–186, 189, 225
  - action 210
  - chiral superfield 203, 208, 209, 211, 214, 218, 220, 223
  - – kinetic energy 212
  - – left-handed – 204–206
  - – products of 206
  - – right-handed – 204, 206
  - covariant derivative 202, 209, 218, 219
  - D-term 219, 233
  - – breaking 221, 222
  - F-term 216, 233
  - – breaking 221, 223, 224, 231
  - fermion mass term 213
  - gauge interaction 217, 218
  - gauge transformation 207–209, 217
  - higgsino 187
  - Lagrangian 215, 220
  - non-Abelian interaction 219
  - off-shell representation 220
  - on-shell representation 220
  - operator 198, 199, 202, 221
  - soft breaking 224
  - sparticle 185
  - spontaneous symmetry breaking 221
  - superfield 192, 201, 202
  - superfield operator 200
  - supermultiplet 192
  - superpotential 213–216, 218, 219, 221, 222
  - U(1) transformation 217
  - vector superfield 206, 218, 220
  - – kinetic energy 216, 218
  - Wess-Zumino gauge 208, 209, 220
  - Yukawa interaction 213
  - surface of last scattering 395
  - SUSY, *see* supersymmetry 14
  - SUSY GUT 173, 185, 187
  - SUSY models 225
    - AMSB 27, 232, 245
    - canonical SUSY scenario 249
    - chargino 228, 238
    - – search 253
    - CMSSM 27, 231, 260
    - CNMSSM: constrained next MSSM 232, 241
    - decoupling regime 27
    - gaugino 237, 242
    - – mass 243
    - GGM 231, 241
    - gluino
    - – search 255
    - GMSB 27, 231, 241, 243, 249
    - – features 244
    - – mass formula 242
    - Goldstino 228, 244, 245
    - gravitino 242, 244
    - – search 262
    - higgsino 187, 228
    - long-lived sparticle 252

- LSP 229, 244, 250, 494
- - search 255
- $m_0$ ,  $m_{1/2}$  231
- $m_0 - m_{1/2}$  plane 260, 266
- mass spectrum 241, 245, 247–250, 259, 263
- MSSM, *see* MSSM 226
- mSUGRA 231, 234, 235, 242
- - mass formula 237
- $\mu$  problem 241
- natural SUSY 263, 265
- neutralino 228, 238
- - search 253
- NLSP: next LSP 244, 252
- nMSSM: next MSSM 241
- photino 228
- pMSSM: phenomenological MSSM 232
- R-hadron 261
- R-parity 229, 261, 308
- searches 248, 263, 264
- selectron search 252
- sfermion mass 243
- singlino 241
- slepton 239
- - search 250
- - smuon search 251, 252
- sneutrino 229
- soft breaking 226, 231, 235, 237, 241, 243, 244, 246
- sparticle 229
- - mass spectrum 235
- split SUSY 28, 232
- squark 239
- - search 255
- stau 244
- - search 250
- stop 25, 26, 240
- - mass 26, 27
- - search 260
- symmetry breaking 231
- - in extra dimension 245
- - scale 243, 244
- wino 238
- zino 228
- symmetry
  - SU(2) 2
  - SU(2)×U(1) 4
- symmetry breaking
  - by boundary condition 277
- synchronous gauge 562, 563
  
- t**
- t'Hooft-Polyakov's monopole 424
- $\tan\beta$  8, 22–25, 55–57
  
- technicolor 29, 184
- condensate 29
- extended – 30
- LSTC, *see* Low Scale Techni-Color model 30
- techni-fermion 29
- techni-gluon 29
- techni-pion 184
- techni-rho 30
- walking – 30
- tensor spherical harmonics 469, 565
- thermodynamics 389
- $\emptyset$  vacuum 329, 347, 348, 352–356
- Thomson scattering 417, 463, 466, 467, 469
- time delay of light 479
- top condensate model 28, 184
- topological charge, *see* topological number 334
- topological defect 278, 424
- topological number 334, 339, 345
- topological structure 334, 337
- topology 552
- torsion experiment 271, 315
- transition magnetic moment 72
- translation operator 200
- transverse polarization 7
- tri-bimaximal 120
- triangle anomaly 158, 159, 228, 352
- triangle anomaly *see also* chiral anomaly 159
- triviality 12, 14
- twisted ribbon 334
- two component formalism 193
- two-point function 456
  
- u**
- U(1) 337
- U(1) problem 355, 356
- ultraviolet cutoff 283
- underground detector 87
- unitarity 12, 13, 20, 23, 67, 115, 116
- unitary condition 122
- unitary triangle 116
- universal extra dimension *see* extra dimension UED 308
- unnatural 18, 68, 183
- UV completion 33, 38
  
- v**
- V+A interaction 69, 128
- V-A interaction 69, 128
- vacuum expectation value 5, 8, 11, 16, 21, 22, 29, 34, 53
- vacuum stability 10
- vector boson fusion 41, 53

- VEV, *see* vacuum expectation value 5
- virial mass 477, 478
- virial temperature 544
- virial theorem 477, 543
- visible sector 231, 232, 236, 241, 242, 244, 246
  - scale 243
- vortex 334
  
- w**
- W boson fusion 39, 40, 45, 46
- W' boson 175, 179–181
- W' boson *see also*  $W_R$  175
- Ward-Takahashi identity 353
- weakly interacting massive particle, *see* WIMP 493, 494
- Weinberg angle 4, 9, 359
  - in GUTs 157, 167, 185
- Weyl
  - field 193, 206, 213
  - representation 193
  - spinor 62, 193, 194, 196, 197, 200, 205
- white dwarf 364, 365
- Wilson phase, *see* Aharonov-Bohm phase 290
- WIMP 493, 494, 496, 497
- WIMPs wind
  - annual modulation 504
  - cross section 500
  - daily modulation 505
  - detection 498, 505
  - detector
    - CDMS 507, 508
    - Xenon 508
    - XENON100 510, 511
  
- x**
- X-ray emitting cluster 478
- Xenon
  - electro luminescence 510
  - scintillator 509
  - two phase operation 509, 510
  
- y**
- y-parity *see* extra dimension  $Z_2$  parity 275
- Yukawa coupling 6, 17, 26, 30, 35, 38
  - constant 11
- Yukawa interaction 4, 37
  
- z**
- Z' boson 175–178
  - mass 178
  - search 178
- zenith angle distributions 80, 100
- zero-point energy 191
- Zwicky 475