

## Name Index

- Aaron, R., 229  
 Achinstein, Peter, 342  
 Adler, Stephen, xviii, 209, 213, 215–216, 218–221, 289, 298–300, 303  
 Aharonov, Yakir, 270  
 Althusser, Louis, 345  
 Ambarzumian, V., 157, 159  
 Amelino-Camelia, G., 361  
 Ampère, André Marie, 26  
 Anderson, Philip W., 249–250, 255–256, 283  
 Appelquist, T., 328  
 Aristotle, xvi–xvii, 6, 342  
 Arnowitt, R., 217  
 Ashtekar, A., 313, 316
- Baker, M., 283  
 Bardeen, William, xviii, 215, 220–221, 249–250, 284, 294  
 Barnes, B., xvi  
 Behrends, R. E., 243  
 Bell, John S., xiv, 215–218, 220–222, 244, 266, 297, 304  
 Berkeley, George, 22  
 Bernstein, Jeremy, 208, 214, 285  
 Besso, Michele, 68  
 Bethe, Hans A., 171–172, 174, 176, 187  
 Bianchi, Luigi, 372  
 Bjorken, James D., 216, 226, 258, 298–300  
 Blankenbecler, R., 199, 230  
 Blatt, J. M., 284  
 Bloor, David, xvi  
 Bludman, Sidney A., 203, 206–207, 242, 245, 262–263  
 Bogoliubov, N. N., 250, 252, 284  
 Bohm, David, xiii, 270  
 Bohr, Niels, 107, 110–111, 114–116, 121, 123, 128–130, 133–134, 158, 348, 358  
 Boltzmann, Ludwig, 41–42  
 Bopp, Fritz, 162, 169  
 Born, Max, 15, 70, 116–118, 121, 126, 128–132, 134–135, 137, 139, 141, 143, 156, 365  
 Borrelli, Arianna, 285
- Boscovich, Roger, 22–23, 27  
 Bose, Satyendra, 119  
 Bouchiat, C., 294  
 Boulware, D., 267  
 Bourbaki, Nicholas, 345  
 Boyle, Robert, xvii, 21–22, 24  
 Brandt, R. A., 231–232  
 Brans, C. H., 76  
 Braunbeck, W., 168  
 Bridgeman, P. W., 124  
 Bromberg, Joan, 151  
 Brout, R., 255–256, 265, 286  
 Brown, Laurie M., xviii, 20, 231, 283  
 Bucella, F., 231  
 Buchwald, Jed, xix  
 Buckingham, M. J., 284  
 Burt, E. A., xvi  
 Butterfield, Jeremy, xviii
- Cabibbo, Nicola, 206  
 Callan, Curt G., 216, 222, 258–260  
 Cantor, G. N., 19  
 Cao, Tian Yu, 86, 231, 288, 349  
 Capra, F., 230  
 Carazzone, J., 328  
 Carnap, Rudolf, 338–339, 345  
 Cartan, Elie, 94, 244, 311  
 Cassidy, D. C., 283  
 Cassirer, Ernst, xiv, 9  
 Castillejo, L., 229  
 Cauchy, A. L., 25  
 Chadwick, James, 157–158  
 Chambers, R. G., 238, 270  
 Chandler, C., 230  
 Chandrasekhar, Subrahmanyan, 99, 101  
 Charap, J. M., 230  
 Chew, G. F., 186, 189, 193, 195–198, 227, 230, 260, 267, 296, 299  
 Cho, Y. M., 245  
 Chomsky, Noam, 345  
 Christoffel, E. B., 372  
 Clifford, William, 33, 371

- Cohen, Robert S., xviii–xix  
 Coleman, Sidney, xviii, 222, 226, 230, 258, 261, 293  
 Collins, J. C., 75  
 Collins, P. D. B., 189, 230  
 Compton, Arthur Holly, 115  
 Cook, L. F., 230  
 Cooper, Leon N., 249  
 Copernicus, Nicolaus, xvii, 3, 7  
 Coster, J., 230  
 Coulomb, C. A., 26  
 Crewther, Rodney, 303  
 Curie, Pierre, 247  
 Cushing, James T., xviii, 229  
 Cutkosky, R. E., 230
- Dalitz, Richard, 229, 295  
 Dancoff, Sidney, 17, 168–170, 172  
 Daniel, M., 319  
 Davisson, Clinton, 120  
 de Broglie, Louis, 95, 113, 118, 120–121, 128–129, 133, 138  
 de Sitter, W., 68, 70–74, 76  
 Debieme, André, 111  
 Debye, Peter, 112, 115, 120, 136–137  
 Descartes, René, xiii, xvii, 5, 7, 9, 21–24, 285  
 DeWitt, Bryce S., 264–266, 292  
 Dicke, R. H., 76  
 Dirac vacuum, 152  
 Dirac, Paul A. M., 3, 14, 16–17, 122–123, 132, 134–136, 138–139, 141–145, 147–150, 156–157, 159, 164, 166–168, 177, 179–180, 184, 216, 252, 261, 270, 272–273, 285, 315, 358, 365  
 Doran, C., 314  
 Duane, W., 115  
 Dürr, H. P., 283  
 Dyson, Freeman J., 176–178, 187–188, 190, 193, 199, 222–224, 226, 240, 245
- Earman, John, xiv, 76, 104, 286  
 Eddington, Arthur, 14, 74, 92–93, 98, 101, 320  
 Ehrenfest, Paul, 112, 119, 133, 136–137  
 Einstein, Albert, xiii, 3, 13, 37, 39, 41, 43, 45–46, 48–49, 51–54, 56, 78, 81, 82, 111–114, 116, 118–121, 129, 136–137, 143, 156, 237, 285, 313, 320, 339, 342, 345, 355, 371  
 Ellis, George, 103  
 Elsässer, Walter, 120  
 Engel, F., 247  
 Engler, F. O., 20  
 Englert, F., 255–256, 265, 286  
 Essam, J. W., 224, 232
- Faddeev, L. D., 265, 267, 269, 292  
 Faraday, Michael, 13, 23, 26–30, 37, 80, 155  
 Feldman, David, 186, 231  
 Fermi, Enrico, 136, 142–143, 153, 157, 159, 186, 203  
 Feyerabend, P., 355
- Feynman, Richard P., 20, 170, 175–176, 179, 203, 205, 207, 235, 259, 262–265, 292, 313, 324  
 Fierz, Markus, 168  
 Fine, Arthur, xiv  
 Finkelstein, David, 99  
 Fisher, Michael E., xviii, 222, 224, 323  
 Fitzgerald, G. E., 32–33  
 Fock, Vladimir, 237  
 Forman, Paul, xv  
 Fourier, Joseph, 28, 141  
 Fradkin, E. S., 267–269  
 Frautschi, S., 195–197, 230  
 French, Steven, 348  
 Frenkel, Yakov, 162–163  
 Fresnel, Augustin, 25–26, 36, 46, 115, 347  
 Friedman, Alexander, 72, 74, 217  
 Friedman, Michael, 55, 239, 244, 311, 351, 362–363  
 Fritzsche, Harald, 261, 295, 302–304, 306  
 Fubini, S., 208, 212, 230, 285, 298  
 Fukuda, H., 232  
 Furlan, G., 212, 298  
 Furry, Wendell, 20, 152, 166, 168
- Galilei, Galileo, 7  
 Gasiorowicz, S. G., 188  
 Gassendi, Pierre, 21  
 Gatto, R., 231  
 Gauss, C. F., 31, 58, 84, 369  
 Gell-Mann, Murray, 188, 193–194, 197–198, 203, 205–207, 209–213, 222–224, 226, 243, 260–261, 283, 291, 294–295, 297, 301–303, 306–308  
 Georgi, Howard, xviii, 309, 331  
 Gershtein, S. S., 203  
 Gerstein, I., 203, 221  
 Giedymin, Jerzy, 48, 55  
 Gilbert, W., 285  
 Ginzburg, V. L., 248  
 Glashow, Sheldon L., xviii, 242, 245–246, 263, 283, 292–293, 309  
 Glauser, R. J., 263  
 Goldberger, Marvin L., 193–195, 207, 230, 296  
 Goldstone, Jeffrey, 247, 253–255, 257, 274, 283, 327  
 Goto, T., 215  
 Green, M. B., 25  
 Greenberg, Oscar, 303  
 Gross, David, xviii, 19, 216, 258, 260–261, 282, 287, 294, 305–306, 330, 333  
 Grossmann, Marcel, 56, 58–59, 66, 86  
 Grünbaum, Adolf, xiv, 104  
 Gull, S., 314  
 Gulmanelli, Paolo, 245  
 Guralnik, G. S., 285–286  
 Gürsey, Feza, 207, 296
- Haag, P. W., 155  
 Haag, Rudolf, 198, 232, 276

424

*Name Index*

- Haas, Arthur, 109–110  
Hagen, Carl, 286  
Hamilton, William Rowan, 44  
Hamprecht, B., 231  
Han, Moo-Young, 297  
Hanson, N. R., 338  
Harman, Peter, xviii  
Harré, Rom, 20  
Hawking, Stephen W., 3, 97, 102–104, 318  
Hawking, Stephen W., 75  
Hegel, G. W. F., xiii, 30  
Hehl, F. W., 311, 314  
Hehler, Walter, 157  
Heilbron, John, 27  
Heimann, Peter, 24  
Heisenberg, Werner, xiii, 15, 17, 107, 117–118, 121–123, 128, 130–132, 134, 136, 138, 142, 156–159, 163, 167, 193, 197, 211, 227, 247–249, 252–253, 283, 348, 358  
Heitler, Walter, 187  
Helmholtz, H. L. F., 27–28  
Hertz, Heinrich, 33, 35, 42, 156  
Herzberg, Gerhard, 157  
Hesse, Mary B., xviii, 341–343, 362  
Hessenberg, Werner, 90  
Hibbs, R. G., 20  
Hiebert, Erwin N., xix  
Higgs, P. W., 256  
Hilbert, David, 89–91, 105, 190  
Hodge, M. J. S., 19  
Hoffmann, Banesh, 43, 86, 95, 187  
Holton, Gerald, xiv, xix, 55  
Houard, J. C., 229  
Houtappel, R. M. F., 283  
Hume, David, 22, 41–42  
Hurst, C. A., 188  
Huygens, Christian, 7, 22
- Iagolnitzer, D., 230  
Iliopoulos, J., 294  
Imamura, I., 215  
Infeld, L., 43, 86  
Isham, Chris, 318  
Ito, D., 174  
Iwanenko, D., 157–158, 160
- Jackiw, Roman, xviii, 215–218, 220–222, 273, 286, 294  
Jaffe, Arthur, 181, 188, 334  
James, William, 10  
Jammer, Max, 130–131, 181  
Johnson, George, 304  
Johnson, Kenneth, xviii, 215–216, 218, 220–221, 224–225  
Jona-Lasinio, G., 247, 249, 284  
Jordan, Pascual, 14, 16–17, 129, 131–132, 134–135, 138–139, 142–143, 145, 147, 149, 156–157, 159, 184
- Jost, Res, 139, 141, 143, 147, 193, 240, 245  
Jouvet, B., 229
- Kadanoff, Leo P., xviii, 222, 225, 232, 323  
Källen, Gunnar, 188  
Kaluza, Theodor, 94, 320  
Kamefuchi, S., 186, 245, 263  
Kant, Immanuel, xiii, 23–24, 30, 44, 338, 341–342, 351  
Karaca, Koray, 286  
Kastrup, H. A., 232  
Kawabe, R., 176  
Kemmer, Nicholas, 158  
Kepler, Johannes, 3, 7–8, 21, 356  
Kern, K., 293  
Kerr, K., 101  
Kibble, T. W. B., 244–245, 286, 314  
Kibble, T.W. B., 244  
Kinoshita, Toichiro, 170  
Kirchhoff, Gustav, 42  
Klein, 147  
Klein, Felix, 50, 320, 372  
Klein, Martin, xiv  
Klein, Oskar, 95, 131, 136, 142, 147, 185, 239  
Kline, M., 55  
Koba, Z., 170, 174  
Koester, D., 293  
Kogut, J., 289  
Komar, A., 245, 263, 292  
Koyré, Alexandre, xvi  
Kramers, Hendric, 115–117, 129–130, 168, 189  
Kretschmann, Eric, 63, 66, 311  
Kronig, R., 229  
Kruskal, Martin, 103  
Kuhn, Thomas, xi, xiv–xvi, 11, 19, 318, 338–341, 344, 350, 355, 364, 366  
Kunsmann, Charles, 120
- Ladyman, James, 348  
Lagrange, Joseph-Louis, 44, 55  
Lamb, Willis, 171  
Landau, Lev D., 188–189, 192, 197, 223, 226, 228, 248, 296, 331  
Laplace, Pierre Simon, 25, 100  
Larmor, Joseph, 32–35  
Lasenby, A., 314  
Laudan, Larry, 341  
Lee, B. W., 269, 290  
Lee, T. D., 263, 292  
Lee, Y. K., 205  
Lehmann, H., 192, 229  
Leibniz, G. W., 5, 7–9, 11, 22, 24, 30, 370  
Lemaître, Georges, 74, 98–99  
Lepage, G. P., 331  
Leutwyler, Heinrich, 301, 306  
Leve-Strauss, Claude, 345  
Levi-Civita, T., 58, 90–91, 321, 372

- Levy, Maurice, 208  
 Lewandowski, J., 313, 316  
 Lewis, H. A., 171–172, 174, 176  
 Lie, Marius Sophus, 45, 247  
 Locke, John, 22  
 Lodge, Oliver Joseph, 32–33  
 London, Fritz, 238  
 Lorentz, Hendric A., xvii, 35–37, 46–49, 80, 110, 113–114, 128  
 Low, Francis E., xviii, 188, 195, 198, 215–216, 218, 221–224  
 Ludwig, G., 126  
 Lurié, V., 231
- Mach, Ernst, 4, 37, 41–43, 45, 64–68, 70–72, 79–80, 85, 89, 104  
 Mack, G., 232  
 Majorana, Ettore, 158  
 Mandelstam, Stanley, 194–195, 230, 266  
 Mandula, J., 230  
 Marshak, Robert Eugene, 203  
 Massimi, M., 340  
 Matsubara, T., 284  
 Matthews, P. T., 263  
 Maxwell, J. C., 10, 26, 28–32, 35, 37, 39, 80, 85, 137, 155, 285  
 May, R. M., 284  
 Mayer, Julius, 9, 31–32  
 McGuire, J. E., 24  
 Melosh, Jay, 303  
 Merton, Robert, 2  
 Merz, J. T., 42  
 Meyer, Ph., 294  
 Meyerson, Emile, 9  
 Michell, John., 100  
 Mie, Gustav, 89  
 Miller, Arthur, 55  
 Mills, Robert L., 206, 240–241, 292, 297, 304  
 Minkowski, Hermann, 46, 50–51, 57–58, 278  
 Minkowski, Peter, 245  
 Misner, C. W., 95  
 Mitter, H., 283  
 Miyamoto, Y., 232  
 Mo, L. W., 205  
 Moffatt, Henry K., xviii  
 More, Henry, 21
- Nagel, Ernest, 337, 357, 361  
 Nambu, Yoichiro, xviii, 192, 195, 204, 208, 231, 243, 247, 249–253, 274, 276, 283, 285, 295, 297, 299, 304, 360  
 Navier, C.L., 25  
 Ne’eman, Yuval, 206  
 Neumann, Carl, 10, 30–32  
 Newman, J. R., 371  
 Newton, Isaac, xvii, 7, 9–10, 21–25, 29, 64–65, 79, 104, 285, 342, 345, 356
- Nishijima, Kazuhiko, 198, 232, 276  
 Nishina, Yoshio, 161  
 Noether, E., 202  
 Norton, J., 76
- Okubo, S., 231  
 Olive, D. I., 230  
 Oppenheimer, Robert, 20, 99, 101, 150, 152, 163, 166, 168, 243  
 Ostwald, Helm, 42  
 Ostwald, Wilhelm, 41
- Pais, Abraham, 162, 170, 172, 239–240, 246, 290–291, 293, 296, 306  
 Parisi, Giorgio, 260  
 Parsons, Talcott, 345  
 Pati, Jogesh, 309  
 Pauli, Wolfgang, 20, 121, 136, 142, 152, 156, 158, 163, 168, 170, 176, 227, 238–241, 246, 283, 297, 304, 324, 374  
 Pavelle, R., 321  
 Peierls, Rudolf, 167  
 Penrose, Roger, 3, 96–97, 102–104, 318  
 Perez, A., 316  
 Perring, Francis, 158  
 Petermann, A., 187–188, 223  
 Piaget, Jean, 345  
 Pickering, Andrew, xvi, 306  
 Pines, David, 249, 284  
 Planck, Max, 41, 109–112  
 Planck, Max K. E. L., 44, 133, 136  
 Poincaré, Henri, 37, 41, 44–48, 50, 55, 83, 104, 162, 247, 345, 347  
 Poisson, S. D., 25–27  
 Polchinski, Joseph, xviii  
 Politzer, H. David, 261  
 Polkinghorne, John C., 207, 229  
 Polyakov, A. M., 273, 321  
 Pomeranchuk, I. Y., 188  
 Popov, V. N., 265, 269, 292  
 Popper, Karl, xiv  
 Post, Heinz R., 337, 357, 361  
 Preparata, G., 216  
 Putnam, Hilary, xvi, 343, 361
- Quinn, Helen, 309
- Radicati, L. A., 283, 296  
 Raine, D. J., 75–76  
 Ramsauer, Carl, 120  
 Ramsey, Frank P., 349  
 Rasetti, Franco, 157  
 Rechenberg, Helmut, 283  
 Redhead, Michael, xiv, xviii, 17, 19, 147, 347  
 Regge, Tullio, 195–196  
 Retherford, Robert, 171  
 Ricci, Gregorio, 58, 372

- Rickaysen, J. G., 284  
Riemann, Bernhard, 31–33, 58, 84–86, 91, 318, 369–371  
Rindler  
  Wolfgang, 75  
Rindler, Wolfgang, 75, 99  
Rivier, D., 176  
Robertson, Howard, 99  
Rohrlich, Fritz, 162  
Rosenberg, L., 219  
Rosenfeld, Leon, 145  
Russell, Bertrand, xiii, 345–346  
Rutherford, Ernest, 295, 348, 358
- Sakata, Shoichi, 162, 170, 172, 176  
Sakita, B., 296  
Sakurai, J. J., 203, 243, 245–246, 297, 304  
Salam, Abdus, 242, 245, 254, 262–263, 292–293, 309  
Schafroth, Max R., 284  
Schelling, F. W. J., 30  
Schlick, Moritz, xiv, 20, 346  
Schlieder, S., 283  
Schmidt, B. G., 102  
Schrieffer, J. Robert, 249, 284  
Schrödinger, Erwin, 15–16, 105, 115, 118, 120–121, 125–129, 131, 133, 135, 138–139, 285, 320  
Schwarzschild, Karl, 67  
Schweber, Silvan S., xviii–xix, 181, 187, 252  
Schwinger, Julian, 20, 152–153, 168, 171–173, 176, 179, 189–190, 203, 207, 214–215, 241–243, 245, 254–255, 263, 304–305, 324–325, 330, 333  
Seelig, Carl, 55  
Sellars, Wilfrid, 337, 341  
Serber, R., 169  
Shaw, Ronald, 241  
Shimony, Abner, xiv, xviii, 6  
Simha, Evelyn, xix  
Slater, John C., 129–130, 143  
Slater, John Clarke, 115  
Slavnov, A., 267, 287  
Sneed, Joseph, 348  
Snyder, Hartland, 99, 101  
Sommerfeld, Arnold, 110, 283  
Speziali, P., 76  
Stachel, John, xiv, xviii, 57, 75–76, 104  
Stapp, H. P., 230  
Stark, Johannes, 111, 114  
Stegmuller, Wolfgang, 348  
Stein, Howard, xiv, 104  
Steinberger, Jack, 217  
Stokes, George, 25, 28, 33  
Straumann, Norbert, 245  
Strawson, P.F., 19  
Streater, R. F., 229  
Stueckelberg, Ernest C., 162, 176, 187, 223  
Sudarshan, E. C. G., 203  
Sullivan, D., 293
- Susskind, Leonard, 254, 289, 301  
Sutherland, D. G., 210, 215, 217, 220  
Symanzik, Kurt, 192, 222, 229, 258–259, 328
- Takahashi, Y., 268  
Tamm, Igor, 160  
Taylor, John C., 207–208, 287, 309  
Thirring, W., 188, 193–194, 208, 211, 285  
Thiry, M., 265  
Thompson, J. J., 348, 358  
Thomson, J. J., 26, 33, 35, 39, 110, 162, 295  
Thomson, William, 25, 27–29, 32–33  
't Hooft, Gerardus, xviii, 220, 228, 235, 258, 260–261, 268–269, 273, 292–293, 305, 308, 321  
Thorne, K. S., 95  
Toll, J., 193  
Tomonaga, Sin-itiro, 169–170, 173–174, 176, 178–179, 324  
Torretti, Roberto, 55  
Toulmin, Stephen, 338  
Touschek, Bruno, 207  
Treiman, Sam, 207, 213, 266, 291  
Tyutin, I. V., 267, 269
- Umezawa, H., 176, 245, 263  
Utiyama, Ryoyu, 241, 244, 314
- Valatin, J. G., 232  
van Dam, H., 267  
Van der Waerden, B. L., 118  
van Fraassen, Bas, 345  
Vaughn, M. T., 229  
Veblen, Oswald, 95  
Velo, G., 229  
Veltman, Martinus, xviii, 210, 215, 217, 220, 228, 235, 243, 261, 266–269, 292, 297, 304–305  
Veneziano, G., 231  
Viallet, C. M., 319  
Vidotto, F., 313  
Villars, Felix, 170, 176, 324
- Waller, Ivar, 163  
Ward, J. C., 242, 245, 263, 268  
Weber, W. E., 26  
Weinberg, E., 226  
Weinberg, Steven, xviii, 19, 151–152, 190, 199–200, 214, 226, 242, 254, 256, 262, 276, 279–280, 292–293, 309, 323, 328, 333  
Weinmann, E., 168  
Weisberger, William, 213  
Weisskopf, Victor F., 17, 148, 152, 159, 164–165, 171, 185, 285  
Welton, Theodore, 148  
Wentzel, Gregor, 139, 152, 164, 283  
Wess, Julius, 220, 232

*Name Index*

427

- Weyl, Hermann, 14, 90–92, 94, 98, 105, 150, 191, 235, 237–238, 241  
 Wheeler, John, 94–97, 100, 311  
 Whewell, William, 5  
 White, D. H., 293  
 Whitehead, A. N., 9–10  
 Whittaker, E. T., 34, 46  
 Widom, B., 222, 224–225  
 Wien, Wilhelm, 109, 111, 124  
 Wightman, Arthur S., xviii, 155, 188, 191, 229, 334  
 Wigner, Eugene P., 16, 131, 136, 142, 145, 147, 156–157, 185, 283  
 Wilczek, Frank, 261, 287, 306  
 Wilson, Kenneth G., xviii, 215, 221–222, 224–226, 232, 258–259, 289, 301, 305, 323  
 Wimsatt, William, 354  
 Wood, David, xviii  
 Worrall, J., 347  
 Wu, C. S., 205  
 Wu, T. T., 319, 321  
 Wu, Tai Tsun, xviii  
 Yamada, E., 176  
 Yamazaki, K., 283  
 Yang, Chen Ning, xviii, 206, 240–241, 263, 270, 288, 292, 297, 304, 319, 321  
 Yates, Frances, 2  
 Young, Ken, 303  
 Young, Thomas, 25–26  
 Yukawa, Hideki, 159–161, 176, 358  
 Zachariasen, F., 230  
 Zahar, Elie, 48, 55  
 Zel'dovich, Y. B., 203  
 Zemach, C., 230  
 Zimmermann, Wolfhart, 192, 198, 229, 232, 276  
 Zumino, Bruno, 220  
 Zweig, George, 291, 294–295, 303  
 Zwicky, Fritz, 99, 101

## Subject Index

- acausality, xv
- action
  - contact, 22, 24
  - electric, 29
  - electromagnetic, 28, 30, 32
  - electrostatic, 28
  - magnetic, 29
  - quantum of, 95, 110
  - transmission of, 25, 27, 34
- ad hoc* device, 25, 27–28, 174, 276, 281
- adiabatic hypothesis, 222
- Adler–Weisberger relation, 243, 266
- Aharonov–Bohm effect, 6, 238, 270–272, 321
- analyticity, 193–194, 196, 201, 204, 229
- annihilation, 14
  - of the quanta, 17
- anomaly, 210, 218–220, 291, 294
  - Adler–Bell–Jackiw, 221, 271, 302
  - cancellation, 232
  - chiral, 187, 272, 293
  - gauge, 202
  - scale, 222, 227, 298, 301
- anticommutation relations, 184
- apriorism, 350
- Archimedeanism, 6
- asymmetry
  - baryon, 310
  - matter–antimatter, 310
- asymptotic freedom, 189, 228, 233, 257–258, 260–261, 282, 287, 291, 306
- asymptotic safety, 323
- atomism, 6, 179–180, 331–332
- attraction
  - of Galileo, 7
- axiomatization, 192
  
- background independent (BI) theory, 313, 315
- Balmer formula, 111
- Bardeen–Bogoliubov theory, 251
- baryon number, 239, 291, 305, 310
- BCS theory, 249, 252, 284–285
  
- BCS–Bogoliubov theory, 250
- Bell inequality, 6
- beta decay, 158, 186, 193, 203
  - Fermi’s theory of, 157, 159–160
  - muon, 205
  - nuclear, 157, 161, 205
  - pion, 205
- beta radioactivity, 158
- beyond the standard model. *See* BSM
- Bianchi identity, 105
- big bang, 14, 103, 360
- Bjorken scaling, 233, 258–260, 287, 291, 299–300
- Bjorken’s inequality, 300
- Bjorken–Johnson–Low (BJL) limit, 216, 302
- black hole, 14, 78, 97, 99–101, 103–105, 182, 360
- blackbody radiation, 113, 137
- Bogoliubov–Valatin equations, 250–251
- Bohr’s frequency condition, 124, 163
- bootstrap hypothesis, 180, 193, 195–198, 227, 229, 295–299, 303, 305
- Born approximation, 209
- boson
  - axial vector, 243
  - gauge, 256, 258
  - massive, 292
  - vector, 243
- bound state, 195–196, 231, 250–251, 255, 285
- boundary condition, 11, 68, 70–72, 75, 121, 126, 194, 272
  - Minkowskian, 68
- Brans–Dicke theory, 68
- BSM, 288
  
- Cabibbo angle, 309
- Cabibbo model, 206
- Callan–Symanzik equations, 258
- Casimir effect, 349
- Cauchy–Riemann formulae, 195, 296
- causality, xvii, 1, 6–7, 21–23, 62, 102, 193, 211, 230, 296

- micro-, 296
- principle of, 5
- CF. *See* framework, constitutive
- charge, 10, 17
  - bare, 222–223, 226
  - density, 127, 165–166, 169
  - effective, 260
  - operator, 211
- charge algebra, 231, 299
- charm, 307
- charmonium, 294, 307
- Chew–Low formulation, 195
- chirality conservation, 231
- Christoffel symbol, 90, 371
- circumference, critical, 99–101
- Clifford algebra, 315
- collapse, gravitational, 99, 102
- color confinement, 257, 262, 282
- colour, 303–304, 359, 363
  - octet, 305–306
- colour confinement, 307
- commutation relations, 109, 118, 122, 155, 164, 174, 184, 190–191, 231
  - canonical, 206, 210, 215, 225, 301
  - equal-time, 210, 212–216, 222, 231, 297, 301, 318
- commutator, 211, 216, 218
  - algebra, 211
    - anomalous, 215–216
    - canonical, 204, 211, 216
    - current, 201, 243, 302
    - equal time, 302
    - operator, 302
    - space–time, 231
- complementarity, 121, 123
- composite model, 296
- Compton’s experiment, 115, 119, 136
- conserved vector current (CVC) hypothesis. See* CVC hypothesis
- constructivism, xvi, 12, 86, 341
- continuity, 11, 19, 22, 26–28
  - equation, 31
  - principle of, 5, 32
- continuity, ontological, 355–356, 361
- continuity, referential, 344, 347–348, 355, 358, 361
- conventionalism, 4, 46
- convergence, 343, 365
- convergence condition, 176
- convergence factor, 175
- Cooper pairing, 249
- correspondence principle, 116–118, 337, 356
- cosmological constant, 69, 71, 73–74, 275
- cosmological model, 57, 71–72, 74–75
- cosmology, 2–3, 68–69, 103, 105, 310, 339
  - relativistic, 70, 74
- Coulomb force, 92, 162, 169, 250
- coupling, 156, 278, 280–281
  - axial, 207
  - axial vector, 262
    - bare, 282
    - effective, 260–261, 282
    - electroweak, 309
    - Fermi, 256, 288
    - gauge, 256–257, 263, 278, 280, 309
    - local, 17, 107, 153, 155, 162, 178, 185, 317
    - pseudoscalar, 207
    - scalar, 280
    - strong, 262, 309
    - vector, 262
    - weak, 293, 309
  - coupling constant, 180, 186, 195, 204–205, 207, 209, 218, 221, 226, 239, 254, 257–258, 288, 328
  - coupling, pseudoscalar, 186
  - coupling-transmutation, 281
  - covariance, 239, 265
    - general, 60, 62–63, 66, 79–80, 82, 105, 310, 327, 355–356
    - Lorentz, 264, 292
  - CP violation, 187, 257
  - CPT invariance, 210
  - creation
    - of the quanta, 17
  - critical exponents, 224
  - critical point, 225
  - cross section, 213, 259, 298, 302
    - scattering, 168–169, 174
  - current, 202
    - axial, 207–208, 212
    - axial vector, 206, 212, 215, 217, 220, 232, 243, 284, 298, 302
    - baryonic, 203, 243
    - charged, 205–206, 263, 293
    - chiral, 293
    - electromagnetic, 203, 205–206, 213, 242
    - hadron, 200, 203, 299
    - hypercharge, 203, 243
    - isoscalar, 206
    - isospin, 203, 243
    - isotopic lowering, 205
    - isotopic raising, 205
    - isovector, 205–206
    - leptonic, 299
    - local, 301
    - neutral, 228, 242, 276, 294
    - operator, 201
    - scale, 226
    - strangeness-changing, 206
    - strangeness-conserving, 206
    - symmetry, 202
    - U(1) symmetry, 203
    - vector, 203, 205, 207, 212, 215, 243, 302
    - weak, 203, 205, 207, 212–213, 230, 242, 294
    - weak axial vector, 204
    - weak vector, 206



430

*Subject Index*

- current algebra, 221, 224, 231–232, 243, 246, 266,  
 296–298, 300–301, 303  
 canonical, 302  
 light-cone, 259, 298, 301, 303–304  
 local, 299  
 current conservation, 175  
 current density, 167  
 hadronic, 299  
 curvature, 14, 72, 86, 90, 103, 244, 314, 317, 321,  
 371  
 cutoff, 172, 175, 216, 269–270, 323–326, 329  
 CVC hypothesis, 205, 209, 211, 230, 297
- D'Alembert's equation, 169  
 de Sitter model, 74, 99  
 de Sitter solution, 97–98  
 decoupling theorem, 326, 328, 329, 332  
 diffeomorphism invariance, 315  
 diffraction  
 of electrons, 118, 131  
 dimension  
 anomalous, 222, 227, 233, 260  
 canonical, 260  
 scale, 222, 225, 232, 260  
 dimensionality, 270, 288, 323  
 Dirac equation, 152, 284  
 Dirac sea, 284  
 Dirac vacuum, 17, 147, 153, 164–166  
 Dirac's multi-time theory, 164  
 dispersion relation, 186, 192, 194, 196, 198, 204,  
 206–208, 227, 296  
 double, 195–196  
 Kramers', 134  
 Mandelstam's double, 229  
 relativistic, 194  
 divergence, 171, 204, 212, 217, 220, 226, 313  
 anomalous, 302  
 infrared, 266  
 operator, 232  
 primitive, 262  
 self-energy, 170  
 ultraviolet, 191  
 divergence equations, 244  
 dual model, 180, 230  
 dualism, 87  
 Duhem–Quine thesis, xv, 342  
 dynamics  
 internal, 277, 279, 281  
 non-linear, 279
- EBH mechanism, xi  
 eigenfunction, 135, 166  
 eigenvalue, 135–136  
 eigenvalue condition, 226  
 elastic scattering, 196, 231  
 electrodynamics, 31, 37, 39, 47–49, 119, 162, 355–356  
 Maxwell's, 112  
 electromagnetic theory, 6  
 electromagnetism, 14, 26–28, 32, 41–42, 80, 92–94,  
 184, 186, 201, 227–228, 237, 239, 242, 244,  
 271, 303, 308  
 SO(2), 241  
 electron–neutrino pair, 160  
 electron–photon system, 278  
 electron–positron pair, 147, 157, 173, 261  
 annihilation, 298, 302–303  
 electron–proton model, 157  
 of the nucleus, 157  
 electron–proton scattering, 204  
 deep inelastic, 258  
 electroproduction, 213, 300  
 electroweak theory, 291, 294, 311, 329  
 emergence  
 heterogeneous, 360  
 ontic, 354  
 ontological, 357, 359–360  
 emergentism, 334  
 empiricism, 337  
 Mach's, 43  
 energeticism, 10, 32, 42  
 energy, 5, 7–8, 10, 14–15, 17, 30  
 density, 72–73, 102, 131, 211  
 effective, 294  
 fluctuation, 119, 165  
 gap, 249–250, 253  
 kinetic, 28  
 potential, 10, 30, 32  
 quanta, 112, 114, 128, 136, 138, 141–142, 148–149  
 scale, 226, 329–330, 360  
 spectrum, 249  
 state, 136  
 tensor, 221  
 energy gap, 285  
 Englert–Brout–Higgs mechanism, 235, 242, 246,  
 256–257, 275–279, 281–282, 286, 291–293  
 entities, xvii, 4, 8–9, 277, 295, 345, 358, 361  
 action of, 5  
 elementary, xvii  
 fundamental, 5, 344–345, 347, 349–350, 352–354,  
 357, 359, 362, 366  
 holistic, 278  
 hypothetical, 7, 42, 348, 353  
 physical, 18, 279, 281, 308, 344, 349–350, 353  
 primary, 18, 277  
 quantum, 313, 340, 359  
 real, 5  
 theoretical, xvi, 338, 353  
 transcendental, 2  
 unobservable, xiv, 3–4, 7–8, 200, 202, 345–346,  
 353, 362, 364  
 EP. *See* equivalence principle  
 epiphenomenon, 5, 8–9, 11, 18, 141, 144, 357–358  
 epistemology, 42, 45, 48, 125, 346  
 equation, electromagnetic, 37

- equivalence principle, 52–54, 56–58, 64, 66, 68, 80–81, 182, 311  
 ether, xvii, 9, 23–25, 27–28, 30–31, 33–34, 36, 46, 48  
   continuous, 39  
   elastic, 35  
   gravitational, 81  
   Lorentz's, 36, 39, 46  
   lumiferous, 25–28  
   mechanical, xiv, 10–11, 28–29, 34–35, 39, 46  
   model, 151  
   non-mechanical, 33  
   Weber's, 32  
 Euler–Lagrange equations, 245  
 excitation, 151, 154, 226  
   bare, 297  
   collective, 231, 250, 284, 360  
   local, xii, 17, 153–155, 162, 178, 185, 189  
   massless, 278  
   quantum, 17  
 exorcism, 70  
 explanation  
   mechanical, 7, 22–23, 37  
   teleological, 7  
  
 FE. *See* entities, fundamental  
 Fermi sphere, 253  
 Fermi surface, 249  
 Fermi's theory  
   of weak interactions, 17, 159, 186–187, 329  
 Fermi-field model, 160  
 fermion, 96, 236  
   massive, 278  
 fermion system, 257, 275, 278  
 fermion, massive, 275  
 fermion, massless, 274  
 Feynman diagram, 17, 176, 194, 197, 199, 216, 219, 262–263  
 Feynman rule, 176, 263, 265–270, 287, 292  
 Feynman–Pauli–Villars scheme, 325  
 fiber bundle, 18, 236, 319–320, 322  
   theory, xi  
 field, xvii, 5, 10, 13–15, 30  
   amplitude, 145, 148, 150, 154  
   auxiliary, 170, 176, 218, 242  
   boson, 254  
   chiral, 232  
   classical, 10, 15  
   C-meson, 170, 174  
   cohesive force, 170  
   compensative, 174  
   Coriolis, 67  
   Coulomb, 164  
   electromagnetic, 10–11, 27, 29, 32, 34–37, 39, 46, 81, 85, 88, 91, 93, 95, 113, 136–137, 143, 145–146, 149, 151, 156, 163, 166, 169–170, 176, 184, 187, 238–239  
   electron-positron, 151, 156, 173  
   energy, 10, 29, 32, 34, 137–138, 148, 165  
   ether, 371  
   fermion, 15–16, 142, 144, 149, 156, 254, 309  
   force, 8, 31, 40, 155–156, 309  
   force-energy, 30, 32  
   gauge, xi, 18, 240, 242, 245, 255–257, 268, 275, 277, 281, 309, 313, 356  
   gravitational, 11, 13–14, 20, 39, 41, 56–57, 80–81, 87, 81, 85–88, 93–94, 97, 100–102, 104, 239, 241, 313, 339, 356, 359  
   local, 147, 155, 184–185, 189, 191–192, 218, 221, 301  
   matter, 309  
   metric, 56, 61–62, 102  
   numerical, 189  
   operator, 147–148, 151, 153–154, 184–185, 189–190, 192, 194, 215, 221, 225, 228, 232  
   oscillator, 16  
   quanta, xi, 16–17, 148, 156, 159–162, 185  
   radiation, 139, 141–142, 163, 171, 173, 175  
   scalar, 152, 242, 254–257, 265–266, 276–277, 279, 281, 287, 309  
   spinor, 96, 257, 285  
   substantial, 137, 146, 148, 355  
   vector, 114, 170, 239–240, 266, 279  
 field equation, 56–57, 85, 95, 97, 102, 146, 201, 241  
   gravitational, 13  
   vacuum, 88  
 field theory, xvii, 7, 10–11, 13, 16, 19–20, 26–27, 30, 34, 80, 146, 156, 159, 194, 197, 199, 226, 229, 249, 251, 254  
   anti-, 197, 227  
   axiomatic, xii, 188, 190–192, 227, 229, 315  
   classical, 39, 43  
   constructive, 188, 191–192, 229  
   effective, 190, 214, 236, 323, 328, 330–333  
   Einstein's, 89  
   electromagnetic, 29, 35, 89, 112  
   ether, 39  
   free, 259, 300, 302  
   gauge, 40, 107  
   global, 235  
   gravitational, 355  
   Lagrangian, 195  
   lattice, 224  
   light-cone, 301  
   local, 180, 190, 192, 201–202, 215–216, 218–220, 246, 260  
   local operator, xii, 189  
   nonlinear, 94, 247–248, 253, 273, 283  
   quark vector-gluon, 303–305  
   scalar, 246, 253  
   unified, 14, 69, 81–82, 84–85, 88, 93, 94, 247–248  
 fine structure, 97  
 fixed point, 225–226, 259, 282, 315, 323, 331  
   Gaussian, 226

- fixed point (cont.)  
 Wilson–Fisher, 227
- fixed pole, 229
- fluctuations, zero point, 148
- FO. *See* ontology, fundamental
- force, xvii, 7–9, 11, 22–24  
 active, 24  
 cohesive, 162  
 electrical, 31  
 electromagnetic, 10, 27, 228  
 electroweak, 236  
 gravitational, 85, 89, 101  
 Lorentz, 36, 38, 164  
 magnetic, 28  
 nuclear, 158, 235, 239–240, 244, 255, 257  
 strong, 236, 304  
 weak, 228, 311
- form factor, 201, 205, 208–209, 233, 299  
 axial, 213, 298  
 elastic, 299  
 electromagnetic, 204  
 inelastic, 299  
 vertex, 219  
 weak, 204
- Fourier expansion, 117, 134
- Fourier transformation, 16, 185
- four-line interactions, 159
- framework, constitutive, 339–341, 350–352, 363–364, 366
- framework, linguistic, 338–339
- Fraunhofer diffraction, 115
- free-field technique, 266–267
- frequency condition  
 Einstein–Bohr, 117
- functionalism, 10
- gamma decay, 295, 298, 302–303
- gauge  
 charge, 261  
 Coulomb, 254, 286  
 Feynman, 265  
 Landau, 265, 287  
 London, 249, 284  
 Lorentz, 285–286  
 unitary, 286–287
- gauge boson, 203, 235, 240–242, 245–246, 254–255, 257, 261–262, 265, 276, 279–280, 286, 293, 304, 308  
 massive, 255, 262, 276–277, 279, 281, 292, 294  
 massless, 276
- gauge covariance, 239
- gauge group, 200, 239, 270–272, 309  
 GL(4), 321  
 SU(2), 201, 203, 205, 239, 241, 248, 258, 273, 315, 321, 334, 374  
 SU(2) × U(1), 292, 311  
 SU(2) × U(1) × U(1), 243
- SU(2)<sub>T</sub>, 293
- SU(2)<sub>T</sub> × U(1)<sub>Y</sub>, 293
- SU(2)<sub>T</sub> × U(1)<sub>Y</sub> and SU(3)<sub>C</sub>, 309
- SU(3), 201, 206, 212, 231, 246, 291, 295, 334
- SU(3), colour, 295, 304–306
- gauge invariance, 17, 91–92, 175, 217–219, 227–228, 232, 235, 237–240, 242, 244, 249–252, 255, 257, 262, 264–266, 268–270, 272, 274, 283–284, 286–287, 292, 298, 305, 314–315, 319
- Abelian, 246
- flavour, 297
- local, 238, 241, 245
- gauge mode, Glashow’s, 278
- gauge principle, 235–239, 243–244, 275, 286, 290–291, 297, 304, 309–311, 314, 319, 365
- gauge quanta, massive, 275
- gauge structure, 95
- gauge theory, xiii, 6–7, 11, 14, 18, 181, 206, 232, 238, 241, 246, 254, 319  
 abelian, 261  
 nonabelian, xi, 161, 189, 203, 227–228, 233, 235, 237, 239–244, 246, 260–261, 264, 276, 313  
 quark-gluon interaction, 306  
 of gravity, 311–312, 314  
 SU(2), 240
- Gauss’s theory of two-dimensional surfaces, 58
- Gaussian coordinate systems, 54
- GC. *See* general covariance
- Gell-Mann–Low eigenvalue condition, 223
- generative entrenchment, 354
- geodesics, 102
- geometrization, 19, 56, 86, 319–320, 322, 357
- geometrodynamics, 96
- geometry, 14, 46, 50, 55, 78, 82, 86, 95, 102, 346  
 (chrono), 84–85  
 axiomatic, 83  
 differential, 96, 369  
 dynamic, 369–370  
 Eddington’s, 95, 320  
 Euclidean, 43–44, 56, 58, 78, 80, 83, 92, 104, 320, 370  
 external, 321  
 internal, 321  
 intrinsic, 369  
 Kaluza’s five-dimensional, 95  
 local, 369  
 Minkowskian, 78, 320  
 non-Euclidean, 43–44, 56, 58, 80, 351  
 projective, 95  
 quantum, 236, 316–317  
 Riemann’s, 90–93, 320, 370, 372  
 Weyl’s, 91–93  
 world, 91
- GFP. *See* programme, gauge field
- ghost field, 129, 268–269, 287  
 covariant, 276  
 Faddeev–Popov, 276, 287

- ghost particle, 265  
 DeWitt, 265  
 Faddeev-Popov, 265, 268  
 Glashow's model, 277, 281  
 gluon, 200, 233, 258, 261, 294–295, 297, 300–301, 304, 308  
 gluon confinement, 308  
 Gödel model, 75, 77  
 Goldberger–Treiman relation, 207–209  
 Goldstone boson, 253–255, 275, 280, 285–286, 327  
 Goldstone theorem, 254, 286  
 Goldstone's model, 274–276  
 Göttingen Society of Science, 31–32  
 gradient coupling model, 208  
 grand unification, 290  
 grand unified theory, 309, 312, 322, 329  
 graph  
   box, 221  
   irreducible, 177  
   pentagon, 221  
   reducible, 177  
   triangle, 216, 218–221, 232  
 gravitation, 14, 24, 31, 51, 56, 87–89, 93, 95, 101, 103, 114, 263, 267, 288, 317, 320  
 gravitino, 312  
 gravitization, 14  
 graviton, 288, 312, 316  
 gravity, 14, 24, 31, 56, 86, 90, 92, 103, 155, 236–237, 241, 244, 312, 321–322, 356  
   Descartes's vortex theory of, 22  
   Newton's theory of, 22  
   quantum, 317–318  
 Green's functions, 178, 188, 192, 216, 230, 268, 328  
 group  
   Abelian U(1), 242  
   chiral SU(2), 242  
   covariance, 239, 244  
   Galileo, 78  
   homotopy, 374  
   isospin, 249, 293  
   Lie, 241, 321, 374  
   Lorentz, 50, 55, 78, 314, 355  
     SO(1,3), 244  
     of transformation, 48, 50  
   Poincaré, 46, 51, 55, 244, 311, 314  
     P(1,3), 244  
   spin, 283  
   SU(2) × U(1), 242  
   SU(8), 312  
   super-Poincaré, 312  
   symmetry, 78, 202, 239, 241, 244, 297  
   transformation, 372  
   U(1), 201, 211, 273, 326, 374  
   U(1)<sub>Y</sub>, 293  
 GTR. *See* relativity, general theory of, *See* relativity, general theory of  
 Haag's theorem, xii, 190  
 hadron  
   dynamic model of, 196  
 hadronization, 300  
 Hamiltonian, 116, 118, 133–134, 140–141, 159, 172, 176–177, 200, 203, 237  
   density, 121  
   equation, 120  
   operator, 191  
 Hartree–Fock approximation, 166, 250–251  
 Hawking–Penrose singularity theorems, 103  
 heat radiation, laws of, 109  
 Hegelian closure, 290  
 Heisenberg's model, 158, 161, 252  
 Higgs boson, 257, 275–277, 281, 309–310  
 Higgs mechanism, 250, 269, 289  
 Hilbert space, 96, 154, 184, 314, 316  
 historicism, 351, 362  
 holonomies, 315  
 homotopy, 374  
 horizon, 78, 97–100, 103–104  
   event, 99  
   particle, 99  
 Hubble's law, 74–75  
 hypercharge, 214  
   weak, 293  
 identity, dynamical, 278–279, 281  
 impenetrability, 99  
 incommensurability, 19, 318, 339, 342, 344, 349, 354, 364  
 inertia, 68  
   relativity of, 70  
 infinite momentum frame, 213, 298, 300–301  
 instanton, 274, 321  
 instrumentalist, xiv, 277, 307  
 interaction, 155, 212  
   electromagnetic, 11, 14, 161–162, 186, 200, 202–205, 210, 220, 237–238, 241–242, 248, 263, 292  
   electroweak, 278, 323  
   fundamental, xi, 17, 78, 86, 94, 107, 147, 161, 181, 235, 290, 292, 308, 317, 321, 354  
   gravitational, 85–88, 187, 241, 288, 310, 320  
   local, 271  
   strong, 14, 157, 161, 197, 199–200, 203–205, 207, 209, 211, 213–214, 221, 225, 227–228, 230, 241–243, 260, 262, 297, 299–300, 304, 306, 323  
   weak, 14, 157, 159, 161, 187, 200, 202–205, 207, 209–210, 212, 228, 241–242, 246, 248, 262–263, 292, 299, 308  
 intermediate-vector-boson theory  
   of the weak interaction, 203  
 invariance principle, 107  
 invariance, rotational, 283

434

*Subject Index*

- irrelevance of the theorem, 254  
 isomorphism, 97  
 isospin, 158, 203, 210, 214, 241–242, 248, 283
- J/ψ* particle, 307
- Kaluza–Klein theory, xi, 18, 239–240, 245, 320–321, 356  
 Kantianism, 43, 45, 338  
 Klein–Gordon equation, 152
- Lagrangian, 34, 179, 187, 192, 201, 210–212, 214, 219, 221–222, 243, 245, 252, 263, 267, 269, 283, 306  
   analytic dynamics, 7  
   density, 241, 253  
   effective, 271  
   model, 229  
   variational principle, 29
- Lamb shift, 148  
 Landau ghost, 189  
 Landau graph, 197  
 Landau–Ginzburg theory, 285  
 Lee model, 216, 229  
 lepton–hadron scattering  
   deep inelastic, 179, 233  
 lepton–parton scattering, elastic, 259  
 Levi–Civita connection, 315  
 LHC, 276  
 Lie algebra, 206, 211
- light  
   electromagnetic theory of, 31  
   quanta, 111–115, 117, 119, 126, 129, 136, 138–142, 148–150, 153, 159, 173  
   wave theory of, 26
- light-cone, 155, 221, 259, 302  
 Liouville’s theorem, 194  
 locality, 184–185  
 localizability, xii  
 loop diagram, 264, 267  
 loop school, 236  
 Lorentz contraction, 57  
 Lorentz invariance, 17, 51, 152, 184–185, 193, 232, 254, 285, 355  
 Lorentz rotation, 314, 320–321  
 Lorentz’s theory of the electron, 11, 13, 20, 49  
 Lorentz’s theory of the electron, 163  
 low energy theorem, 213  
 LQG. *See* quantum gravity, loop  
 LSZ reduction formula, 192
- Mach’s criticism, 43  
 Mach’s empirico-criticism, 42  
 Mach’s principle, 64–66, 68–69, 73–75, 81, 85, 88  
 magnetic moment, 187, 296  
   anomalous, 174  
 magnetic monopole, 270, 272–273
- many-body problem, 15, 136, 144, 146, 157  
 mass, 7, 10, 17  
   auxiliary, 176  
   difference, 187  
   distant, 69–70, 73  
   electromagnetic, 168, 171–172, 174  
   gravitational, 52, 94  
   inertial, 64–65, 68  
   Newtonian, 60  
   point, 67, 80, 97, 130  
 mass gap, 155  
 mass–energy equivalence, 52  
 matrix mechanics, 116, 118, 135  
 matter, 5, 13–14, 21  
   subtle, 24  
 Maxwell field, 138, 145–146, 164  
 Maxwell’s equation, 35, 90, 110, 169, 237  
 Maxwell’s theory, 163  
   of the electromagnetic field, 28, 33, 36, 44, 113–114
- medium  
   continuous, 23–28, 34  
   elastic, 27  
   immaterial, 34  
   luminiferous, 29  
   magneto-electric, 29  
   mechanical, 30
- Meissner effect, 249, 284  
 meson theory, 296  
   of strong nuclear force, 17, 186, 240  
 meson–nucleon interaction, 240  
 metaphysics, xiii, xvii, 1, 4–6, 30, 307–308  
   Platonic, 3
- metric  
   Kerr, 75  
   Minkowskian, 51, 53–54, 61, 63, 67, 72, 87  
   negative, 263  
 Michelson–Morley experiment, 36, 42, 45–47, 55  
 microcausality, 192, 194, 211  
 microwave background, 75, 103  
 microwave radiation, 102  
 model, mechanical, 7  
 moment, scalar, 278, 281  
 momentum quanta, 17  
 momentum transfer, 204, 299  
 monism, 88  
 monopole, 273, 288, 321  
 motion, 7  
   laws of, 7  
   principle of, 7  
 mysticism, mathematical, 3, 201
- Nambu–Goldstone boson. *See* Goldstone boson  
 negative energy, 153  
   electron, 150, 152, 163, 169, 285  
   photon, 164  
   sea, 150–151, 285  
   state, 150, 157, 160

- neo-Kantianism, 362–363  
 Neoplatonism, xvi, 3, 6, 8, 21–23, 26, 332  
 neutrino-nucleon reaction, inelastic, 298  
 neutron star, 101  
 neutron-proton model, 157  
 Noether current, 210  
 non-commutation relations, 134, 143  
 non-renormalizable theory, 191, 329–330  
 non-renormalization theorem, 220  
 nuclear democracy, 196–197, 296, 299  
 nuclear force, 159, 161  
   beta theory, 160  
   pair theory, 160  
 nucleon-antinucleon pair, 207–208, 251  
  
 objectivity, 340, 341, 353  
 omega-meson, 204  
 ontology, xv, xvii, 1, 4–5, 8–11, 13, 15, 18, 24, 39, 44, 70, 107, 125–126, 128–129, 132, 141, 150, 199, 294, 339, 346, 355, 357, 364  
   electromagnetic, 37  
   field, 14–17, 39, 143, 146, 185  
   fundamental, 340, 344, 354  
   particle, 15–16, 39, 128, 130, 139, 143–144, 146, 149, 153  
   physical, 344  
   theoretical, 342–343, 356, 361  
   unobservable, 343  
   wave, 130–131  
 OPE. *See* operator product expansions  
 operator  
   annihilation, 16, 136, 141, 143, 147–148, 151, 153, 157  
   creation, 16, 136, 141, 147, 151, 153, 157  
   Hermitian, 135, 140, 143  
   local, 107, 302  
   local field, 16  
 operator field, 17, 147, 150, 153, 179, 184–185  
 operator product expansions, 215, 221, 224–225, 227, 233, 258–259, 301, 303  
 oscillator, 112, 136  
   amplitude, 145  
   field, 136–137, 141  
   harmonic, 128, 133, 136  
   Hertzian, 110  
   model, 138, 143  
  
*p* meson, 195  
 pair annihilation, 152  
 pair production, 152  
 paradigm-shift, 339  
 parastatistics, 303  
 parity violation, 203, 242, 262, 292, 294  
 partial conservation of axial current, 246  
 partially conserved axial current. *See* PCAC  
 particle  
   composite, 193, 196, 198–199, 252, 276  
   elementary, 193, 196, 198–199, 202, 236, 241, 276, 296  
   massless, 264–265  
   particle pole, 194, 196  
   parton, 291, 298, 300  
   parton model, 259, 287, 301, 303–304, 359  
   path integral, xii, 20, 232, 264–265, 273, 287, 316  
   Pauli exclusion principle, 145, 150, 165  
   Pauli moment, 187  
   PCAC, 284, 297–298, 360  
   PCAC hypothesis, 206–210, 213–215, 217–218, 220, 231  
   perturbation theory, 172, 181, 186, 188, 191, 197, 215, 221–222, 233, 269, 287, 301–303, 306  
   renormalizable, 192  
   phase factor, 271–272  
   phase transition, 248, 275, 309, 327  
   phenomenology, 360  
   phonon, 226  
   photon, 310  
   photon-parton scattering  
     quasi elastic, 300  
   picture  
     field-theoretical, xiii  
     Heisenberg, 158, 228  
     interaction, xii, 174  
     Newtonian, xiii  
   pion decay constant, 207  
   pion-nucleon scattering, 194–195, 207, 209, 213, 231, 282, 298, 323  
   Planck constant, 109, 123, 141, 360  
   Planck scale, 322  
   Planck spectrum, 113, 137  
   Planck's law, 113–115, 119–120  
   Planck's quantum of action, 109  
   plasmon, 226, 250, 252, 255, 284  
   plenum, 9, 21, 24–25, 30, 33, 35, 252  
   pluralism, 11, 331, 338  
   Poincaré invariance, 155, 190, 355  
   point model, 163, 179–180, 191  
   point-electron theory, 163–164  
   Poisson's equation, 32, 59  
   polarization, 166–167, 250, 265  
     transverse, 264  
     vacuum, 167, 170, 173–177  
     vector, 268  
   positivism, 337  
   postmodernism, xvi  
   potential, 5, 15  
     continuous, 26  
     electromagnetic, 90–91, 94, 238–239  
     electrostatic, 250  
     gauge, xvii, 18, 235, 238–239, 241, 270–273, 304, 314–316, 319, 321, 375  
     gravitational, 25, 59, 67–68, 73, 81, 86, 89, 91, 319  
     Poisson's, 27  
     quantum, 6

- potential (cont.)  
 scalar, 169  
 scattering, 169  
 vector, 143
- precession of Mercury's perihelion, 61
- principle of equivalence, 52, 355–356
- priori* constitutive principles, 338–339
- probability amplitude, 96–97, 122, 139, 145, 159
- probability interpretation, 126–128, 130–131, 144–146
- probability, negative, 254
- programme  
 dispersion theory, 193–194  
 Dyson's renormalization, 262  
 Einstein's, 89  
 field theory, 10, 37, 39, 56, 86, 88  
 gauge field, xi, xviii, 17–19, 235, 270–271, 290, 317, 356–357, 365  
 Gell-Mann's current algebra, 211  
 geometrical, xi, xviii, 13–14, 18, 40, 78, 86, 290, 317, 354, 356  
 Machian, 68  
 mechanical, 11  
 Newtonian, 89  
 PCAC-current algebra, 201, 213–215, 219, 232, 244  
 quantum field, xi, xviii, 14, 16–18, 107, 184, 290, 317, 354, 357  
 renormalization, 107, 171–172, 174, 176–178, 181, 189, 193, 269  
 Riemann's unification, 32  
 symmetry, 201–202, 204
- propagator, 175, 177, 264–266, 288
- pseudoscalar meson, 251
- q numbers, 134, 140–143, 153, 228
- quantization, 15–16, 19, 78, 107, 125, 131–132, 159, 211, 246, 262, 292, 305, 356–357  
 canonical, 191, 315, 318  
 of atomic motion, 111, 118  
 of charge, 235, 270  
 of energy, 141  
 of field, 137, 139, 141–142, 146–149  
 of gravity, 323  
 of motion, 16, 109–110  
 second, xi, 15, 137, 150, 153
- quantization condition, 16, 109, 133, 135–136, 154, 228, 273  
 Bohr–Sommerfeld, 133–134  
 Heisenberg–Born, 138
- quantum chromodynamics (QCD), 189, 228, 290, 294, 297, 306–308, 323, 329, 351, 358
- quantum condition, 116, 118, 121, 138, 145, 147
- quantum electrodynamics (QED), 14, 17, 156, 159, 184–188, 219, 223, 227, 233, 249, 260, 268, 355
- quantum field, 16, 150, 155  
 global, 153–154  
 local, 153–154
- quantum field theory (QFT), xi–xiii, 6–7, 14–15, 17, 40, 94, 107, 109, 125, 162, 186, 199–201, 215, 222, 225, 227, 229, 233, 250, 252, 282, 331–333, 359
- quantum fluctuations, 96, 122, 154, 162
- quantum gravity, xi, 18, 182, 236, 244, 290, 310, 313, 351, 360  
 loop, 313, 315–317, 322
- quantum jump, 160
- quantum mechanics, xv, 6, 15–16, 96, 101, 118, 121, 123, 126, 131, 135–136, 146, 150, 184, 237
- quantum number, 185, 214, 293–294, 309  
 colour, 303, 305, 308  
 internal, 248
- quark, xvii, 200, 233, 294–295, 300, 308, 310  
 charmed, 307  
 constituent, 297, 301, 303  
 current, 297, 299, 301, 303, 363
- quark confinement, 257, 288, 307–308, 323
- quark model, 216, 257, 291, 296–297, 358  
 constituent, 302, 308, 359, 363  
 free, 302  
 SU(6), 296
- quark–antiquark pair, 261
- quark–gluon model, 302
- quark-parton model, 228
- quasi-particle, 226, 250
- quasi-point model, 179
- radiation  
 black body, 41  
 electromagnetic, 111, 119  
 quanta, 115  
 thermal, 104
- radiation cavity, 112
- radiation correction, 168, 171–173, 177, 219–220, 250
- Raman spectrum, 157
- rationalism, 2, 30  
 Kantian, 43
- rationality, xvii–xviii, 1, 19, 337, 338, 340, 363
- rationality, scientific, 364, 366
- Rayleigh–Jeans law, 113
- realism, 1, 6, 363  
 convergent, 19  
 internal, xvi, 4  
 metaphysical, 366  
 phenomenal, 341  
 scientific, xi, 19, 337, 340, 341, 344, 350–351, 361–362, 366  
 structural, xi, 4, 44–45, 344–345, 347–349
- reality, xv, xvii, 5, 7–9, 15, 21, 23, 278, 295, 345  
 logical construction of, 8  
 metaphysical, xvi, 4, 6  
 objective, xvi, 130  
 of gluon, 308  
 of quark, 307–308



- physical, 6, 8, 10, 14, 27–28, 30, 61, 80, 81–83, 85, 128, 145, 277, 294
- unobservable, 359
- redshift, xvi, 99
- reduction formula, 209, 212
- reduction, dimensional, 239–240
- reductionism, 1, 307, 334
- Reeh-Schlieder theorem, xii, 154
- reference frame, 41, 49, 51–54, 56, 59, 61, 65
- Regge pole, 193, 196–198, 227
- Regge trajectory, 193, 196, 198, 210, 296, 298
- regularization, 175–176, 216, 218, 220, 268–269, 292, 323–324
  - dimensional, 233, 267, 270
  - Pauli–Villars, 218–219
- relativism, xvi, 1, 338–339
- relativity
  - general theory of, xiii, xvi, 6, 11, 13, 18, 21, 43, 46, 52, 54, 56, 78, 88, 313–314, 317, 319, 351, 359
  - principle of, 6, 41, 46–50, 52, 54, 59, 63, 66
  - special theory of, 6, 13, 17, 20, 39, 46, 50, 57–58, 61
  - theory of, 6
- relativity, general, 244
- relativity, special, 360
- Renaissance, 7
- renormalizability, 17, 186–187, 189–190, 202, 215, 221, 223, 226–228, 235, 240–244, 246, 262–264, 266–270, 272, 274, 282, 288, 290–294, 323, 326–327, 329
- renormalization, 17, 125, 147, 153, 155, 162, 166–169, 174, 176–177, 179, 186, 188–189, 191, 197, 200–202, 207, 211–212, 215, 219–221, 227, 233, 263, 268, 270, 305, 311, 324–326, 328
  - charge, 170, 173, 177, 260
  - effect, 221–222, 225, 301, 328, 328, 331
  - factor, 173, 205, 207
  - group, 222
  - invariance, 223
  - mass, 165, 171, 173, 177
  - scale, 223–224
- renormalization equation, 301
- renormalization group, 154, 190, 222–227, 233, 257, 259, 282, 291, 298, 323, 327
  - equation, 202, 222, 224–226, 259–260, 309, 328, 330–332
  - transformation, 225
- renormalization theory, 191
  - perturbative, 188, 190
- reorganizability, 279, 281
- reorganization, 279–281
- representation
  - angular momentum, 135
  - coordinate, 135
  - energy, 135
  - field, 148
  - Fock, 146, 148, 154, 191
  - Mandelstam, 195
  - particle number, 136, 146
- resonators, 113
  - electromagnetic, 109
- Reynolds number, 247
- rotation, isotopic, 205, 300
- Rutherford's model of the atom, 111
- safety, asymptotic, 226–227
- Sakata model, 296
- saturation mechanism, 300
- scalar boson, 254, 274, 276
  - massive, 277
  - massless, 277
- scalar meson, 263
- scalar mode, 256, 278, 281
  - Goldstone's, 278
  - massless, 277, 280
- scalar theory, five-dimensional, 226
- scale invariance, 221–222, 224–226, 233, 259, 301–302, 327
- scaling, 260–261, 298, 300, 302–303, 306, 308
  - anomalous, 259
  - non-canonical, 260
  - precocious, 260
  - Wilsonian, 260
- scaling law, 222–225, 228, 301
- scaling violation, 301
- scattering amplitude, 193–196, 209, 296
- scattering angle, 195, 259
- scattering theory, potential, 195
- scattering, deep inelastic, 228, 259–260, 291, 300
- Schrödinger equation, 146, 174, 195
- Schrödinger field, 145
- Schrödinger wave, 140–142, 144–146, 149
- Schwarzschild radius, 180
- Schwarzschild solution, 67–68, 72, 97–101
- Schwarzschild sphere, 99
- Schwinger model, 232, 255
- Schwinger terms, 215, 231
- Schwinger's pole, 256
- Schwinger's source theory, 268, 333
- selection rule, 296
- self-coupling, 256, 258, 261–262, 265, 278–281, 360
- self-energy, 17, 148, 162–165, 167, 169–170, 173, 176–177, 187, 250, 267–268
- SHASR, 351, 354, 357–359, 362–364, 366
- short-distance behavior, 224, 259, 307
- simplicity
  - principles of, 5
- simultaneity, 48–49
- singularity, 14, 78, 97, 101–105, 113, 128, 155, 167, 170, 194–200, 221, 226, 228, 272, 296, 302
  - de Sitter, 98
  - metric, 98
  - Schwarzschild, 98–100
- SLAC, 259–260, 291, 299–300



- Slavnov–Taylor identities, 287  
 S-matrix, 176–177, 193–196, 198, 205, 228, 266–267, 296, 299, 306  
 S-matrix theory, 19, 180, 186, 192–193, 197–201, 227, 229–230, 296, 300, 344, 366  
 SMT. *See* S-matrix theory  
 soft pion, 212, 214, 231  
 soft-mass, 243  
 space, xiii, 5, 7, 9–10, 13–14, 25  
   absolute, 73, 75  
   Clifford, 371  
   de Sitter, 73  
   Euclidean, 6, 369  
   Fock, 107  
   internal, 18  
 spacetime, xiii–xiv, xvii, 5, 10, 13, 18, 20, 39, 56, 61–62, 78–79, 81, 82, 85, 102, 270, 278, 282, 315  
   absolute, 51, 79  
   chrono-geometrical structures of, 66  
   dimension, 233  
   Euclidean, 57  
   geometrical structures of, 53, 56, 66, 86–92, 94–95, 244, 317–319, 322, 355  
   manifold, 51, 107, 155, 290, 313, 315–316, 318, 355  
   micro-, 296  
   Minkowskian, 46, 51, 53, 59, 68, 86, 97, 236, 313–314, 360  
   point, 10, 57, 61–62, 154–155, 174, 191, 215, 237–238  
   quantum, 317  
   Riemann–Cartan, 314  
   Riemannian, 93, 102, 244  
   Riemannian manifold, 57  
   Riemann–Cartan geometry, 244  
   Schwarzschild, 103  
   spinor structures of, 96  
   topological structure of, 318  
 spatio-temporal visualizability, 5  
 spin, 10  
   density of, 94  
 spin foam, 316–317  
 spin wave, 226  
 spin-connection, 315–316  
 spinor, 96  
 spinor theory, nonlinear, 252–253  
 SSB. *See* symmetry-breaking, spontaneous  
 standard model, 221, 236, 242, 275–276, 290–291, 309, 323, 332, 357  
 state, collective, 251  
 state, stationary, 111, 116, 133–134, 138, 140–141  
 statistics  
   Boltzmann, 119  
   Bose–Einstein, 119, 124, 131, 157  
   Fermi–Dirac, 124, 131, 142, 265  
   para-Fermi, 295  
   quantum, 15  
 Stefan–Boltzmann law, 115  
 STR. *See* relativity, special theory of  
 strangeness, 210, 248  
 stress-energy tensor, 60–61, 69, 85  
 string theory, 333  
 structuralism, 345–348, 350–351, 362, 366  
 structure, 5, 8  
   chronogeometrical, 51, 59, 84, 155  
   geometrical, 13, 18, 39, 70, 79, 236  
   gravitational, 59  
   hypothetico-deductive, 6, 8  
   inertial, 51, 53, 56  
   internal, 19, 300  
   lexical, 340–341  
   mathematical, xvii, 6, 9, 15, 18, 21, 44, 63, 240, 344, 346–348  
   mechanical, 35  
   of spacetime, 69–70  
   socio-economic, 12  
   spacetime, 57, 59, 74  
   theoretical, xvii, 8, 18, 20, 347, 365  
 structure function, 259  
 structures  
   mathematical, 125  
 Stueckelberg formalism, 287  
 $SU(2)_L \times SU(2)_R$  algebra, 231  
 $SU(3) \times SU(3)$   
   chiral algebra, 211  
   symmetry, 211–213, 221  
 $SU(3)_L \times SU(3)_R$  algebra, 206, 231  
 $SU(4) \times SU(4)$  model, 309  
 $SU(5)$  model, 309  
 substance, xvii, 5, 8–11, 15–17, 24, 31  
   active, 24  
   continuous, 26  
   dynamic, 28  
   ethereal, 23  
   non-mechanical, 36  
   physical, 32  
   primordial, 33  
 substantiality, 10  
 sum rule, 213, 216, 231, 258, 298–301  
   Adler–Weisberger, 213  
   Callan–Gross, 213  
   high energy, 213  
 superconductivity, 231, 248–253, 275, 284  
 supergravity, 18, 230, 312–313, 322  
 superimposability, 355  
 supernova, 101  
 superselection rule, 253–254  
 superstring theory, 180, 200, 230, 313, 318, 332  
 supersymmetry theory, 180, 200, 312, 366  
 Sutherland–Veltman theorem, 213  
 symbiont, 256, 277, 279–280  
   holistic, 278, 281  
   of spacetime, 281

- primary, 277
- scalar-vector, 277–278, 281
- symbolism, mathematical, 3
- symmetry
  - BRST, xii
  - chiral, 203, 206, 214, 231, 242, 254, 292
  - chiral  $SU(2) \times SU(2)$ , 206
  - colour, 304, 306
  - colour gauge, 295
  - continuous, 327
  - crossing, 194
  - dynamical, 219, 297
  - external, 241, 310–312, 355
  - flavour, 231, 246
  - gauge, 211, 237, 267–268, 271, 309–310
  - global, 231, 235, 296, 303, 311, 355
  - internal, 19, 95, 210, 241, 311–312, 320, 322
  - isospin, 205, 211, 239
  - isotopic, 203
  - kinematic, 78
  - local, 235, 309, 311
  - partial, 292
  - Poincaré, 319
  - rotational, 283
- symmetry-breaking, 94, 208, 211–212, 219–220, 222, 246, 249, 254–257, 277–279, 281, 291, 309, 329
  - anomalous, 213, 215, 231, 323, 327, 331
  - dynamical, 276
  - induced, 256
  - spontaneous, 203, 208, 231, 243, 247–249, 252–253, 269, 273–274, 283–284, 286–287, 292, 323, 326–328, 331, 332
- synthesis
  - conceptual, xi
  - great, 302–303
  - ontological, xi, 13, 18–19, 236, 313, 322, 337, 354, 356, 358–359, 362, 365
- tensor, 96, 373
  - anti-symmetrical, 91, 93
  - curvature, 63, 85, 92
  - energy, 64, 93
  - Hermitian, 93
  - metric, 57–60, 66, 69
  - polarization, 255
  - Ricci, 60, 76, 373
  - Riemann, 76, 90
  - Riemann–Christoffel, 373
  - Riemannian metric, 56
  - stress-energy, 69
  - symmetric, 93, 95
- Thirring model, 215, 221, 224–225, 232
- Thomas–Kuhn sum rule, 211
- 't Hooft's model, 293
- time, xiii, 5, 7, 9
  - absolute, 6
- topology, 105
- torsion, 94
- transform
  - Fourier, 147, 151, 153
- transformation
  - Bell–Treiman, 266, 268, 287
  - canonical, 172–174, 176–177
  - contact, 324
  - diffeomorphism, 316
  - Fourier, 121
  - function, 122
  - Galilean, 49–50
  - gauge, 91, 238, 244, 266, 271–274, 288, 315, 375
  - group, 239
  - Lorentz, 46–50, 55, 148, 311
  - of coordinate, 98
  - phase, 238
  - principal axis, 123
  - scale, 224
  - space-time, 62
  - unitary, 135, 174
- transition
  - amplitude, 117, 209
  - probability, 116–117
- transmutation, 280, 294
- transmutation, dimensional, 226
- tree diagram, 264, 267
- tree theorem, 264
- UFT. *See* field theory, united
- uncertainty principle, 128, 179, 185, 318
- uncertainty relation, 17, 109, 122–123, 130, 150, 154–155
- uniformity of nature, 3
- unitarity, 185, 192–197, 201, 263–265, 267–270, 287, 292, 296
- universality, xiv, 248, 290
- universe, Machian Robertson-Walker, 75
- V–A theory of the weak interaction, 266
- vacuum, 7, 13, 150, 252, 273, 275, 283–284
  - bare, 185
  - electron, 170
  - expectation value, 192, 215, 253, 255, 257, 289
  - fluctuation, 148, 152, 173, 175, 177, 185, 283
  - polarization, 255–256, 260–261
  - state, 16–17, 107, 151, 153–155, 181, 184, 208, 231, 246, 249, 252–253
  - state, topological, 274
- vacuum, degenerate, 246, 248–249, 252–253, 255–256, 273, 278, 283–285
- variational principle, 90
- vector boson, 203, 211, 214, 242, 252, 263, 265–266, 270, 296
  - charged, 266–267, 269
  - massive, 266–267, 277
  - massless, 277

440

vector meson, 186, 262, 266, 286, 310  
   charged, 263  
   massive, 290  
   massless, 261  
 vector meson dominance model, 203, 243  
 vector mode, 278–280  
   massless, 277  
 vector theory, massless, 265  
 velocity of light, 100, 128  
 vertex  
   axial vector, 219–220  
   irreducible, 268  
   mass, 233  
 virtual quanta, 17, 185, 199, 317  
  
 W boson, 242, 276, 287, 294, 310, 329  
 Ward identity, 219–220, 250, 268, 270, 287, 292  
 wave, 128–129  
   de Broglie, 118, 120, 126, 129, 132, 139, 143, 165  
   de Broglie–Schrödinger, 126  
   electromagnetic, 33, 42, 107, 127, 129, 138, 141  
   equation, 29, 31, 120, 129, 135  
   field, 107, 138  
   function, 15–16, 118, 121, 125–126, 128–129, 131, 135, 139, 144–146, 151, 177, 238, 248  
   gravitational, 360  
   light, 29, 31, 126, 140  
   matter, 120  
   mechanics, 124, 127, 130  
   packet, 128, 130  
   probabilistic, 129–132, 142, 146  
   radiation, 130  
   Schrödinger, 139  
 wave mechanics, 125, 144

*Subject Index*

wavelength, 118, 134  
   Compton, 300, 307  
 wave-particle duality, 114–115, 118, 123, 129, 148–149  
 Weinberg angle, 242, 293, 309–310  
 Weinberg’s model, 277, 281  
 Wheeler–DeWitt equation, 318  
 Wien’s law, 113, 115, 119  
 Wightman function, xii  
 Wigner’s rule, 157  
 Wilson loops. *See* holonomies  
 winding number, 374  
 W-meson theory, 186, 228  
 world function, 89  
  
 X boson, 310  
  
 Yang–Mills theory, 203, 206, 213, 228, 230, 245, 252, 261–262, 264–265, 267, 269, 283, 287, 293, 320  
 Yang–Mills–Lee–Sakurai theory, 252  
 Yukawa coupling, 256–257, 275, 278, 280, 366  
 Yukawa’s theory of mesons, 157  
  
 Z boson, 287, 294, 310, 329  
 zero-energy theorems, 216  
 zero-mass, 240–241, 243–244, 246, 253, 255, 264–267  
  
 $\gamma_5$  invariance, 219–222, 231–232, 251, 284, 327  
 $\theta$  vacuum, 274, 294  
 $\sigma$  model, 208, 217–218, 220, 269  
   non-linear, 208  
 $\phi^4$  theory, 232, 258