

Chapter 12 Key Equations

$$\rho = \frac{m}{V} \quad (\text{definition of density}) \quad (12.1)$$

$$p = \frac{dF_{\perp}}{dA} \quad (\text{definition of pressure}) \quad (12.2)$$

$$p_2 - p_1 = -\rho g(y_2 - y_1) \quad (\text{pressure in a fluid of uniform density}) \quad (12.5)$$

$$p = p_0 + \rho gh \quad (\text{pressure in a fluid of uniform density}) \quad (12.6)$$

$$p = \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{and} \quad F_2 = \frac{A_2}{A_1} F_1 \quad (12.7)$$

$$A_1 v_1 = A_2 v_2 \quad (\text{continuity equation, incompressible fluid}) \quad (12.10)$$

$$\frac{dV}{dt} = Av \quad (\text{volume flow rate}) \quad (12.11)$$

$$p_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 = p_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2 \quad (\text{Bernoulli's equation}) \quad (12.17)$$

Chapter 17 Key Equations

$$T_F = \frac{9}{5} T_C + 32^\circ \quad (17.1)$$

$$T_C = \frac{5}{9} (T_F - 32^\circ) \quad (17.2)$$

$$T_K = T_C + 273.15 \quad (17.3)$$

$$\frac{T_2}{T_1} = \frac{p_2}{p_1} \quad (\text{constant-volume gas thermometer, } T \text{ in kelvins}) \quad (17.4)$$

$$\Delta L = \alpha L_0 \Delta T \quad (\text{linear thermal expansion}) \quad (17.6)$$

$$\Delta V = \beta V_0 \Delta T \quad (\text{volume thermal expansion}) \quad (17.8)$$

$$\frac{F}{A} = -Y\alpha \Delta T \quad (\text{thermal stress}) \quad (17.12)$$

$$Q = mc \Delta T \quad (\text{heat required for temperature change } \Delta T \text{ of mass } m) \quad (17.13)$$

$$Q = nC \Delta T \quad (\text{heat required for temperature change of } n \text{ moles}) \quad (17.18)$$

$$Q = \pm mL \quad (\text{heat transfer in a phase change}) \quad (17.20)$$

$$H = \frac{dQ}{dt} = kA \frac{T_H - T_C}{L} \quad (\text{heat current in conduction}) \quad (17.21)$$

$$H = Ae\sigma T^4 \quad (\text{heat current in radiation}) \quad (17.25)$$

$$H_{\text{net}} = Ae\sigma T^4 - Ae\sigma T_s^4 = Ae\sigma (T^4 - T_s^4) \quad (17.26)$$

Chapter 18 Key Equations

$$m_{\text{total}} = nM \quad (\text{total mass, number of moles, and molar mass}) \quad (18.2)$$

$$pV = nRT \quad (\text{ideal-gas equation}) \quad (18.3)$$

$$M = N_A m \quad (\text{molar mass, Avogadro's number, and mass of a molecule}) \quad (18.8)$$

$$K_{\text{tr}} = \frac{3}{2} nRT \quad (\text{average translational kinetic energy of } n \text{ moles of ideal gas}) \quad (18.14)$$

$$\frac{1}{2} m \langle v^2 \rangle_{\text{av}} = \frac{3}{2} kT \quad (\text{average translational kinetic energy of a gas molecule}) \quad (18.16)$$

$$v_{\text{rms}} = \sqrt{\langle v^2 \rangle_{\text{av}}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}} \quad (\text{root-mean-square speed of a gas molecule}) \quad (18.19)$$

$$\lambda = v t_{\text{mean}} = \frac{V}{4\pi\sqrt{2}r^2 N} \quad (\text{mean free path of a gas molecule}) \quad (18.21)$$

$$C_v = \frac{3}{2}R \quad (\text{ideal gas of point particles}) \quad (18.25)$$

$$C_v = \frac{5}{2}R \quad (\text{diatomic gas, including rotation}) \quad (18.26)$$

$$C_v = 3R \quad (\text{ideal monatomic solid}) \quad (18.28)$$

$$f(v) = 4\pi \left(\frac{m}{2\pi kT} \right)^{3/2} v^2 e^{-mv^2/2kT} \quad (\text{Maxwell – Boltzmann distribution}) \quad (18.32)$$

Chapter 19 Key Equations

$$W = \int_{V_1}^{V_2} p dV \quad (\text{work done in a volume change}) \quad (19.2)$$

$$W = p(V_2 - V_1) \quad (\text{work done in a volume change at constant pressure}) \quad (19.3)$$

$$U_2 - U_1 = \Delta U = Q - W \quad (\text{first law of thermodynamics}) \quad (19.4)$$

$$dU = dQ - dW \quad (\text{first law of thermodynamics, infinitesimal process}) \quad (19.6)$$

$$C_p = C_v + R \quad (\text{molar heat capacities of an ideal gas}) \quad (19.17)$$

$$\gamma = \frac{C_p}{C_v} \quad (\text{ratio of heat capacities}) \quad (19.18)$$

$$W = nC_v(T_1 - T_2) \quad (\text{adiabatic process, ideal gas}) \quad (19.25)$$

$$W = \frac{C_v}{R}(p_1V_1 - p_2V_2) = \frac{1}{\gamma - 1}(p_1V_1 - p_2V_2) \quad (\text{adiabatic process, ideal gas}) \quad (19.26)$$

Chapter 20 Key Equations

$$e = \frac{W}{Q_H} = 1 + \frac{Q_C}{Q_H} = 1 - \left| \frac{Q_C}{Q_H} \right| \quad (\text{thermal efficiency of an engine}) \quad (20.4)$$

$$e = 1 - \frac{1}{r^{\gamma-1}} \quad (\text{thermal efficiency in Otto cycle}) \quad (20.6)$$

$$K = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|} \quad (\text{coefficient of performance of a refrigerator}) \quad (20.9)$$

$$e_{\text{Carnot}} = 1 - \frac{T_C}{T_H} = \frac{T_H - T_C}{T_H} \quad (\text{efficiency of a Carnot engine}) \quad (20.14)$$

$$K_{\text{Carnot}} = \frac{T_C}{T_H - T_C} \quad (\text{coefficient of performance of a Carnot refrigerator}) \quad (20.15)$$

$$\Delta S = \int_1^2 \frac{dQ}{T} \quad (\text{entropy change in a reversible process}) \quad (20.19)$$

$$S = k \ln w \quad (\text{microscopic expression for entropy}) \quad (20.22)$$

Chapter 21 Key Equations

$$F = \frac{1}{4\pi\epsilon_0} \frac{|q_1 q_2|}{r^2} \quad (\text{Coulomb's law: force between two point charges}) \quad (21.2)$$

$$\vec{E} = \frac{\vec{F}_0}{q_0} \quad (\text{definition of electric field as electric force per unit charge}) \quad (21.3)$$

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r} \quad (\text{electric field of a point charge}) \quad (21.7)$$

$$\tau = pE \sin \phi \quad (\text{magnitude of the torque on an electric dipole}) \quad (21.15)$$

$$\vec{\tau} = \vec{p} \times \vec{E} \quad (\text{torque on an electric dipole, in vector form}) \quad (21.16)$$

$$U = -\vec{p} \cdot \vec{E} \quad (\text{potential energy for a dipole in an electric field}) \quad (21.18)$$

Chapter 22 Key Equations

$$\Phi_E = \int E \cos \phi dA = \int E_{\perp} dA = \int \vec{E} \cdot d\vec{A} \quad (\text{general definition of electric flux}) \quad (22.5)$$

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{encl}}}{\epsilon_0} \quad (\text{Gauss's law}) \quad (22.8)$$

$$\Phi_E = \oint E \cos \phi \, dA = \oint E_{\perp} dA = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{encl}}}{\epsilon_0} \quad (\text{various forms of Gauss's law}) \quad (22.9)$$

$$E_{\perp} A = \frac{\sigma A}{\epsilon_0} \quad \text{and} \quad E_{\perp} = \frac{\sigma}{\epsilon_0} \quad (\text{field at the surface of a conductor}) \quad (22.10)$$

Chapter 23 Key Equations

$$W_{a \rightarrow b} = U_a - U_b = -(U_b - U_a) = -\Delta U \quad (\text{work done by a conservative force}) \quad (23.2)$$

$$U = \frac{1}{4\pi\epsilon_0} \frac{qq_0}{r} \quad (\text{electric potential energy of two point charges } q \text{ and } q_0) \quad (23.9)$$

$$U = \frac{q_0}{4\pi\epsilon_0} \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \dots \right) = \frac{q_0}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i} \quad (\text{point charge } q_0 \text{ and collection of charges } q_i) \quad (23.10)$$

$$V = \frac{U}{q_0} = \frac{1}{4\pi\epsilon_0} \frac{q}{r} \quad (\text{potential due to a point charge}) \quad (23.14)$$

$$V = \frac{U}{q_0} = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i} \quad (\text{potential due to a collection of point charge}) \quad (23.15)$$

$$V = \frac{1}{4\pi\epsilon_0} \int \frac{dq}{r} \quad (\text{potential due to a continuous distribution of charge}) \quad (23.16)$$

$$V_a - V_b = \int_a^b \vec{E} \cdot d\vec{l} = \int_a^b E \cos \phi \, dl \quad (\text{potential difference as an integral of } \vec{E}) \quad (23.17)$$

$$E_x = -\frac{\partial V}{\partial x} \quad E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial z} \quad (\text{components of } \vec{E} \text{ in terms of } V) \quad (23.19)$$

$$\vec{E} = -\left(\hat{i} \frac{\partial V}{\partial x} + \hat{j} \frac{\partial V}{\partial y} + \hat{k} \frac{\partial V}{\partial z} \right) \quad (\vec{E} \text{ in terms of } V) \quad (23.20)$$

Chapter 24 Key Equations

$$C = \frac{Q}{V_{ab}} \quad (\text{definition of capacitance}) \quad (24.1)$$

$$C = \frac{Q}{V_{ab}} = \epsilon_0 \frac{A}{d} \quad (\text{capacitance of a parallel-plate capacitor in vacuum}) \quad (24.2)$$

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots \quad (\text{capacitors in series}) \quad (24.5)$$

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \dots \quad (\text{capacitors in parallel}) \quad (24.7)$$

$$U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV \quad (\text{potential energy stored in a capacitor}) \quad (24.9)$$

$$u = \frac{1}{2} \epsilon_0 E^2 \quad (\text{electric energy density in a vacuum}) \quad (24.11)$$

$$C = KC_0 = K \epsilon_0 \frac{A}{d} = \epsilon \frac{A}{d} \quad (\text{parallel-plate capacitor, dielectric between plates}) \quad (24.19)$$

$$u = \frac{1}{2} K \epsilon_0 E^2 = \frac{1}{2} \epsilon E^2 \quad (\text{electric energy density in a dielectric}) \quad (24.20)$$

$$\oint \mathbf{KE} \cdot d\vec{\mathbf{A}} = \frac{Q_{\text{encl-free}}}{\epsilon_0} \quad (\text{Gauss's law in a dielectric}) \quad (24.23)$$

Chapter 25 Key Equations

$$I = \frac{dQ}{dt} = n|q|\nu_d A \quad (\text{general expression for current}) \quad (25.2)$$

$$\vec{\mathbf{J}} = nq\vec{\nu}_d \quad (\text{vector current density}) \quad (25.4)$$

$$\rho = \frac{E}{J} \quad (\text{definition of resistivity}) \quad (25.5)$$

$$\rho(T) = \rho_0[1 + \alpha(T - T_0)] \quad (\text{temperature dependence of resistivity}) \quad (25.6)$$

$$R = \frac{\rho L}{A} \quad (\text{relationship between resistance and resistivity}) \quad (25.10)$$

$$V = IR \quad (\text{relationship among voltage, current, and resistance}) \quad (25.11)$$

$$V_{ab} = \mathcal{E} - Ir \quad (\text{terminal voltage, source with internal resistance}) \quad (25.15)$$

$$P = V_{ab}I \quad (\text{rate at which energy is delivered to or extracted from a circuit element}) \quad (25.17)$$

$$P = V_{ab}I = I^2R = \frac{V_{ab}^2}{R} \quad (\text{power delivered to a resistor}) \quad (25.18)$$

$$\rho = \frac{m}{ne^2\tau} \quad (25.24)$$

Chapter 26 Key Equations

$$R_{eq} = R_1 + R_2 + R_3 + \dots \quad (\text{resistors in series}) \quad (26.1)$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \quad (\text{resistors in parallel}) \quad (26.2)$$

$$\sum I = 0 \quad (\text{junction rule, valid at any junction}) \quad (26.5)$$

$$\sum V = 0 \quad (\text{loop rule, valid for any closed loop}) \quad (26.6)$$

$$q = C\mathcal{E}(1 - e^{-t/RC}) = Q_f(1 - e^{-t/RC}) \quad (R\text{-}C \text{ circuit, charging capacitor}) \quad (26.12)$$

$$i = \frac{dq}{dt} = \frac{\mathcal{E}}{R}e^{-t/RC} = I_0e^{-t/RC} \quad (R\text{-}C \text{ circuit, charging capacitor}) \quad (26.13)$$

$$q = Q_0e^{-t/RC} \quad (R\text{-}C \text{ circuit, discharging capacitor}) \quad (26.16)$$

$$i = \frac{dq}{dt} = -\frac{Q_0}{RC}e^{-t/RC} = I_0e^{-t/RC} \quad (R\text{-}C \text{ circuit, discharging capacitor}) \quad (26.17)$$

Chapter 33 Key Equations

$$n = \frac{c}{v} \quad (\text{index of refraction}) \quad (33.1)$$

$$\theta_r = \theta_a \quad (\text{law of reflection}) \quad (33.2)$$

$$n_a \sin \theta_a = n_b \sin \theta_b \quad (\text{law of refraction}) \quad (33.4)$$

$$\lambda = \frac{\lambda_0}{n} \quad (\text{wavelength of light in a material}) \quad (33.5)$$

$$\sin \theta_{\text{crit}} = \frac{n_b}{n_a} \quad (\text{critical angle for total internal reflection}) \quad (33.6)$$

$$I = I_{\text{max}} \cos^2 \phi \quad (\text{Malus's law, polarized light passing through an analyzer}) \quad (33.7)$$

$$\tan \theta_p = \frac{n_b}{n_a} \quad (\text{Brewster's law for the polarizing angle}) \quad (33.8)$$

Chapter 34 Key Equations

$$m = \frac{y'}{y} \quad (\text{lateral magnification}) \quad (34.2)$$

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \quad (\text{object-image relationship, thin lens}) \quad (34.16)$$

$$\frac{1}{f} = (n-1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right) \quad (\text{lensmaker's equation for a thin lens}) \quad (34.19)$$

$$f\text{-number} = \frac{\text{Focal length}}{\text{Aperture diameter}} = \frac{f}{D} \quad (34.20)$$

$$M = \frac{\theta'}{\theta} = \frac{y/f}{y/25 \text{ cm}} = \frac{25 \text{ cm}}{f} \quad (\text{angular magnification for a simple magnifier}) \quad (34.22)$$

Chapter 35 Key Equations

$$d \sin \theta = m\lambda \quad (m = 0, \pm 1, \pm 2, \dots) \quad (\text{constructive interference, two slits}) \quad (35.4)$$

$$d \sin \theta = \left(m + \frac{1}{2}\right) \lambda \quad (m = 0, \pm 1, \pm 2, \dots) \quad (\text{destructive interference, two slits}) \quad (35.5)$$

$$y_m = R \frac{m\lambda}{d} \quad (\text{constructive interference in Young's experiment}) \quad (35.6)$$

$$E_p = 2E \left| \cos \frac{\phi}{2} \right| \quad (\text{amplitude in two-source interference}) \quad (35.7)$$

$$I = I_0 \cos^2 \frac{\phi}{2} \quad (\text{intensity in two-source interference}) \quad (35.10)$$

$$\phi = \frac{2\pi}{\lambda} (r_2 - r_1) = k(r_2 - r_1) \quad (\text{phase difference related to path difference}) \quad (35.11)$$

$$2t = m\lambda \quad (m = 0, 1, 2, \dots) \quad (\text{constructive reflection from thin film, no relative phase shift}) \quad (35.17a)$$

$$2t = \left(m + \frac{1}{2}\right) \lambda \quad (m = 0, 1, 2, \dots) \quad (\text{destructive reflection from thin film, no relative phase shift}) \quad (35.17b)$$

$$2t = \left(m + \frac{1}{2}\right) \lambda \quad (m = 0, 1, 2, \dots) \quad (\text{constructive reflection from thin film, half-cycle relative phase shift}) \quad (35.18a)$$

$$2t = m\lambda \quad (m = 0, 1, 2, \dots) \quad (\text{destructive reflection from thin film, half-cycle relative phase shift}) \quad (35.18b)$$

Chapter 36 Key Equations

$$\sin \theta = \frac{m\lambda}{a} \quad (m = \pm 1, \pm 2, \pm 3, \dots) \quad (\text{dark fringes in single-slit diffraction}) \quad (36.2)$$

$$I = I_0 \left\{ \frac{\sin[\pi a(\sin \theta)/\lambda]}{\pi a(\sin \theta)/\lambda} \right\}^2 \quad (\text{intensity in single-slit diffraction}) \quad (36.7)$$

$$d \sin \theta = m\lambda \quad (m = 0, \pm 1, \pm 2, \pm 3, \dots) \quad (\text{intensity maxima, multiple slits}) \quad (36.13)$$

$$2d \sin \theta = m\lambda \quad (m = 1, 2, 3, \dots) \quad (36.16)$$

(Bragg condition for constructive interference from an array)

$$\sin \theta_1 = 1.22 \frac{\lambda}{D} \quad (\text{diffraction by a circular aperture}) \quad (36.17)$$