

# Index

- Absolute centigrade temperature scale, *see* Kelvin absolute temperature  
Absolute temperature, 385, 387, 458  
and kinetic energy, 458, 466  
Absolute truth, 98  
Absolute zero, 387, 425  
and specific heat, 476  
Abstractions and experience, 307 (ftn)  
Academy of Sciences, French, 369, 374  
Acceleration, due to the earth's rotation, 282  
and force, 221  
in free fall, 162–163  
in one dimension, 176–177  
in uniform circular motion, 244–245  
vector, 232–233  
Acceleration of gravity, 165  
apparent and true, 282–283  
dependence of, on latitude, 282  
measurement of, 165, 353  
standard value of, 239, 481  
Action at a distance, 263–264  
Action and reaction, 205, 221–222, 252–253, 265  
Adams, John Couch, 280  
Adiabatic reversible change of state, 417  
Adiabatic lines, on Carnot cycle diagram, 417  
as lines of constant entropy, 431–432  
Aether, lumeniferous, 264  
of space, 263  
Age of the universe, 146  
Agricola, Georgius, 400  
Air, density of, 322–323  
Alchemy, 106, 439  
Alexander the Great, 65, 66, 73  
Alexandria, 73  
Library of, 73, 87  
Museum of, 73, 79  
Alexandrian school of science, 26, 73  
Altitude, astronomical, 18  
Amplitude of simple harmonic motion, 350  
Anaximander, 69  
Anaximenes, 69, 438  
Andromeda galaxy, 136, 141  
Animism, 25, 86  
Antimeridian, 14  
Aphelion, 108  
Apollonius of Perga, 73, 84  
Apparent brightness of a star, 123–124, 132–133  
Apparent motions of the stars, 10–15  
Approximations in scientific theory, 280–281  
Aquinias, *see* St. Thomas Aquinas  
Archimedes of Syracuse, 4, 73, 159, 166, 204, 207 (ftn), 312  
Archimedes' principle, 204, 312, 372  
Area, scale unit of, 179  
Aristarchus of Samos, 10, 73, 75, 79–82, 89, 118  
Aristotelean physics, 159–161, 356  
Aristotle, 3, 32, 67, 72–75, 88–89, 106, 159, 205, 225, 299, 304, 438  
Aristotle's concentric spheres, 74, 89  
Aristotle's theory of motion, 159–160  
Arithmetic, origin of, 8–9  
Arstillus, 26  
Asteroids, 107, 113, 119  
Astrology, 25, 83, 104, 106, 159  
Atmosphere, convection currents in, 368, 372, 397  
density of, 322–323  
frictional resistance of, 161  
of planets, 279  
pressure of, 321–322, 324–325  
re-entry into, 370 (ftn)  
Atomic heat, 472, 475  
Atomic theory, early history of, 438–440  
kinetic-molecular assumptions in, 441–443  
Atomic weights, chemical scale, 463–464  
physical scale, 464  
Atoms, evolution of, 148  
first Greek conception of, 439  
Authority vs. observation, 151–152  
Automobile engine, efficiency of, 381  
Automobiles, braking of, 231  
overturn of, 249  
skidding of, 247–249  
Avogadro, Amedeo, 453  
Avogadro number, 465, 467–468  
Avogadro's law, 453, 463–465, 468–469  
Azimuth, 18  
Btu, 364  
Bacon, Sir Francis, 5, 294, 296, 441  
Balance, equal-arm, 202–204, 240  
spring, 202, 204  
Barometer, 321–322  
Barrow, Isaac, 217  
Bellarmine, Robert Cardinal, 156  
Bernoulli, Daniel, 441, 452 (ftn), 458  
Bernoulli formula, 458  
Bessel, Friedrich W., 121  
Binding energy, 447–448  
Biological systems, 433–434  
Black, Joseph, 356–357, 380, 404, 441  
Boiler pressure, 402, 407, 408, 411, 426–427  
Boiling temperature, 450 (ftn)  
Boltzmann, Ludwig, 469  
Bond, chemical, 448  
Bondi, Hermann, 149  
Borelli, Giovanni Alfonso, 262  
Boulton, Matthew, 406  
Boyle, Robert, 299, 313, 323 (ftn), 441, 443  
Boyle's law, 99, 323, 381, 423, 443, 445  
and equipartition theorem, 469  
explanation of, 459  
Boys, C. V., 275  
Brahe, Tycho, *see* Tycho Brahe  
Branca, Giovanni, 400  
Bridgman, P. W., 290  
Brightness of stars, apparent, 123–124, 132–133  
intrinsic, 123–124, 129, 132–134  
British thermal unit, 364  
Brown, Robert, 467  
Brownian motion, 466–468  
Bruno, Giordano, 103, 299

- Buridan, Jean, 160  
 Butterfield, Herbert, 160, 287  
 CGS system, 241-243, 329  
 Calculus, differential, 166, 175-176, 482-483  
     integral, 166, 424, 484-490  
 Calendars, 25-26  
 Calibration, 203, 359  
 Caloric theory, 361, 369, 441, 444  
 Calorimetry, 361-364  
 Carbon dioxide, as fire extinguisher, 372-373  
     solid, 226, 227  
 Carnot, Lazare, 412 (ftn), 413  
 Carnot, Sadi, 374, 409, 411-417, 420-421, 477-478  
 Carnot cycle, 417-418  
     entropy changes in, 432  
     for a gas, 419  
 Carnot theorem, 418-419  
     proof of, 427-428  
     and thermodynamic temperature scales, 421  
 Carnot's ideal heat engine, 413-418, 445, 454  
     efficiency of, 419, 421, 425  
 Cassini, Jean Dominique, 118  
 Cavendish, Henry, 274  
     gravitational experiment of, 274-275  
 Celestial equator, 15-16  
 Celestial latitude, 44  
 Celestial longitude, 44, 91  
 Celestial sphere, 11-15  
     mapping of, 37, 41-50  
     polar axis of, 13  
 Celsius, Anders, 359  
 Celsius temperature scale, 359, 385, 388, 421-423  
 Center of gravity, 204, 210-211, 249, 259  
 Center of mass, 257-259, 278, 339  
 Cepheid variable stars, 131-132  
 Chalmers, T. W., 452 (ftn)  
 Change of state, 379, 430  
     adiabatic, 417  
     isothermal, 416  
     reversible adiabatic, 417  
 Charles, Jacques, 382  
 Charles and Gay-Lussac, law of, 382-383  
 Chemical bond, 448  
 Chemical compounds, 439, 442  
 Chemical energy, 375-376  
 Chemical equilibrium, 433  
 Chemical reactions, 356, 376, 439  
 Chemical systems, 430  
 Childe, V. Gordon, 25 (ftn), 61, 65  
 Chronometer, 40, 51  
 Church, early Christian, 87  
 Circle of reference, 350  
 Circles, diurnal, 16, 21, 37-38, 41  
 Classical mechanics, *see* Newtonian mechanics  
 Clausius, Rudolf, 420, 421, 428, 430, 441, 452 (ftn)  
 Clocks. 50-54  
     sidereal, 43  
 Clouds, formation of, 372  
 Cohen, I. Bernard, 273 (ftn)  
 Cohesion, forces of, 281, 314, 446  
 Collisions, 254-259  
     elastic and inelastic, 256, 257  
     intermolecular, 454-455, 458  
     molecule-wall, 456-457  
 Colloidal particles, 466  
 Color-components, 125  
 Columbus, Christopher, 32 (ftn), 34  
 Comets, 107  
     orbits of, 108, 274  
 Compounds, chemical, 439, 442  
 Compression, adiabatic, 417, 445  
 Conant, James B. xiv, 100, 290 (ftn), 294  
 Condensation, 365, 397, 404-405, 450  
 Condenser, invention of, 405-406  
 Conductivity, thermal, 367-369  
 Conjunctions, inferior and superior, 77, 92  
 Conservation of energy, 149, 327, 343, 353  
     as formalism, 375  
     general law of, 374-376  
 Conservation of momentum, 253, 259  
 Constellations, 11, 24-25, 44  
     autumnal, 49  
     circumpolar, 47  
 Constraints, 235  
 Convection currents, 368, 372, 397  
 Convection of heat, 367-369, 372, 397  
 Coordinates, 13  
     celestial, 41-44  
     of diatomic molecules, 470  
     geographic, 13, 33-40  
     in one dimension, 167  
     polar, 193, 273  
 Copernican theory, 82, 90-96, 101-102, 153-154  
     acceptance of, 103, 112-113, 151-156  
     final, 95-96  
     frame of reference of, 92  
     merits of, 101-102  
     simplified, 91-95  
 Copernicus, Nicolaus, 75, 82, 89-90, 102-103, 154, 281  
*Little Commentary, 90*  
*De Revolutionibus Orbium Cælestium, 90, 102-103, 156*  
 Cosmo II, Grand Duke of Tuscany, 155  
 Cosmological theory, "Big Bang," 146-147  
     steady-state, 149, 434  
     *see also*, Universe  
 Couple, 207 (ftn)  
 Crystal lattices, 449  
 Crystalline spheres, 74  
 Crystals, 443, 448, 449  
 Culmination, 16, 37, 41  
 Current, electric, 376  
 Currents, convection, 368, 372, 397  
 Curvature of space, 147  
 Cycle, of the Carnot engine, 417-419  
     of the Watt engine, 407, 409-410  
 Cycles, in the growth of science, 295  
 Dalton, Robert, 441-443  
 Dalton's law of partial pressures, 453-454  
 Dampier, William Cecil, 73 (ftn)  
 Dante Alighieri, 75, 299  
*Divine Comedy, 89*  
 Dark Ages, in Europe, 86  
     in Greece, 65  
 Davy, Sir Humphry, 374, 441  
 Day, apparent solar, 54  
     mean solar, 53  
     sidereal, 53, 54  
 Declination, 35, 41, 48  
     of the zenith, 50  
 Deferent, 84-85  
 Deformation, elastic, 256-257, 313, 315  
     inelastic, 256-257, 313, 370  
 Degree of freedom, 471, 474, 475, 478  
 Democritus, 70, 300, 438, 439  
 Density, of air, 322-323  
     of the earth, 275  
     of the earth's core, 276  
     of the moon, 279  
     of the sun, 277  
 Derivative, 175-176, 482-484  
     of position vector, 200  
 de Santillana, Giorgio, 156  
 Descartes, René, 262, 296, 297, 299, 310, 439  
 Determinism, 300  
 Dew, formation of, 397  
 Diamond, specific heat of, 476  
 Diatomic molecules, coordinates of, 470  
 Dick, Robert, 403  
 Dickinson, H. W., 402 (ftn)  
 Differentiation, *see* Derivative  
 Diffusion, 450  
     and molecular speeds, 461  
 Disorder and entropy, 435  
 Displacement, 166, 190, 198-201  
     as an area, 179-180  
 Diurnal motion, of the stars, 16, 19  
     of the sun, 19, 21  
 Domain of a function, 169  
 Doppler effect, 129-131, 142  
 Dreyer, J. L. E., 28, 29 (ftn), 32, 74 (ftn), 79 (ftn), 80 (ftn), 81, 94 (ftn)  
 Dry ice, *see* Carbon dioxide, solid  
 Dualism, 304  
 Dulong, P. L., 475  
 Dulong and Petit, specific-heat rule of, 475, 476  
 Dynamics, 159, 201, 220  
 Dyne, 242, 481  
 Earth, age of, 66, 147  
     axis of, 13  
     composition of the core of, 276  
     equatorial bulge of, 285  
     as a frame of reference, 75, 251  
     geographic coordinates of, 33-40, 285  
     mass of, 275, 480  
     and moon as a system, 278-279  
     orbital motion of, 82, 95, 109-110, 279  
     perturbation in orbit of, due to moon, 279  
     as a planet, 95  
     radius of, 32, 480  
     rotation of, 52, 74, 76, 81, 282-283  
     satellites of, 339, 354-355  
     shape of, 29-31, 281-285  
     stationary conception of, 82-83  
 Eccentric circle, 84-85, 95, 102  
 Eccentricity of an ellipse, 107  
 Eclipse seasons, 57  
 Eclipses, 19, 31, 57  
 Eclipsing variable stars, 131

## INDEX

- Ecliptic, 19-21, 28, 42  
axis of, 21, 27  
location on star map, 48  
obliquity of, 21, 28  
poles of, 27  
École Polytechnique, 412  
Ephantus, 74  
Efficiency, of a Carnot engine, 419, 421, 425, 432  
of machines, 347, 381  
of a power plant, 408, 425  
of a steam-engine, 407-408  
thermodynamic, 408, 411  
Einstein, Albert, 9, 147, 219, 264, 468  
Einstein's theory of relativity, 147, 271.  
Elasticity, 313, 446  
Hooke's law of, 315, 447  
Elements, early Greek conception of, 438-439  
present-day definition of, 442  
specific heats of, 473, 475-476  
synthesis of, 148  
Ellipse, definition of, 107  
Empedocles of Agrigentum, 438, 439  
Empiricism, of Bacon, 296  
of Galileo, 151-152  
of Hume, 297  
Energy, 326  
binding, 447-448  
conservation of, 146, 149, 343, 353  
degradation of, 429, 432  
high-grade and low-grade, 429  
internal, 377-378, 380, 392, 472  
internal, of a gas, 453-454  
mechanical, dissipated as heat, 369-371  
sources of, 374  
transmission of, 344  
units of, 329, 481  
varieties of, 375, 376  
see also, Kinetic energy and Potential energy  
Energy principle, for mechanical systems, 343  
and machines, 344-347  
and simple harmonic motion, 353  
Engine, heat, see Heat engine  
Engine, steam, see Steam engine  
Entropy, of biological systems, 434  
cosmological significance of, 434  
definition of, 431  
growth in irreversible processes, 432, 435  
as a measure of disorder, 435  
and the nature of life, 434  
Eötvös, Roland, 234 (ftn)  
Epicurus, 439  
Epicycle, 84-85, 89, 95, 102  
Equal areas, law of, see Kepler's second law  
Equalization, thermal, 357-358, 361-362, 444  
Equant, 84-85, 110  
Equation of state of an ideal gas, 383-385, 389, 453, 465  
Equations, complete physical, 178  
Equator, celestial, 15-16, 33  
terrestrial, 33  
Equilibrium, 203, 205, 207, 209, 223  
chemical, 433  
kinetic, 366, 468-469  
rotative, of an accelerated body, 249  
thermal, 357-358, 361, 458, 469  
thermodynamic, 378, 433  
of working fluid in ideal heat engine, 415  
Equinoctial colure, 41-42  
Equinoxes, 20, 22, 46, 50  
precession of, 24, 26-28, 42, 44, 76, 285  
Equipartition theorem, elementary form of, 469  
general form of, 469-472  
and specific heats, 472-478  
Eratosthenes, 32, 73  
Erg, 329, 481  
Eros, 119  
Errors of observation, 168  
Ether, see Aether  
Euclid, 9-10, 71, 73  
Eudoxus, 74  
concentric spheres of, 74  
Evans, Oliver, 407  
Evaporation, cooling by, 365  
heat of, see Vaporization  
rate of, 366  
Evolution of the universe, 145-149  
Expansion, adiabatic reversible, 417, 422, 445  
Experimentation of Galileo, 162-164  
of Huygens, 165  
of Newton, 219  
External galaxies, 130, 136, 139-147  
Fahrenheit, Gabriel Daniel, 359  
Fahrenheit temperature scale, 359, 388  
Faith, and science, 307-309  
Farrington, Benjamin, 4, 70 (ftn)  
Fixed-earth theory of the astronomical universe, 10, 74, 82-85  
Flow, plastic, 281 (ftn)  
Fluid friction, 161-162, 224-225, 227, 232, 317 (ftn), 370  
Fluids, definition of, 317  
nature of, 315-317  
Foot-pound, 329, 481  
Force, centrifugal, 246  
centripetal, 245-249, 263  
of cohesion, 446  
concept of, 161, 201-202  
conservative and nonconservative, 343  
frictional, 224, 227-232  
gravitational, 263-269  
interatomic and intermolecular, 446-447  
restoring, 348-349  
and stress, 314  
torque of, 207-210, 249  
transmission of, 204-205, 263-264, 344-346  
unbalanced, 221, 223, 232  
Formalisms, 375  
Foucault pendulum, 252  
Frame of reference, 13, 75, 188  
Copernican, 92, 250  
earth's surface as, 250-251  
geographic, 33  
and motion of the moon, 56-57  
Fraunhofer, Joseph 127  
Frederick II of Denmark, 104  
Freedom, degrees of, 471, 474, 475, 478  
Free-fall acceleration, see Acceleration of gravity  
Fresnel, Augustin, 371  
Friction, 224-237  
of atmosphere, 161  
definition of, 228  
fluid, 161-162, 224-225, 227, 232, 317 (ftn), 370  
and relative motion, 224  
rolling, 232  
sliding, 229-230, 331  
static, 229, 230-232  
work against, 327, 444  
Friedman, Aleksandr A., 147  
Frost, formation of, 397  
Functions, mathematical, 169-171  
physical, 170, 420  
Fusion, latent heat of, 367  
Galaxies (external), 136, 139-147  
red shift and recessional velocities of, 142, 144-147  
Galaxy (Milky Way System), 124, 135-136  
Galileo Galilei, 112, 151-157, 223-224, 287, 300, 327, 356, 374, 439, 441  
*Dialogue on the Great World Systems*, 156, 183 (ftn)  
*Dialogues Concerning Two New Sciences*, 156, 162, 164 (ftn)  
and ecclesiastical authority, 155-157  
experiments of, 164  
free-fall theory of, 161-163  
*Il Saggiatore*, 151  
and law of inertia, 183, 223  
projectile theory of, 183-185  
telescopic discoveries of, 153-155  
Galle, J. G., 280  
Gas constant, per unit mass, 389  
universal, 465, 482  
Gas pressure, kinetic formula for, 453-458  
kinetic theory of, 441, 443, 445  
static conception of, 443  
Gaseous state, 445-446  
Gas law. see Equation of state of an ideal gas  
Boyle's, 323  
Charles and Gay-Lussac's, 382-383  
Gases, Carnot cycle for, 419  
as fluids, 315-316  
ideal, see Ideal gas  
internal energy of, 453-454  
kinetic theory of, 452-458  
properties of, 445, 453  
specific heats of, 390-393, 472-474  
molar, 472  
Gassendi, Pierre, 441  
Gauge, pressure, 320-321  
Gay-Lussac, Joseph Louis, 382, 453  
Geographic latitude, 13, 16, 23, 285  
Geographical coordinates, 13, 33-40  
Geometry, 9-10  
coordinate, 174 (ftn)  
Greek, 68-69  
of the universe, 147  
Gibbs, Josiah Willard, 469  
Gilbert, William, 262

- Glanville, S. R. K., 26 (ftn)  
 Glass, 449  
 Globe, celestial, 44  
 Globular star clusters, 136, 138  
 Gnomon, 17, 52  
 Gold, Thomas, 149  
 Governor, steam-engine, 407  
 Gradient of temperature, 367  
 Gram atom, 465  
 Gram-calorie, 364, 481  
 Gram mass, 241  
 Gram molecule, 464-465  
 Gravitation, law of, *see* Newton's law of gravitation  
 universal constant of, 266, 274-275, 481  
 Gravitational potential energy, on the earth's surface, 337  
 astronomical, 339-342  
 Gravity, acceleration of, *see* Acceleration of gravity  
 center of, 204, 210-211, 249, 259  
 work of, 331, 336, 339  
 Greek science, 66-86, 304, 434  
 astronomical theories of, 74-86  
 and atomic theory, 437-440  
 chronology of, 66  
 and philosophy, 67-72, 83  
 Greenwich hour angle, 40  
 Greenwich meridian, 33, 39  
 Gregory, J. G., 440  
 Guericke, Otto von, 312  
 Halifax, Lord, 218  
 Halley, Edmond, 268, 270  
 Halley's comet, 274  
 Harvey, William, 303  
 Hawkins, Gerald S., 57-58  
 Heat, in Aristotelean physics, 356  
 atomic, 472, 475  
 Black's theory of, 357, 360-361, 369  
 as a form of energy, 327, 369-371  
 generation of, 232, 369-371  
 kinetic conception of, 441, 443-444  
 latent, *see* Latent heat  
 matter of, *see* Caloric theory  
 mechanical equivalent of, 370-371, 481  
 specific, *see* Specific heat  
 units of, 363, 364  
 use of term, in thermodynamics, 380  
 as a vibrational motion, 348, 449  
 Heat engine, types of, 399, 412  
 ideal, of Carnot, 413-418  
 efficiency of, 419, 420, 425  
 Heat flow, 360-361, 367-369  
 and degradation of energy, 429  
 and kinetic theory, 444  
 by radiation, convection, and conduction, 367-369, 444  
 spontaneous, 418  
 Heat of vaporization, *see* Latent heat of vaporization  
 Heat pump, ideal, 418  
 Heating coil, 376  
 Heating function, 395  
 Heeschen, D. S., 142 (ftn)  
 Heliocentric theory, 80-84, 90-96, 103-113  
 Helmholtz, Hermann von, 380, 441  
 Henderson, Lawrence J., 366 (ftn)  
 Heraclides of Pontus, 75-79, 89  
 Heraclitus, 69, 438  
 Hero of Alexandria, 399  
 Herschel, Sir William, 280  
 Hertzprung, Ejnar, 134  
 Hicetas, 74  
 Hipparchus, 26, 28, 73, 84, 118  
 Hobbes, Thomas, 310  
 Hogben, Lancelot, 26 (ftn), 31 (ftn)  
 Holton, Gerald, 106 (ftn), 111 (ftn)  
 Hooke, Robert, 262, 268, 270, 315, 441, 452 (ftn)  
 Hooke's law of elasticity, 315, 447  
 Horizon, astronomical and visible, 14  
 Horsepower, 329, 481  
 Horsepower-hour, 329  
 Hour (unit of angular measure), 38  
 Hour angle, 36-39, 42  
 Greenwich, 40  
 Hour circles, 36, 37  
 Hoyle, Fred, 149  
 Hubble, Edwin P., 142, 145  
 Hubble age of the universe, 145, 147  
 Hume, David, 297  
 Huygens, Christian, 165, 222, 259, 262, 268, 327  
 Hydraulic machines, 319  
 Hydrogen, in the sun, 277  
 in the universe, 148  
 Hydrostatics, 159, 312, 317-319  
 Ice, melting of, 367  
 dry, *see* Carbon dioxide, solid  
 Ice point, 359  
 Ideal gas, definition of, 382, 393  
 equation of state, 383-385, 389, 453, 465  
 Joule's law for, 392, 393  
 Ideal-gas temperature scale, 423-424  
 Idealism, 304  
 Idealization of physical problems, 344  
 Impetus, 160  
 Impulse, 254  
 Inductive inference, 298  
 Industrial revolution, first, 398  
 and steam engine, 399  
 Inertia, 160, 183, 221, 233  
 moment of, 356, 489-490  
 Inertial frame of reference, 250  
 Infinite universe, 103  
 Inquisition, 156  
 Integration, 424, 484-490, *see also*, Displacement as an area  
 Intermolecular forces, 446-447, 452  
 Internal energy, and specific heat, 396  
 Intrinsic brightness, *see* Brightness of stars, intrinsic  
 Inverse square law, 265-267, 270  
 and closed planetary orbits, 273  
 Irreversible physical processes, 429  
 and entropy growth, 432  
 Islamic culture, 88  
 Isochronous motion, 352  
 Isothermal change of state, 416  
 Isotopes, 464  
 James, William, 99  
 Jammer, Max, 83 (ftn)  
 Jones, Howard Mumford, 2 (ftn)  
 Jones, Sir H. Spencer, 119  
 Joule, James P., 371, 375, 380, 392-393, 441, 452 (ftn)  
 Joule (energy unit), 329, 481  
 Joule's law, 382, 392-393, 423, 453-454  
 Jupiter, atmosphere of, 277 (ftn), 279  
 mass and composition of, 277  
 satellites of, 153, 277  
 as a source of energy, 277  
 Kant, Immanuel, 307  
 Kelvin, Lord (Sir William Thomson), 303, 385, 393, 420, 428  
 porous-plug experiment of, 393  
 and concept of thermodynamic temperature, 385, 420-423  
 Kelvin absolute temperature, 388, 423, 425  
 and kinetic energy, 458, 466  
 negative values, 425 (ftn)  
 Kepler, Johannes, 106-113, 262, 281, 287, 296  
 Kepler's laws of planetary motion, 107  
 first law, 111-113, 269, 273  
 second law, 108, 269, 271-273  
 third law, 108, 112-113, 265, 267  
 Kilogram-calorie, 364  
 Kilowatt, 329  
 Kinetic energy, 326  
 of harmonic motion, 353  
 and Kelvin temperature, 458, 466  
 of rotation, 335-337  
 of thermal agitation, 458, 466, 470-473  
 of translation, 334  
 Kinetic equilibrium, 468-469  
 Kinetic theory of gas pressure, 441, 455-458  
 Kinetic-molecular theory, 430  
 basic assumptions of, 441-443  
 Kronig, A., 441  
 Kuhn, T. S., 74 (ftn), 101 (ftn), 412 (ftn)  
 Latent heat of fusion, 367  
 Latent heat of vaporization, 365, 404, 426, 436, 450  
 Latitude, 13, 16, 23, 33-35  
 astronomic *versus* geocentric, 285  
 celestial, 44  
 and variation of gravity, 282-284  
 Leavitt, Henrietta, 131, 294  
 Lee, O. J., 121  
 Leibniz, Gottfried Wilhelm, 219  
 Lemaître, Abbé Georges E., 146  
 Leucippus, 70, 438, 439  
 Lever arm, 209  
 Leverrier, J. J., 280  
 Levers, 204, 209, 345  
 Life, and entropy, 434  
 Light, emission of, 444  
 speed of, 130, 482  
 Light-years, 122, 481  
 Line of nodes, 57  
 Line vector, 188  
 Lippershey, Hans, 153  
 Liquids, 315-316, 449-450  
 free surface of, 319  
 Lobachevski, 9, 147

- Locke, John, 305, 306, 310  
 Longitude, 13, 33, 39-40, 54  
 celestial, 44, 91  
 Lowell, Percival, 280  
*Luminosity*, *see* Brightness of stars, intrinsic  
 Lunar month, 25  
 Lunar Society of Birmingham, 406  
 MKS system, 241-243, 329  
 Machines, simple, 344-347  
 perpetual-motion, 374  
 Magellanic clouds, 131, 133  
 Magnitude of stars, 123 (ftn)  
 Manometer, 320-321  
 Mapping, of the celestial sphere, 37, 44-50  
 of the earth, 33-36, 39-40  
 Mars, atmosphere of, 279  
 orbit of, 80, 108 (ftn), 112  
 variations in brightness, 78  
 Mass, 233  
 center of, 257-259, 278, 334  
 of the earth, 275, 480  
 measurement of, 240-241  
 of moon and planets, 278-279, 480  
 of the sun, 277, 480  
 Materialism, 302, 304, 440  
 Mathematics, beginnings of, 8  
 Greek, 68-71  
 role of in science, 297  
 Matter, solid, liquid, and gaseous states of, 315-316, 445-450  
 Matter of heat, 361  
 Maxwell, James Clerk, 452 (ftn), 469  
 Mayer, Julius Robert von, 374, 392  
 Mean solar units of time, 53, 241  
 Measure value of a physical quantity, 189  
 Mechanical advantage, 346, 402  
 Mechanical efficiency of a heat engine, 408  
 Mechanical energy, 326  
 Mechanical equivalent of heat, 370-371, 481  
 Mechanics, Newtonian, 100, 220-259, *see also*, Newton's laws of motion  
 failure of, 474-478  
 statistical, 469, 471-472  
 Melting, 366, 449  
 Mercury, 77-81  
 precession of the perihelion of, 270  
 Meridian, terrestrial, 33  
 celestial, 14, 39  
 Meridian plane, 14, 33  
 Meridian telescope (transit), 18, 41, 43  
 Meteorites, 276  
 Meteors, 276, 370 (ftn)  
 Metric systems, 241-243, 329  
 Michell, Rev. John, 274  
 Milky Way, galactic system of stars, 124, 135-136  
 Miller and Kusch's measurements of molecular speeds, 463  
 Mind-and-matter problem, 303-305  
 Mines, pumping of, 400-401  
 Models, molecular, 470  
 Molar specific heat, 472, 473  
 Mole (gram molecule), 465  
 Molecular beams, 461-463  
 Molecular weights, chemical scale of, 463-465  
 short table of, 473  
 Molecules, application of Newton's laws to, 455, 477  
 basic conception of, 442-443  
 diatomic, 422, 470, 477  
 forces between, 446, 447, 452  
 in molecular beams, 461-462  
 monatomic, 442  
 reality of, 467  
 stability of, 448  
 Moment of inertia, 336, 489-490  
 Momentum, 252-259  
 angular, 273  
 conservation of, 253  
 Monists, 438  
 Moon, absence of atmosphere on, 279  
 acceleration of, 268-269, 279 (ftn)  
 distance of, 118, 480  
 eclipses of, 57  
 influence of, on the earth, 251, 278-279  
 motion of, 56, 57  
 and ocean tides, 106, 285-286  
 orbit of, 57  
 phases of, 55-56  
 surface of, 153  
 synodic and sidereal periods of, 55-57  
 Moons of Jupiter, 153, 277  
 Morison, Samuel Eliot, 32 (ftn)  
 Moslem influence on revival of learning, 88  
 Motion, degrees of freedom of, 471, 474, 478  
 free fall, 161-163  
 Galileo's analysis of, 161-185  
 "natural" and "violent," 160  
 in one dimension, 167-182  
 perpetual, 374  
 projectile, 183-185  
 simple harmonic, 348-353  
 uniform circular, 244-249  
 uniformly accelerated, 162-163, 177, 179-181  
 vibrational, 348-353  
 vibratory, in solids, 448-449, 475, 477  
 Motions of the stars, apparent, 10-15  
 proper, 44, 121-122  
 Mumford, Lewis, 51 (ftn), 309  
 Mycenae, 64  
 NCP (north celestial pole), 11  
 Nadir, 14  
 Nautical Almanac, American, 34  
 Navigation, 40  
 Neoplatonic mysticism, 87, 102, 111  
 Neptune, discovery of, 280  
 Newcomen, Thomas, 402  
 Newcomen steam engine, 365, 402-403  
 Newton, Sir Isaac, 166, 439, 441  
 achievements of, 218-220  
 discovery of law of gravitation by, 262-267  
 impact of ideas of, 269-270, 287, 299-311  
 impact of, on social thinking, 309-311  
 life of, 217-220  
*Opticks*, 219  
*Principia*, 69, 157, 269-270  
 Newton (unit of force), 243, 481  
 Newton's law of gravitation, 266  
 and closed planetary orbits, 273 (ftn)  
 mathematical formulation of, 264-267  
 for a uniform spherical shell, 269  
 Newton's laws of motion, 220-259  
 application to molecules, 455  
 first law, 183, 221, 223-227  
 as formalisms, 375  
 frames of reference for, 250-252  
 limitations of, 220, 259, 271, 474-478  
 second law, 221, 232-235, 254  
 third law, 205 (ftn), 221, 252-253  
 and time scales, 250-251  
 Newtonian mechanics, 100, *see also*, Newton's laws of motion  
 failure of, 474-478  
 Non-Euclidean geometry, 9-10, 147  
 Novae, 130, 153  
 Nuclear reactions, 148  
 Numerology, 106  
 Objectivity in science, 306  
 Observations, by Aristotle, 73  
 astronomical, 74, 104, 135  
 casual, 292  
 versus authority, 151-152  
 versus reason, 296-297  
 One-dimensional motion, 167-183  
 Orbital radius, relative, 93, 95  
 Orbits, planetary, 75-85, 91-96, 101-102, *see also* Kepler's laws of planetary motion of comets, 274  
 Order, disorder, and entropy, 435  
 Oresme, Nicole, 160  
 Oscillatory motion, 348-353  
 Osiander, Andreas, 103  
 Parallax, 117  
 annual or heliocentric, 121  
 horizontal geocentric, 118-119  
 Parallelogram of forces, 159, *see also*, Vector algebra, addition  
 Parallels of latitude, 33  
 Parmenides, 29  
 Parsec, 122  
 Pascal, Blaise, 312  
 Pascal's principle, 319  
 Peirce, Charles S., 99  
 Pendulum, Foucault, 252  
 simple, 165, 348, 353  
 torsion, 274  
 Perfect gas, *see* Ideal gas  
 Perihelion, 108  
 precession of, 270  
 Period, of loaded spring, 352  
 of simple pendulum, 353  
 Periods of orbital motion,  
 sidereal, 56, 92-95, 109  
 synodic, 55, 57, 60, 92  
 Perrin, Jean, 467, 468  
 Perpetual-motion machines, 374  
 Petit, A. T., 475  
 Phase angle, 351  
 Philolaus, 74  
 Philosophy, and acceptance of scientific theories, 101  
 and atomic theory, 438-441

- Philosophy (*continued*)  
 of common sense, 83  
 of Descartes, 262, 296-297  
 divorce of science from, 289  
 in the eighteenth century, 299-311  
 of empiricism, 151, 296-297  
 Greek, 67-73, 82-83, 434, 438-440  
 mind-and-matter problem in, 303-305  
 of neoplatonic mysticism, 87, 102, 111  
 of pragmatism, 98-99  
 scholastic, 88
- Photosynthesis, 434
- Physical equations, complete, 178
- Physical quantities, 178, 188-189  
 primary and secondary, 178, 243  
 scalar and vector, 166-167, 188
- Plague, 89, 218, 262
- Planck, Max, 476
- Planetary orbits, 75-85, 91-96, 101-102, *see also*, Kepler's laws of planetary motion
- Planets, atmospheres of, 279  
 inferior, 76, 78  
 masses of, 279, 480  
 observed motion of, 59-60  
 orbital radii and periods, 93-94, 109, 113, 480  
 in Ptolemaic theory, 85  
 retrograde motion of, 42, 59-60, 77, 92  
 variations in brightness of, 60, 78-79
- Plastic flow, 281 (ftn)
- Plato, 9, 70-71, 86, 87, 438, 440
- Pluto, discovery of, 280
- Polar axis, 13
- Polar coordinates, 193, 273
- Polaris, 11, 18, 35, 39
- Pole star, 11, 28
- Poles, celestial, 11-12
- Pope Gregory XIII, 26
- Pope Paul V, 156
- Pope Urban VIII, 156
- Populations, stellar, 135
- Position-time graphs, 168-171
- Position vector, 191, 198-200
- Positivism, 304
- Potential energy, 326  
 astronomical, 339-342  
 and center of mass, 339  
 of harmonic motion, 353  
 and latent heat, 451  
 local gravitational, 337
- Pound-force, 239, 481
- Poundal, 240
- Power, 326-327  
 sources of, 374  
 steam, 398-399
- Power plant, 327  
 efficiency of, 381, 408, 425-427  
 steam, 408
- Pragmatism, 99
- Precession, of the equinoxes, 24, 26-28, 42, 44, 76, 285  
 of the perihelion of Mercury, 270
- Pressure, absolute, 322  
 atmospheric, 321-322, 324-325  
 definition of, 314  
 gauge, 321  
 hydrostatic, 317-319  
 and kinetic theory of gases, 453-458
- of mixture of gases, 453
- Pressure-volume diagram, 323, 379, 409, 416, 419
- Pressure-volume relation for a gas, 323
- Pressure gauge, 320-321
- Priestley, Joseph, 406
- Prime meridian, 33
- Projectile motion, 183-185
- Proper motion of a star, 44, 121-122
- Proportionality, 163, 233
- Ptolemy, Claudius, 73, 84-85, 89-90, 95-96  
*Almagest*, 85, 89, 101 (ftn)  
 astronomical system of, 85, 101-102
- Ptolemy I, 73
- Pumps, air, 312, 319-320  
 heat, 418  
 water, force, 400 (ftn)  
 for mines, 400-401  
 steam-driven, 401-402  
 suction, 400
- Purpose in nature, 71, 161, 299, 301, 440
- Pythagoras of Samos, 29, 70-71, 438
- Pythagoreans, 73, 83, 87, 106
- Qualities, primary and secondary, 300, 439
- Quantity of motion, 252
- Quantum theory, 271, 394  
 and specific heat, 476, 478
- Quasars, 136, 142, 145
- RAZ, 46
- Radian, 18 (ftn)
- Radiation, heat, 367, 369  
 wave theory of, 371
- Ramus, Petrus, 111
- Randall, J. H., Jr., 67, 68 (ftn), 296, 299, 302
- Rate of change of variable quantity, 172, 175
- Rationalism, 301-302
- Reactions, chemical, 376, 453  
 nuclear, 148
- Reality and appearance, 98, 304, 306
- Reason *versus* observation, 296-297
- Red shift in stellar spectra, 142, 144
- Re-entry of space vehicles into atmosphere, 370 (ftn)
- Relativity, general, 147, 271
- Religion and science, 289, 300-302, 307-309
- Renaissance, 89, 158
- Restitution, coefficient of, 256, 257
- Resultant (vector sum), 167, 194-195, 205, 223
- Retrograde motion, 42, 92
- Reversibility of the Carnot cycle, 417-418
- Reversibility of physical processes, 371-372
- Reversible changes of state, 416-417  
 and entropy, 430
- Revival of Learning, 158
- Richer, Jean, 118
- Right ascension, 41-44, 46, 48, 59
- Roebuck, John, 406
- Roman civilization, 87
- Root-mean-square speed, 459
- Rotation of the earth, 52, 74-76, 81, 282-283
- Rotative equilibrium, 209, 249
- Royal Society of London, 218, 268, 406
- Rudolf II of Bohemia, 104, 106
- Rumford, Count (Benjamin Thompson), 370, 374, 380
- concept of heat of, 441
- STP, 384
- St. Augustine, 87
- St. Thomas Aquinas, 88, 103
- Sandage, Alan R., 136
- Satellite, artificial, 339-342  
 escape energy of, 342  
 speed of, 354-355
- Satellites, of Jupiter, 153, 277
- Savery, Thomas, 402
- Scalar components of vectors, 191-194, 328
- Scalar-vector distinction in mathematics, 191
- Scalar-vector distinction in physics, 166-167, 191
- Schiaparelli, Giovanni V., 80
- Scholastic philosophy, 88-89
- Schrödinger, Erwin, 434
- Science, classifications of, 6-8  
 and communication, 291  
 cycles in growth of, 295  
 definition of, 5-6  
 limitations of, 306-307  
 mathematical foundation of, 297  
 origin of, 4  
 and religion, 289, 300-302, 307-309  
 and technology, 2-5, 158, 293, 398-399
- Scientific knowledge, nature of, 306  
 and religious faith, 307-309
- Scientific method, 98  
 evolution of, 296-298
- Scientific procedures, 289, 291-296  
 mathematical, 295, 297  
 observational, 292  
 theory-building, 293-295
- Scientific theories, *see* Theories, scientific
- Sea breeze, 397
- Seasons, 19-23
- Sense-experience and knowledge, 304-305
- Sextant, 36
- Shapley, Harlow, 134
- Shear, 314-315, 316, 370
- Sidereal period, 56, 92-95, 109
- Simple harmonic motion, 348-353
- Slope of a line in physical units, 174 (ftn)
- Slug, 239
- Smoluchowski, Marian, 468
- Snell, Bruno, 65
- Snow, carbon dioxide, 373
- Social thinking and Newtonian physics, 309-311
- Socrates, 70-71, 86
- Solar system, Copernican theory of, *see* Copernican theory
- Ptolemaic theory of, 84-85, 101-102
- Tychonic theory of, 80, 104

- Solid elements, atomic heats of, 475-476  
 Solid state, 315-316, 445, 448-449  
 Solstices, winter and summer, 20, 22-23  
 Sound, speed of, *see* Speed of sound  
 Space, curvature of, 147  
 Specific heat, classical theory of, 472-474  
     definition of, 363, 394-396  
     of gases, 389-393, 473  
     influence of vibrational frequency on, 477  
     and internal energy, 396  
     molar, 472-473  
     and quantum theory, 478  
     of solid elements, 475-476  
     table of, 365, 473  
     variation of, with temperature, 393-394  
     of water, 363, 366 (ftn)  
 Specific heat function, 395  
 Spectra, 125-127  
     absorption, 126-127  
     bright-line, 125, 126  
     of stars, 127-130, 144  
 Spectroscope, 125  
 Speed, 166 (ftn), 171-172  
     of free fall, 161-163  
     terminal, 162  
 Speed of gas molecules, root-mean-square value, 459  
     and Brownian movement, 466-467  
     and diffusion, 461  
     measurement of, 461-463  
     and speed of sound, 460  
     table of, 460  
 Speed of sound, 453, 460  
     and specific heat, 391, 393, 477  
 Spring balance, 202, 204  
 Springs, potential energy of, 342  
     stiffness of, 342, 352  
 Stability of a molecule, 448  
 Standard location, 239  
 Star maps, construction of, 41, 44-50  
     use of, 46  
 Star populations, 135  
 Stars, apparent motion of, 10-15  
     brightness of, *see* Brightness of stars  
     circumpolar, 16, 47  
     as clocks, 50  
     culmination of, 16, 18  
     distances of, 120-125  
     double, 131  
     evolution of, 148  
     globular cluster of, 138  
     magnitude of, 123 (ftn)  
     morning and evening, 77  
     parallax of, 121-123  
     proper motions of, 44, 121-122  
     pulsating, 131  
     trails of, 12, 38  
     variable, 130  
 State, thermodynamic, 377-378  
     changes of, 379  
     equation of 383-385, 389, 453, 465  
 Statics, 159, 201, 203-215  
 Statistical mechanics, 425 (ftn), 430, 469, 471-472  
 Steady-state cosmology, 149  
 Steam engine, cyclic, 408-410  
     *and the first industrial revolution*, 399  
     *mechanical and thermodynamic efficiency of*, 408  
     Newcomen, 402-403  
     noncondensing, 408  
     Watt's condensing, 405  
     *see also*, Heat engine  
 Steam jets, 399  
 Steam point, 359  
 Steam pumps, of Savery and Newcomen, 402  
 Steam turbines, 373, 400  
 Stern, Otto, 463  
 Stevin, Simon, 159, 204, 205, 374  
 Stone Age, 61  
 Stonehenge, 25, 57-58  
 Strain, elastic, 315  
 Strato, 79  
 Stress, 314  
     in a fluid, 317  
     frictional, 316  
     shear, 316  
 Suction pump, 400  
 Summation sign, 258  
 Sun, chemical constitution of, 127  
     as a clock, 50  
     distance from earth, 119, 480  
     interior of, 277  
     mass of, 277, 480  
     motions of, 19-21  
     right ascension and declination of, 48  
     spectrum of, 127  
 Sundial, 52  
 Sundial time, 34, 40  
 Sunspots, 153  
 Supernovae, 131  
 Superposition of motions, 71-72, 84-85, 469-471, 475  
 Surface tension, 451  
 Synodic period, 55, 57, 60, 92  
 Systems, biological, 433-434  
     chemical, 430  
     isolated, 433  
     mechanical, 342, 343 (ftn)  
     thermodynamic, 343 (ftn), 377  
 Technology, 2, 5, 158, 293  
     *and the industrial revolution*, 398  
 Telescope, equatorial mounting of, 44  
     Galileo's, 153  
     Lick, refracting, 45  
     meridian, 18, 41  
     Mt. Palomar, 134  
 Temperature, and chemical reaction, 356  
     equality of, 358  
     gradient of, 367  
     *and kinetic energy*, 458, 466  
     measurement of, 357  
     thermodynamic, 386, 420-425  
 Temperature scales, absolute, 387  
     absolute centigrade, 385, 388, 421  
     Celsius, 359, 385, 388  
     Celsius thermodynamic, 421-423  
     Fahrenheit, 359, 388  
     ideal gas, 423-424  
     Kelvin thermodynamic, 388, 423-425  
     thermodynamic, 386, 388, 420-425  
     *see also*, Thermometers  
 Tension, 314-315  
 Terminal speed, 162  
 Thales of Miletus, 9, 69, 438  
 Theodolite, 17  
 Theophilus, 87  
 Theories, scientific, 7, 293-295  
     acceptance of, 101  
     criteria of excellence for, 100, 101  
     evolution of, 394  
     Greek and modern views of, 98, 99  
     nature of, 96, 97  
     *and reality*, 98  
     value of, 97, 98  
 Thermal energy, of a solid, 449  
     *and degrees of freedom*, 474, 475  
     *distribution of*, *see* Equipartition theorem  
     *and specific heats*, 472-478  
 Thermal equilibrium, 357-358, 361-362, 458  
     *and concept of temperature*, 425 (ftn)  
     *and entropy*, 431, 433  
 Thermodynamic efficiency, 408  
 Thermodynamic equilibrium, 378, 433  
 Thermodynamic state, 377-378  
 Thermodynamic temperature scales, 386, 388, 420-425  
 Thermodynamics, 376, 420  
     first law of, 377-378, 380, 421  
     second law of, 377, 399, 428-429  
     third law of, 377 (ftn)  
     use of the term "heat" in, 380  
 Thermometers, calibration of, 359  
     constant-volume gas, 358, 385-387  
     helium, 386  
     ice point and steam point of, 359  
     invention of, 356-357  
     mercury-in-glass, 358, 385  
     primary and secondary, 359, 385  
 Thompson, Benjamin, *see* Rumford, Count  
 Thomson, Sir William, *see* Kelvin, Lord  
 Tides, 106, 285-286  
 Time, civil, 53  
     equation of, 54  
     local apparent solar, 40, 51, 54  
     local mean solar, 53, 54  
     measurement of, 50-54  
     sidereal, 43  
     standard, 53  
     sundial, 34, 40  
     universal, 54  
     zones of, 53  
 Timocharus, 26  
 Tombaugh, Clyde W., 280  
 Torricelli, Evangelista, 312, 321  
 Torque, 207-211  
     about center of gravity, 249  
 Toynbee, Arnold J., 62  
 Transit, meridian, of an astronomical body, 41, 43, 48  
 Transit, surveyor's, 17, 35  
     astronomical, 18, 41  
 Trevithick, Richard, 407  
 Triangulation, 115-118  
 Truth, absolute, 98  
 Two-body system, 259, 278  
     *gravitational potential energy of*, 339-342  
 Tycho Brahe, 80, 104, 111

- Uniform circular motion, 71, 244–246, 350  
 Uniformly accelerated motion, in one dimension, 163, 177, 179–183  
     in two dimensions, 183–185  
 Units of measure, 189, 481  
     consistent, 178–179, 234  
 Unit systems, 178–179  
     British gravitational, 239–240, 329  
     CGS and MKS, 241–243, 329  
 Units of area, scale, 179  
 Units of structure, chemical, 442  
 Universe, age and birth of, 146–147  
     Dante's view of, 299  
     earth-centered, 74, 84–85  
     energy of, 146, 148  
     entropy of, 433  
     evolution of, 145–149  
     heliocentric, 83, 90–96  
     infinite, 103  
     as a machine, 300  
 Universities, early, 88  
 Uraniborg, 104  
 Uranus, irregular motion of, 280  
 Vacuum, 440, 461  
 Vacuum pump, invention of, 319–320  
 Vapor pressure, 366, 402, 416  
     and temperature, 436, 450–452  
 Vaporization, latent heat of, 365, 404, 426, 436  
     two-current theory of, 366, 451–452  
 Variables, independent and dependent, 169–171
- Vector algebra, 166–167, 188–189, 198, *see also, Vectors, mathematical*  
 Vector components, 196  
 Vector physical quantities, 166–167, 191  
     in one dimension, 167  
 Vector sum rule of statics, 205–207, 223  
 Vectors, addition of, 195–196  
     mathematical, 190–198  
     multiplication by a scalar, 198  
     scalar components of, 191–194  
     subtraction of, 197  
     vector components of, 196–197  
 Velocity and speed, 166 (ftn), 171  
 Velocities, addition of, 201  
     in one dimension (scalar velocity), 171–176  
     in two and three dimensions (vector velocity), 198–201  
 Venus, maximum elongation of, 93  
     observed behavior of, 77–81  
     phases of, 154–155  
 Vertical circle, 17  
 Vertical motion, 163, 181–182  
 Vinci, Leonardo da, 158, 159, 296, 374  
 Viscosity, 232, 317 (ftn), 370  
 Voltaire, 291  
 Vowles, H. P., 402 (ftn)
- Water, decomposition of, 376  
     specific heat of, 363  
     unique properties of, 366  
 Water-wheel analogy, 411–414  
 Watt, James, 365 (ftn), 402–407
- condensing steam engine of, 405  
 Watt (unit of power), 329  
 Wave motion in solids, and heat, 449  
 Weber, H. F., 393  
 Weight, 202  
     as distributed force, 210, 266  
     and law of gravitation, 263, 266  
     and mass, 234, 239  
 Whitehead, Alfred North, 304 (ftn)  
 Worcester, Marquis of, 402  
 Work, 326  
     as the area under a graph, 330  
     as a definite integral, 331  
     definition of, basic, 328  
     definition of, corrected, 333  
     of gravity, 331, 336  
     reversible, 371–373  
     on rolling bodies, 332–333  
     and sliding friction, 331  
     units of, 329, 481  
 Wren, Sir Christopher, 268  
 Wright, J. K., 31 (ftn)
- Year, length of, 24–26, 28, 481  
 sidereal, 28, 481  
 tropical (seasonal), 19–21, 26, 28, 481  
 Young, Thomas, 219, 371, 441
- Zenith, 14  
     declination of, 48, 50  
     right ascension of, 46–47  
 Zenith distance, 18, 36  
 Zero, absolute, 385, 387, 425  
     absolute, and specific heat, 476  
 Zero state of internal energy, 378  
 Zodiac, 24, 76