velocity, 43-46 (see also constant velocity; horizontal velocity; **speed**); angular, 900–901, 900*f*, 901t; average, 43–44, 43f, 45, 45f, 52, 52f; changes in, 48–51, 50f, 51t (see also acceleration); of charge carriers, 610-611, 611*f*; components of, 95, 95*f*; constant acceleration and, 54–58, 58*t*; drift, 610–611, 611*f*; escape, 243; of fluid, 284, 285–286, 285f, 286f; frame of reference and, 102, 102f; graphs of position-time and, 45-46, 45f, 46*f*; instantaneous, 46, 46*f*, 46*t*; of mass-spring system, 368-369, 375t; momentum and, 198–199, 198f; negative, 43, 46, 46f, 51, 51t; one-dimensional, 43-46, 43f, 45f, 46f, 46t; positive, 43, 46, 46f,51, 51t; relative, 103–104; relativistic, 916–917, 916f, 917t; resultant, 84, 84f; speed compared to, 45; terminal, 64; unit of, 43; as vector quantity, 82, 82f

velocity-time graphs, 50, 50*f*; with constant acceleration, 52, 52*f*; of freely falling body, 61, 61*f*

vibrational energy: of atoms in conductors, 611; of molecules, 299, 299*t*

vibrations (*see also* **waves**): damping of, 369; forced, 418–419, 418*f*, 419*f*; of mass-spring system, 368–371, 368*f*, 375*t*; in physics, 5*t*; sound production by, 408–409, 408*f*, 409*f*, 414, 414*f*; symbols in, 852; waves produced by, 383–385, 383*f*, 384*f*, 385*f*

virtual image: in flat mirrors, 453, 453*f*; with lenses, 496, 497*t*, 498, 498*f*, 499; with microscopes, 503, 503*f*; in spherical mirrors, 455, 455*f*, 459, 460*t*, 463, 463*f*; with telescopes, 505, 505*f*

virtual object, 503 viscosity, 284

visible light, 447*t*, 731, 735*f*, 736, 736*f* (*see also* **light; spectrum, visible**); from hot objects, 752, 752*f*, 753*f*; wave-particle duality and, 771

volt (V), 596

voltage (see also potential difference): ac potential difference as, 726; lightning and, 593 voltmeters, 693, 726

volume: constant-volume processes, 339, 339*f*, 344*t*; displaced, 276, 276*f*, 277; of gas, 908–909, 908*f*; of geometric shapes, 842*t*; of liquid, 274; mass density and, 275; work and, 337–338, 337*f*

$\mathbf{V}_{\mathbf{V}}$

water: bipolar molecules of, 579; boiling point of, 301, 302*t*; heating of, 317, 317*f*, 317*t*; melting point of, 301, 302*t*; volume and temperature of, 300

water wheel, 347 watt (W), 180, 620 Watt, James, 294 waveforms, 384, 384f, 385, 385f, 428-429, 428t

wave fronts, 449, 449*f*; of incoherent light, 541; refraction and, 489, 489*f*; spherical, 410–411, 411*f*, 412, 412*f*

wave function, 776–777, 776*f*, 777*f*, 924

wavelength, 384, 384*f*; diffraction and, 535–536, 539; of electromagnetic waves, 447, 447*t*, 448, 732, 735, 735*f*; index of refraction and, 492, 509–510, 509*f*, 510*f*, 511, 511*f*; interference and, 526, 526*f*, 530; of laser, 542, 543; of matter waves, 772, 774, 774*f*, 922–923; refracting wave fronts and, 489, 489*f*; resolving power and, 539; of sound, 411, 411*f*

wavelets, 449, 449*f*; diffraction pattern and, 533, 533*f*

wave-particle duality, 734, 771–774, 773*f*, 774*f*, 922–923, 923*f*

waves (see also diffraction; electromagnetic waves; interference; light; matter waves; reflection; refraction; sound; standing **waves**): amplitude of, 384, 384*f*, 388; coherent sources of, 527 (see also lasers); Doppler effect for, 412-413, 412f, 912, 912t; energy transfer by, 388; frequency of, 385, 386–387; Huygens' principle for, 449, 449f, 532, 533, 533f; interaction of, 389-391, 389f, 390f, 391f (see also interference); longitudinal, 385, 385f, 391, 409, 409f; measures of, 384, 384f (see also wavelength); mechanical, 382, 382f, 386, 388; period of, 386; in physics, 5t; ray approximation for, 449; speed of, 386–387, 448; spherical, 410–411, 411*f*, 414–415, 449, 489, 489*f*; symbols in, 848, 852; transverse, 384, 384*f*, 732, 732*f*; types of, 383–385, 383*f*, 384*f*, 385*f*

weak interaction, 143, 811, 812, 812*t*, 815–817, 815*f*, 816*f*

wedge, 258, 259f

weight, 120–121, 135, 135*f*, 252; apparent, of object in fluid, 275, 276, 277, 278; location and, 246

weightlessness, 252–253, 252f wheel and axle, 258, 259f Wheeler, John, 243 wide-angle lenses, 504 Wilson, Robert, 913, 913f wire, 642; magnetic force on, 690–693, 690f, 691f, 693f; in schematic diagrams, 640, 640f,

work, 160-161, 160f, 161f; in charging a capacitor, 605; electrical, 594, 595, 600, 605, 620; energy transfer and, 336–337, 336*f*; first law of thermodynamics and, 342-345, 342f, 343t, 344t; force and, 160–163, 160f, 161f, 162f, 164, 164f; gas expansion or compression and, 337–338, 337f, 345; heat and, 309-310, 336-337, 336f; by heat engine, 347–348, 347f, 352-354, 356, 356f; kinetic energy and, 164, 166–167, 166f; by machine, 260, 260*f*; by motor, 720; net, 161, 163, 166; power and, 179, 180; by refrigerator, 350–351; sign of, 162–163, 162f, 343,343t; in thermodynamic processes, 339–341, 340f, 341f, 344t; unit of, 161

work function, 757, 759 work-kinetic energy theorem, 166–167, 166*f*



X rays, 447*t*, 735*f*, 737, 737*f*; from sun, 733*f*

Z

zero level: of electrical potential energy, 595; of electric potential, 598, 600; of gravitational potential energy, 170

zeroth-order maximum, 536, 536*f* **zoom lenses,** 504 **Zweig, George,** 813