Equations

Chapter 2 Motion in One Dimension

DISPLACEMENT	$\Delta x = x_f - x_i$
AVERAGE VELOCITY	$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$
AVERAGE SPEED	$\text{average speed} = \frac{\text{distance traveled}}{\text{time of travel}}$
AVERAGE ACCELERATION	$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$
DISPLACEMENT *These equations are valid only for constantly accelerated, straight-line motion.*	$\Delta x = \frac{1}{2}(v_i + v_f)\Delta t$ $\Delta x = v_i \Delta t + \frac{1}{2}a(\Delta t)^2$
FINAL VELOCITY *These equations are valid only for constantly accelerated, straight-line motion.*	$v_f = v_i + a\Delta t$ $v_f^2 = v_i^2 + 2a\Delta x$

Chapter 3 Two-Dimensional Motion and Vectors

PYTHAGOREAN THEOREM *This equation is valid only for right triangles.*	$c^2 = a^2 + b^2$
TANGENT, SINE, AND COSINE FUNCTIONS *These equations are valid only for right triangles.*	$\tan\theta = \frac{\text{opp}}{\text{adj}}$ $\sin\theta = \frac{\text{opp}}{\text{hyp}}$ $\cos\theta = \frac{\text{adj}}{\text{hyp}}$
VERTICAL MOTION OF A PROJECTILE THAT FALLS FROM REST *These equations assume that air resistance is negligible, and apply only when the initial vertical velocity is zero. On Earth's surface, $a_y = -g = -9.81$ m/s^2.*	$v_{y,f} = a_y \Delta t$ $v_{y,f}^2 = 2a_y \Delta y$ $\Delta y = \frac{1}{2}a_y(\Delta t)^2$
HORIZONTAL MOTION OF A PROJECTILE *These equations assume that air resistance is negligible.*	$v_x = v_{x,i} = \text{constant}$ $\Delta x = v_x \Delta t$

PROJECTILES LAUNCHED AT AN ANGLE *These equations assume that air resistance is negligible. On Earth's surface, $a_y = -g = -9.81$ m/s^2.*	$v_x = v_i \cos\theta = \text{constant}$ $\Delta x = (v_i \cos\theta)\Delta t$ $v_{y,f} = v_i \sin\theta + a_y\Delta t$ $v_{y,f}^2 = v_i^2(\sin\theta)^2 + 2a_y\Delta y$ $\Delta y = (v_i \sin\theta)\Delta t + \frac{1}{2}a_y(\Delta t)^2$
RELATIVE VELOCITY	$\mathbf{v_{ac}} = \mathbf{v_{ab}} + \mathbf{v_{bc}}$

Chapter 4 Forces and the Laws of Motion

NEWTON'S FIRST LAW	An object at rest remains at rest, and an object in motion continues in motion with constant velocity (that is, constant speed in a straight line) unless the object experiences a net external force.
NEWTON'S SECOND LAW *$\Sigma\mathbf{F}$ is the vector sum of all external forces acting on the object.*	$\Sigma\mathbf{F} = m\mathbf{a}$
NEWTON'S THIRD LAW	If two objects interact, the magnitude of the force exerted on object 1 by object 2 is equal to the magnitude of the force exerted on object 2 by object 1, and these two forces are opposite in direction.
WEIGHT *On Earth's surface, $a_g = g = 9.81$ m/s^2.*	$F_g = ma_g$
COEFFICIENT OF STATIC FRICTION	$\mu_s = \frac{F_{s,max}}{F_n}$
COEFFICIENT OF KINETIC FRICTION *The coefficient of kinetic friction varies with speed, but we neglect any such variations here.*	$\mu_k = \frac{F_k}{F_n}$
FORCE OF FRICTION	$F_f = \mu F_n$

Chapter 5 Work and Energy

NET WORK *This equation applies only when the force is constant.*	$W_{net} = F_{net} d \cos \theta$
KINETIC ENERGY	$KE = \frac{1}{2} mv^2$
WORK-KINETIC ENERGY THEOREM	$W_{net} = \Delta KE$
GRAVITATIONAL POTENTIAL ENERGY	$PE_g = mgh$
ELASTIC POTENTIAL ENERGY	$PE_{elastic} = \frac{1}{2} kx^2$
MECHANICAL ENERGY	$ME = KE + \Sigma PE$
CONSERVATION OF MECHANICAL ENERGY *This equation is valid only if nonmechanical forms of energy (such as friction) are disregarded.*	$ME_i = ME_f$
POWER	$P = \frac{W}{\Delta t} = Fv$

Chapter 6 Momentum and Collisions

MOMENTUM	$\mathbf{p} = m\mathbf{v}$
IMPULSE-MOMENTUM THEOREM *This equation is valid only when the force is constant.*	$\mathbf{F}\Delta t = \Delta \mathbf{p} = m\mathbf{v_f} - m\mathbf{v_i}$
CONSERVATION OF MOMENTUM *These equations are valid for a closed system, that is, when no external forces act on the system during the collision. When such external forces are either negligibly small or act for too short a time to make a significant change in the momentum, these equations represent a good approximation. The second equation is valid for two-body collisions.*	$\mathbf{p_i} = \mathbf{p_f}$ $m_1\mathbf{v_{1,i}} + m_2\mathbf{v_{2,i}} = m_1\mathbf{v_{1,f}} + m_2\mathbf{v_{2,f}}$

CONSERVATION OF MOMENTUM FOR A PERFECTLY INELASTIC COLLISION *This is a simplified version of the conservation of momentum equation valid only for perfectly inelastic collisions between two bodies.*	$m_1\mathbf{v_{1,i}} + m_2\mathbf{v_{2,i}} = (m_1 + m_2)\,\mathbf{v_f}$
CONSERVATION OF KINETIC ENERGY FOR AN ELASTIC COLLISION *No collision is perfectly elastic; some kinetic energy is always converted to other forms of energy. But if these losses are minimal, this equation can provide a good approximation.*	$\frac{1}{2}m_1v_{1,i}^2 + \frac{1}{2}m_2v_{2,i}^2 = \frac{1}{2}m_1v_{1,f}^2 + \frac{1}{2}m_2v_{2,f}^2$

Chapter 7 Circular Motion and Gravitation

CENTRIPETAL ACCELERATION	$a_c = \frac{v_t^2}{r}$
CENTRIPETAL FORCE	$F_c = \frac{mv_t^2}{r}$
NEWTON'S LAW OF UNIVERSAL GRAVITATION *The constant of universal gravitation (G) equals 6.673×10^{-11} N•m²/kg².*	$F_g = G\frac{m_1m_2}{r^2}$
KEPLER'S LAWS OF PLANETARY MOTION	**First Law:** Each planet travels in an elliptical orbit around the sun, and the sun is at one of the focal points. **Second Law:** An imaginary line drawn from the sun to any planet sweeps out equal areas in equal time intervals. **Third Law:** The square of a planet's orbital period (T^2) is proportional to the cube of the average distance (r^3) between the planet and the sun, or $T^2 \propto r^3$.
PERIOD AND SPEED OF AN OBJECT IN CIRCULAR ORBIT *The constant of universal gravitation (G) equals 6.673×10^{-11} N•m²/kg².*	$T = 2\pi\sqrt{\frac{r^3}{Gm}}$ $v_t = \sqrt{G\frac{m}{r}}$
TORQUE	$\tau = Fd\sin\theta$

MECHANICAL ADVANTAGE *This equation disregards friction.*	$MA = \frac{F_{out}}{F_{in}} = \frac{d_{in}}{d_{out}}$
EFFICIENCY *This equation accounts for friction.*	$eff = \frac{W_{out}}{W_{in}}$

Chapter 8 Fluid Mechanics

MASS DENSITY	$\rho = \frac{m}{V}$
BUOYANT FORCE *The first equation is for an object that is completely or partially submerged. The second equation is for a floating object.*	$F_B = F_g\,(displaced\ fluid) = m_f g$ $F_B = F_g\,(object) = mg$
PRESSURE	$P = \frac{F}{A}$
PASCAL'S PRINCIPLE	Pressure applied to a fluid in a closed container is transmitted equally to every point of the fluid and to the walls of the container.
HYDRAULIC LIFT EQUATION	$F_2 = \frac{A_2}{A_1}F_1$
FLUID PRESSURE AS A FUNCTION OF DEPTH	$P = P_0 + \rho gh$
CONTINUITY EQUATION	$A_1 v_1 = A_2 v_2$
BERNOULLI'S PRINCIPLE	The pressure in a fluid decreases as the fluid's velocity increases.

Chapter 9 Heat

TEMPERATURE CONVERSIONS	$T_F = \frac{9}{5}T_C + 32.0$ $T = T_C + 273.15$

CONSERVATION OF ENERGY	$\Delta PE + \Delta KE + \Delta U = 0$
SPECIFIC HEAT CAPACITY	$c_p = \frac{Q}{m\Delta T}$
CALORIMETRY *These equations assume that the energy transferred to the surrounding container is negligible.*	$Q_w = -Q_x$ $c_{p,w} m_w \Delta T_w = -c_{p,x} m_x \Delta T_x$
LATENT HEAT	$Q = mL$

Chapter 10 Thermodynamics

WORK DONE BY A GAS *This equation is valid only when the pressure is constant. When the work done by the gas (W) is negative, positive work is done on the gas.*	$W = PAd = P\Delta V$
THE FIRST LAW OF THERMODYNAMICS *Q represents the energy added to the system as heat and W represents the work done by the system.*	$\Delta U = Q - W$
CYCLIC PROCESSES	$\Delta U_{net} = 0$ and $Q_{net} = W_{net}$
EFFICIENCY OF A HEAT ENGINE	$eff = \frac{W_{net}}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$

Chapter 11 Vibrations and Waves

HOOKE'S LAW	$F_{elastic} = -kx$
PERIOD OF A SIMPLE PENDULUM IN SIMPLE HARMONIC MOTION *This equation is valid only when the amplitude is small (less than about 15°).*	$T = 2\pi\sqrt{\frac{L}{a_g}}$
PERIOD OF A MASS-SPRING SYSTEM IN SIMPLE HARMONIC MOTION	$T = 2\pi\sqrt{\frac{m}{k}}$
SPEED OF A WAVE	$v = f\lambda$

Chapter 12 Sound

INTENSITY OF A SPHERICAL WAVE *This equation assumes that there is no absorption in the medium.*	$\text{intensity} = \frac{P}{4\pi r^2}$
HARMONIC SERIES OF A VIBRATING STRING OR A PIPE OPEN AT BOTH ENDS	$f_n = n\frac{v}{2L} \quad n = 1, 2, 3, \ldots$
HARMONIC SERIES OF A PIPE CLOSED AT ONE END	$f_n = n\frac{v}{4L} \quad n = 1, 3, 5, \ldots$
BEATS	frequency difference = number of beats per second

Chapter 13 Light and Reflection

SPEED OF ELECTROMAGNETIC WAVES *This book uses the value $c = 3.00 \times 10^8$ m/s for the speed of EM waves in a vacuum or in air.*	$c = f\lambda$
LAW OF REFLECTION	angle of incidence (θ) = angle of reflection (θ')
MIRROR EQUATION *This equation is derived assuming that the rays incident on the mirror are very close to the principal axis of the mirror.*	$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$
MAGNIFICATION OF A CURVED MIRROR	$M = \frac{h'}{h} = -\frac{q}{p}$

Chapter 14 Refraction

INDEX OF REFRACTION *For any material other than a vacuum, the index of refraction varies with the wavelength of light.*	$n = \frac{c}{v}$
SNELL'S LAW	$n_i \sin \theta_i = n_r \sin \theta_r$

THIN-LENS EQUATION

This equation is derived assuming that the thickness of the lens is much less than the focal length of the lens.

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

MAGNIFICATION OF A LENS

This equation can be used only when the index of refraction of the first medium (n_i) is greater than the index of refraction of the second medium (n_r).

$$M = \frac{h'}{h} = -\frac{q}{p} \quad (\text{for } n_i > n_r)$$

CRITICAL ANGLE

This equation can be used only when the index of refraction of the first medium (n_i) is greater than the index of refraction of the second medium (n_r).

$$\sin \theta_c = \frac{n_r}{n_i} \quad (\text{for } n_i > n_r)$$

Chapter 15 Interference and Diffraction

CONSTRUCTIVE AND DESTRUCTIVE INTERFERENCE

The grating spacing multiplied by the sine of the angle of deviation is the path difference between two waves. To observe interference effects, the sources must be coherent and have identical wavelengths.

Constructive Interference:

$$d \sin \theta = \pm m\lambda$$

$$m = 0, 1, 2, 3, \ldots$$

Destructive Interference:

$$d \sin \theta = \pm(m + \tfrac{1}{2})\lambda$$

$$m = 0, 1, 2, 3, \ldots$$

DIFFRACTION GRATING

See the equation above for constructive interference.

LIMITING ANGLE OF RESOLUTION

This equation gives the angle θ in radians and applies only to circular apertures.

$$\theta = 1.22\frac{\lambda}{D}$$

Chapter 16 Electric Forces and Fields

COULOMB'S LAW

This equation assumes either point charges or spherical distributions of charge.

$$F_{electric} = k_C\left(\frac{q_1 q_2}{r^2}\right)$$

ELECTRIC FIELD STRENGTH DUE TO A POINT CHARGE

$$E = k_C\frac{q}{r^2}$$

Chapter 17 Electrical Energy and Current

ELECTRICAL POTENTIAL ENERGY *The displacement, d, is from the reference point and is parallel to the field. This equation is valid only for a uniform electric field.*	$PE_{electric} = -qEd$
POTENTIAL DIFFERENCE *The second half of this equation is valid only for a uniform electric field, and Δd is parallel to the field.*	$\Delta V = \frac{\Delta PE_{electric}}{q} = -E\Delta d$
POTENTIAL DIFFERENCE BETWEEN A POINT AT INFINITY AND A POINT NEAR A POINT CHARGE	$\Delta V = k_C \frac{q}{r}$
CAPACITANCE	$C = \frac{Q}{\Delta V}$
CAPACITANCE FOR A PARALLEL-PLATE CAPACITOR IN A VACUUM *The permittivity in a vacuum (ε_0) equals $8.85 \times 10^{-12}\ C^2/(N \cdot m^2)$.*	$C = \varepsilon_0 \frac{A}{d}$
ELECTRICAL POTENTIAL ENERGY STORED IN A CHARGED CAPACITOR *There is a limit to the maximum energy (or charge) that can be stored in a capacitor because electrical breakdown ultimately occurs between the plates of the capacitor for a sufficiently large potential difference.*	$PE_{electric} = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2 = \frac{Q^2}{2C}$
ELECTRIC CURRENT	$I = \frac{\Delta Q}{\Delta t}$
RESISTANCE	$R = \frac{\Delta V}{I}$
OHM'S LAW *Ohm's law is not universal, but it does apply to many materials over a wide range of applied potential differences.*	$\frac{\Delta V}{I} = \text{constant}$
ELECTRIC POWER	$P = I\Delta V = I^2R = \frac{(\Delta V)^2}{R}$

Chapter 18 Circuits and Circuit Elements

RESISTORS IN SERIES: EQUIVALENT RESISTANCE AND CURRENT	$R_{eq} = R_1 + R_2 + R_3 \ldots$ The current in each resistor is the same and is equal to the total current.
RESISTORS IN PARALLEL: EQUIVALENT RESISTANCE AND CURRENT	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$ The sum of the current in each resistor equals the total current.

Chapter 19 Magnetism

MAGNETIC FLUX	$\Phi_M = AB\cos\theta$
MAGNITUDE OF A MAGNETIC FIELD *The direction of $F_{magnetic}$ is always perpendicular to both B and v, and can be found with the right-hand rule.*	$B = \frac{F_{magnetic}}{qv}$
FORCE ON A CURRENT-CARRYING CONDUCTOR PERPENDICULAR TO A MAGNETIC FIELD *This equation can be used only when the current and the magnetic field are at right angles to each other.*	$F_{magnetic} = BI\ell$

Chapter 20 Electromagnetic Induction

FARADAY'S LAW OF MAGNETIC INDUCTION *N is assumed to be a whole number.*	$\text{emf} = -N\frac{\Delta\Phi_M}{\Delta t}$
EMF PRODUCED BY A GENERATOR *N is assumed to be a whole number.*	$\text{emf} = NAB\omega \sin \omega t$ $\text{maximum emf} = NAB\omega$
FARADAY'S LAW FOR MUTUAL INDUCTANCE	$\text{emf} = -M\frac{\Delta I}{\Delta t}$

RMS CURRENT AND POTENTIAL DIFFERENCE	$I_{rms} = \frac{I_{max}}{\sqrt{2}} = 0.707\ I_{max}$ $\Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}} = 0.707\ \Delta V$
TRANSFORMERS *N is assumed to be a whole number.*	$\Delta V_2 = \frac{N_2}{N_1} \Delta V_1$

Chapter 21 Atomic Physics

ENERGY OF A LIGHT QUANTUM	$E = hf$
MAXIMUM KINETIC ENERGY OF A PHOTOELECTRON	$KE_{max} = hf - hf_t$
WAVELENGTH AND FREQUENCY OF MATTER WAVES *Planck's constant (h) equals 6.63×10^{-34} J•s.*	$\lambda = \frac{h}{p} = \frac{h}{mv}$ $f = \frac{E}{h}$

Chapter 22 Subatomic Physics

RELATIONSHIP BETWEEN REST ENERGY AND MASS	$E_R = mc^2$
BINDING ENERGY OF A NUCLEUS	$E_{bind} = \Delta mc^2$
MASS DEFECT	$\Delta m = Z(\text{atomic mass of H}) + Nm_n - \text{atomic mass}$
ACTIVITY (DECAY RATE)	$\text{activity} = -\frac{\Delta N}{\Delta t} = \lambda N$
HALF-LIFE	$T_{1/2} = \frac{0.693}{\lambda}$

Appendix J Advanced Topics

CONVERSION BETWEEN RADIANS AND DEGREES	$\theta(\text{rad}) = \frac{\pi}{180°}\theta(\text{deg})$
ANGULAR DISPLACEMENT *This equation gives $\Delta\theta$ in radians.*	$\Delta\theta = \frac{\Delta s}{r}$
AVERAGE ANGULAR VELOCITY	$\omega_{avg} = \frac{\Delta\theta}{\Delta t}$
AVERAGE ANGULAR ACCELERATION	$\alpha_{avg} = \frac{\Delta\omega}{\Delta t}$
ROTATIONAL KINEMATICS *These equations apply only when the angular acceleration is constant. The symbol ω represents instantaneous rather than average angular velocity.*	$\omega_f = \omega_i + \alpha\Delta t$ $\Delta\theta = \omega_i\Delta t + \frac{1}{2}\alpha(\Delta t)^2$ $\omega_f^2 = \omega_i^2 + 2\alpha(\Delta\theta)$ $\Delta\theta = \frac{1}{2}(\omega_i + \omega_f)\Delta t$
TANGENTIAL SPEED *For this equation to be valid, ω must be in rad/s.*	$v_t = r\omega$
TANGENTIAL ACCELERATION *For this equation to be valid, α must be in rad/s^2.*	$a_t = r\alpha$
NEWTON'S SECOND LAW FOR ROTATING OBJECTS	$\tau = I\alpha$
ANGULAR MOMENTUM	$L = I\omega$
ROTATIONAL KINETIC ENERGY	$KE_{rot} = \frac{1}{2}I\omega^2$
IDEAL GAS LAW *Boltzmann's constant (k_B) equals 1.38×10^{-23} J/K.*	$PV = Nk_BT$
BERNOULLI'S EQUATION	$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$