University Physics, 13/e

Young/Freedman

Formula Sheet

Chapter 12 Key Equations

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

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

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

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

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

$$A_1 \upsilon_1 = A_2 \upsilon_2 \quad \text{(continuity equation, incompressible fluid)} \tag{12.10}$$

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

$$p_1 + \rho g y_1 + \frac{1}{2}\rho \upsilon_1^2 = p_2 + \rho g y_2 + \frac{1}{2}\rho \upsilon_2^2 \quad \text{(Bernoulli's equation)} \tag{12.17}$$

Chapter 17 Key Equations

$$T_F = \frac{9}{5} T_C + 32° \tag{17.1}$$

$$T_C = \frac{5}{9}\left(T_F - 32°\right) \tag{17.2}$$

$$T_K = T_C + 273.15 \tag{17.3}$$

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

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

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

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

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

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

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

$$H = \frac{dQ}{dt} = kA\frac{T_{\mathrm{H}} - T_{\mathrm{C}}}{L} \quad \left(\text{heat current in conduction}\right) \tag{17.21}$$

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

$$H_{\text{net}} = Ae\sigma T^4 - Ae\sigma T_{\mathrm{s}}^4 = Ae\sigma\left(T^4 - T_{\mathrm{s}}^4\right) \tag{17.26}$$

Chapter 18 Key Equations

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

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

$$M = N_{\mathrm{A}} m \quad \left(\text{molar mass, Avogadro's number, and mass of a molecule}\right) \tag{18.8}$$

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

$$\frac{1}{2} m\left(\upsilon^2\right)_{\text{av}} = \frac{3}{2} kT \quad \left(\text{average translational kinetic energy of a gas molecule}\right) \tag{18.16}$$

$$\upsilon_{\text{rms}} = \sqrt{\left(\upsilon^2\right)_{\text{av}}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}} \quad \left(\text{root-mean-square speed of a gas molecule}\right) \tag{18.19}$$

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

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

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

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

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

Chapter 19 Key Equations

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

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

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

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

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

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

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

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

Chapter 20 Key Equations

$$e = \frac{W}{Q_{\mathrm{H}}} = 1 + \frac{Q_{\mathrm{C}}}{Q_{\mathrm{H}}} = 1 - \left|\frac{Q_{\mathrm{C}}}{Q_{\mathrm{H}}}\right| \quad \text{(thermal efficiency of an engine)} \qquad (20.4)$$

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

$$K = \frac{|Q_{\mathrm{C}}|}{|W|} = \frac{|Q_{\mathrm{C}}|}{|Q_{\mathrm{H}}| - |Q_{\mathrm{C}}|} \quad \left(\text{coefficient of performance of a refrigerator}\right) \qquad (20.9)$$

$$e_{\mathrm{Carnot}} = 1 - \frac{T_{\mathrm{C}}}{T_{\mathrm{H}}} = \frac{T_{\mathrm{H}} - T_{\mathrm{C}}}{T_{\mathrm{H}}} \quad \left(\text{efficiency of a Carnot engine}\right) \qquad (20.14)$$

$$K_{\mathrm{Carnot}} = \frac{T_{\mathrm{C}}}{T_{\mathrm{H}} - T_{\mathrm{C}}} \quad \left(\text{coefficient of performance of a Carnot refrigerator}\right) \qquad (20.15)$$

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

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

Chapter 21 Key Equations

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

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

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

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

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

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

Chapter 22 Key Equations

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

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

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

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

Chapter 23 Key Equations

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

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

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

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

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

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

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

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

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

Chapter 24 Key Equations

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

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

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

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

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

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

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

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

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

Chapter 25 Key Equations

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

$$\vec{J} = nq\vec{v}_{\text{d}} \quad \text{(vector current density)} \qquad (25.4)$$

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

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

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

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

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

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

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

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

Chapter 26 Key Equations

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

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

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

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

$$q = C\varepsilon(1 - e^{-t/RC}) = Q_{\text{f}}(1 - e^{-t/RC}) \quad (R\text{-}C \text{ circuit, charging capacitor}) \qquad (26.12)$$

$$i = \frac{dq}{dt} = \frac{\varepsilon}{R} e^{-t/RC} = I_0 e^{-t/RC} \quad (R\text{-}C \text{ circuit, charging capacitor}) \qquad (26.13)$$

$$q = Q_0 e^{-t/RC} \quad (R\text{-}C \text{ circuit, discharging capacitor}) \qquad (26.16)$$

$$i = \frac{dq}{dt} = -\frac{Q_0}{RC} e^{-t/RC} = I_0 e^{-t/RC} \quad (R\text{-}C \text{ circuit, discharging capacitor}) \qquad (26.17)$$

Chapter 33 Key Equations

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

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

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

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

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

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

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

Chapter 34 Key Equations

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

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

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

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

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

Chapter 35 Key Equations

$$d\sin\theta = m\lambda \quad (m = 0, \pm1, \pm2, \ldots) \quad \text{(constructive interference, two slits)} \tag{35.4}$$

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

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

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

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

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

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

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

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

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

Chapter 36 Key Equations

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

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

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

$$2d \sin\theta = m\lambda \quad (m = 1, 2, 3, \ldots)$$
(Bragg condition for constructive interference from an array) (36.16)

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