# INDEX

## A

absolute stationary space, 26, 28–31, 33, 35 acceleration, 14–16, 69–72, 95–96, 120, 124–132. *See also* equivalence principle action and reaction, law of, 22, 95 adding velocity, 43, 44–46, 48–49 Alpha Centauri, 80–81 Andromeda galaxy, 81–82 anomalous perihelion, 162, 164 antiparticles, 102–103

## В

bending light, 16, 133–142, 162–163 Big Bang theory, 150–152 black holes, 162, 164

#### С

centrifugal force. 127-129 centripetal force, 129 conservation of energy, law of, 97-99 conservation of mass. law of. 97\_98 constructive interference. 41-42 contraction of length, 86-91, 106-109 calculating, 106–107 and muons. 108–109 coordinate systems, 28-29 and Galilean transformation. 47-48.109 space-time, 37 and special relativity theory, 70-71, 120

cosmic rays, 108–109 curvatures, in space-time, 140, 162 Cygnus, 164

#### D

destructive interference, 41–42 diffraction, light, 41–42 dispersion, light, 40–41

## E

Earth's movement, 20-21, 35, 94 Finstein Albert on gravity and acceleration, 120.131 on Newtonian Mechanics. 34-36 on speed of light, 34-37 Einstein field equations, 162 electrical energy, 98 electromagnetic radiation, 24-26, 40.103 electrons. 43. 102-103 elementary particles, 108–109  $E = mc^2$  (mass-energy equivalence), 99-102, 112-113 energy conservation of, law of, 97-99 electrical, 98 kinetic, 98, 113, 160 mass-energy equivalence  $(E = mc^2)$ , 99–102, 112-113 pair annihilation, 102-103 equivalence principle, 72, 120-121, 131 ether. 26-30 ether wind. 31-33

#### F

F = ma equation, 22, 47, 95, 109, 111–112 Friedman, Alexander Alexandrovich, 150

#### G

Galilean principle of relativity, 17-22, 33, 47-48, 109-111 Galilean transformation, 47-48, 109-111 Galilei, Galileo, 17 gamma ( $\gamma$ ) rays, 40, 102–103 general relativity theory. See relativity, general theory of Global Positioning System (GPS), 165 gravitational lensing, 162–163 gravitational potential, 158, 160-162 gravity, 16 acceleration and, 14-16, 69-72, 95-96, 124-132 elimination of, 131-133 equivalence principle and, 72, 120-121, 131 light bending, 16, 133-142, 162-163 moon's vs. Earth's, 94 time dilation and, 70-72, 143-148 warped space-time, 136, 141-144, 158. 162, 164 zero-gravity space, 94-95 great circles, 140

## H

Hubble, Edwin, 150–152

#### Ι

inertia, law of, 18, 22, 95, 123 inertial forces centrifugal force, 127–129 centripetal force, 129 examples of, 120–129 inertial reference frames, 15 and Newton's three laws of motion, 18 and the Galilean principle of relativity, 19, 22, 47 and space-time, 139 and special relativity theory, 34, 69–70, 120–122 infrared light, 40 interference, light, 41–42

## K

kinetic energy, 98, 113, 160

## L

law of action and reaction. Newton's 22 95 law of conservation of energy. 97-99 law of conservation of mass. 97\_98 law of inertia. Newton's. 18. 22. 95 123 laws of motions. See Newton's three laws of motion length. contraction of. 86-91. 106-109 calculating, 106–107 muons and. 108-109 lensing, gravitational, 162–163 life spans, muon, 108–109 light bending of, 16, 133-142, 162-163 as electromagnetic wave, 24-26.40 electrons and. 102 Maxwell's equations, 40-41

measuring time by, 58, 60–65, 78–79 properties of dispersion, 40–41 interference and diffraction, 41–42 polarization, 42 reflection, 40–41, 58–59 refraction, 40–41 scattering, 42 speed of. See speed of light types of, 40–42 light clocks, 58, 60–65, 78–80 Lorentz transformation, 48, 106–107, 111–112

## Μ

mass. 94 conservation of mass, law of, 97-98 F = ma equation, 22, 47, 95, 109, 111-112 positron/electron collisions. 102-103 speed of light and, 92-97, 109-113 vs. weight, 93-94 mass-energy equivalence  $(E = mc^2)$ , 99–102. 112-113 maximum velocity. 92–93 Maxwell, James Clerk, 24 Maxwell's equations, 24-26, 40 medium(s). 26-27. 40. See also ether Mercury, anomalous perihelion procession of, 162, 164 Michelson, Albert Abraham, 32 Milky Way galaxy, 35, 81-82 Morley, Edward Williams, 32 motion See also Newtonian Mechanics of Earth. 20-21. 35 laws of action and reaction. 22. 95 F = ma equation, 22, 47, 95. 109. 111-112 inertia, 18, 22, 95, 123

perceived motion, 20–21 uniform linear motion, 18, 69, 95, 134 muons, 108–109

#### Ν

near-light speeds. See also speed of liaht and length contraction, 86–91 and mass. 92 muons traveling at, 108–109 and time dilation. 54-55. 57-63.73-75 and the twin paradox, 65-68 Newtonian Mechanics basis for 22 Einstein on, 34–36 Galilean principle of relativity and, 47-48 expansion of space, 151 speed of light and, 25, 32, 43, 112-113 time and space as separate, 37 Newtonian velocity addition, 43, 44-45.48-49 Newton's three laws of motion. 22, 95 equation of motion (F = ma). 22, 47, 95, 109, 111-112 law of action and reaction. 22.95 law of inertia, 18, 22, 95, 123 non-inertial reference frames, 15 nonrelatavistic addition of velocity, 43, 44-45, 48-49

## Ρ

pair annihilation, 102–103 parabolas, 134, 137–139 particles, 102–103 perceived motion, 20–21 perihelion, 162, 164 polarization, light, 42 polarizing filters, 42 positrons, 102–103 Pythagorean theorem, 61–63, 73–75, 78–80

#### R

radio waves, 40, 165 reference frames inertial references frames. See inertial reference frames non-inertial references frames, 15 reflection, light, 40-41, 58-59 refraction, light, 40-41 relativistic addition of velocity, 44, 46,47 relativity Galilean principle of, 17-22 general theory of, 14–16 bending light, 16, 133-142, 162-163 Big Bang theory and, 150-152 equivalence principle and, 72, 120-121, 131 time dilation, 70-71, 158-162 universe, expanding and contracting, 150-151 special theory of, 14-15, 34-37 time and space as coordinate system, 37,91 twin paradox and time dilation, 67-73 and the universe, 149–152

#### 9

scattering, light, 42 simultaneity mismatch, 44–46 slowing of time. *See* time dilation solar system, 35, 80 space-time, 37, 139–144, 158, 162, 164 special relativity theory. *See* relativity, special theory of speed of light, 22-24. See also near-light speeds as a constant, 24-26, 30, 33, 36-37, 43, 57 and Einstein, 34-37 electromagnetic waves and, 24-26, 40 ether and, 26–30 ether wind and, 31-33 mass-energy equivalence  $(E = mc^2)$ , 99–102, 112-113 maximum velocity, 92–93 Maxwell's equations and, 24-26.40 Newtonian Mechanics and, 25, 32, 43, 112-113 relativistic addition of velocity, 44, 46, 47 weight/mass and, 92–97 SPring-8 Lab, 43 stars Alpha Centauri, 80–81 black holes and, 162, 164

## Т

time dilation, 53–66 calculating, 80–82 equation for, 88, 90 general relativity theory and, 70–71, 143–148, 158–162 measuring with light clocks, 58, 60–65, 78–80 twin paradox and, 67–73 transformation, Galilean, 47–48, 109–111 transformation, Lorentz, 48, 106–107, 111–112 twin paradox, 67–73

#### U

ultraviolet rays, 40 uniform linear motion, 18, 69, 95, 134 universe, relativity and, 149–152 Urashima effect. *See* time dilation

#### ۷

velocity. adding of, 43, 44–46, 48–49 and length, contraction of, 86–91 mass and, 96–97, 113 maximum, 92–93 visible light, 40

#### W

wavelengths, 40, 42 weight, 92–94. *See also* mass weightlessness, 94–95, 121, 131–132, 145 white light, 40–41

#### Х

x-rays, 40, 164

## Ζ

zero-gravity space, 94-95