Fundamental Constants

$g =$ 9.80 m s^{-2}
$c =$ speed of light in vacuum $= 3.00 \times 10^8$ ms^{-1}
$e =$ charge of electron $= 1.60 \times 10^{-19}$ C
$m_e =$ mass of electron $= 9.11 \times 10^{-31}$ kg
$m_n =$ mass of neutron or proton $= 1.67 \times 10^{-27}$ kg
$N_A =$ Avogadro's number $= 6.022 \times 10^{23}$ molecules/mol
$k_B =$ Boltzmann's constant $= 1.38 \times 10^{-23}$J/K
$R =$ universal gas constant $= 8.31 \frac{\text{J}}{\text{mol K}} = 0.0821 \frac{\text{l atm}}{\text{mol K}}$
$c_W =$ specific heat of water = 1 cal/(g K)
1 cal = 4.186 J
$\sigma =$ Stefan-Boltzmann constant $= 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2\text{K}^4}$
$\mu_0 =$ permeability of space $= 4\pi \times 10^{-7}$WbA^{-1}m^{-1}
$\varepsilon_0 =$ permittivity of space $= 8.85 \times 10^{-12}$C^{2}N^{-1}m^{-2}
$k =$ Coulomb's constant $= 8.99 \times 10^9$Nm^{2}C^{-2}
$G =$ Newton's constant $= 6.67 \times 10^{-11}$Nm^{2}kg^{-2}
$h =$ Planck's constant $= 6.63 \times 10^{-34}$Js

Mechanics

constant acceleration:

$$v = v_0 + at, \quad d = v_0 t + \frac{1}{2}at^2, \quad v^2 = v_0^2 + 2ad$$

Newton's second law $\vec{F} = m\vec{a}$
kinetic energy $K = \frac{1}{2}mv^2$
potential energies $U_g = mgy$, $U_s = \frac{1}{2}kx^2$
work done by a force $W = \vec{F} \cdot \vec{d}$
work-energy principle $W_{nc} = \Delta E$
power $= \frac{\Delta E}{\Delta t}$; 1 hp = 746 W

Fluids

hydrostatic pressure: $P = P_0 + \rho g h$
flow rate: $Q = Av$
incompressible flow: $A_1 v_1 = A_2 v_2$

$$\text{Bernoulli: } P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

$$\text{fluid resistance: } Q = \frac{\Delta P}{R}$$

$$\text{Poiseuille: } R = \frac{8\eta L}{\pi r^4}, \qquad \eta = \text{viscosity}$$

$$\text{buoyancy: } F_B = \rho_f V_f g$$

Mechanical properties of matter

stress $\propto$ strain

$$F = Y\frac{\Delta L}{L_0}A, \qquad Y = \text{Young's modulus}$$
$$F = S\frac{\Delta X}{L_0}A, \qquad S = \text{shear modulus}$$
$$\frac{F}{A} = B\frac{\Delta V}{V_0}, \qquad B = \text{bulk modulus}$$

pressure $P = F/A$

$$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} = 760 \text{ torr} = 760 \text{ mm Hg}$$

mass density = mass per unit volume, $\rho = m/V$
specific gravity of X $= \rho_X/\rho_{H_2O}$, $\rho_{H_2O} = 1000\,\text{kg/m}^3$

Heat and thermodynamics

$$T_F = \frac{9}{5}\frac{°\text{F}}{°\text{C}}T_C + 32°\text{F}, \qquad T_C = \frac{5}{9}\frac{°\text{C}}{°\text{F}}(T_F - 32°\text{F}),$$

absolute $T = T_C + 273$

thermal expansion:

$$\text{length (1D):} \quad \Delta L = \alpha L_0 \Delta T$$
$$\text{volume (3D):} \quad \Delta V = \beta V_0 \Delta T$$

heat capacity $Q = C\Delta T$, specific heat $Q = cm\Delta T$
latent heat: $Q = mL_f$ (fusion), $Q = mL_v$ (vaporization)
heat conduction: $\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{L}$
radiation: $\frac{\Delta Q}{\Delta t} = e\sigma A\left(T^4 - T^4_{\text{surround}}\right)$
ideal gas law: $\frac{pV}{T} = k_B N = nR$
Maxwell distribution: $\frac{1}{2}mv^2_{rms} = \frac{3}{2}k_B T$, $v_{rms} = \sqrt{\frac{3RT}{M}}$
thermal energy of an ideal gas: $\Delta E_{\text{th}} = \frac{3}{2}Nk_BT = \frac{3}{2}nRT$
heat capacity of an ideal gas (monatomic):
$C_V = \frac{3}{2}R = 12.5$ J/mol · K, @ const V
$C_P = \frac{5}{2}R = 20.8$ J/mol · K, @ const P
first law of thermodynamics: $\Delta U = +Q - W$

$W = P\Delta V$ (isobaric), $W = nRT\ln\frac{V_f}{V_i}$ (isothermal)
heat engine efficiency: $e = \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h} = 1 - \frac{T_c}{T_h}$
heat pump CoP cooling: $e = \frac{Q_c}{W_{in}} = \frac{T_c}{T_h - T_c}$
entropy: $\Delta S = \frac{Q}{T}$ (reversible process)
$\Delta S = mc\ln(T_f/T_i) + nC\ln(V_f/V_i)$
second law of thermodynamics: $\Delta S_{\text{total}} \geq 0$

Waves and Sound

simple harmonic oscillator, $F = -kx$, $U = \frac{1}{2}kx^2$

$$f = 1/T \quad \omega = 2\pi/T = 2\pi f = \sqrt{k/m}$$
$$\begin{cases} x = A\cos\phi = A\cos\omega t, \\ v = -A\omega\sin\omega t \\ a = -A\omega^2\cos\omega t \end{cases}$$

travelling wave

$$y = A\cos\left(\frac{2\pi}{T}t \mp \frac{2\pi}{\lambda}x + \phi_0\right), \quad v = \lambda f = \lambda/T$$

waves on a string under tension F

$$v_{\text{string}} = \sqrt{\frac{F}{m/L}}$$

standing waves (nodes at both ends, string length L)

$$f_n = \frac{v}{2L}n \qquad n = 1(\text{fundamental}); 2, 3, ...(\text{harmonics})$$

sound intensity

$$\beta = 10\log\frac{I}{I_0},\ \text{dB} \qquad I_0 = 1 \times 10^{-12}\ \text{W/m}^2$$

point source

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

Doppler (upper sign = approach, lower = recede)

$$f = f_s\left(\frac{v \pm v_o}{v \mp v_s}\right) \qquad \text{s=source, o=observer}$$

Light and Optics

diffraction $\sin\theta = m\lambda/W$
two-slit interference fringes ($m = 0, 1, 2, \dots$)

$$\sin\theta = m\frac{\lambda}{d} \text{ (bright)} \quad \sin\theta = \left(m + \frac{1}{2}\right)\frac{\lambda}{d} \text{ (dark)}$$

single-slit interference minima ($m = 0, 1, 2, \dots$

$$\sin\theta = m\frac{\lambda}{a}$$

thin-film interference ($\lambda_{film} = \lambda/n\,;\ v = c/n$)

$$2t = m\lambda_{film} \qquad 2t = \left(m + \frac{1}{2}\right)\lambda_{film}$$

Bragg peaks (X-ray diffraction, atom spacing d)

$$\sin\theta = \frac{m}{2}\frac{\lambda}{d} \qquad m = 1, 2, \dots$$

diffraction-limited resolving power (first dark fringe, aperture size d)

$$\theta_{min} = \frac{\lambda}{d} \text{ (slit)} \qquad \theta_{min} = 1.22\frac{\lambda}{d} \text{ (circular)}$$

reflection $\theta_i = \theta_r$, refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$
index of refraction of a medium m

$$n = \frac{c}{v} = \frac{\lambda}{\lambda_m} \quad \textit{e.g. } n_{air} \approx 1 \quad n_{water} \approx 1.33$$

total internal reflection $\theta_{\text{critical}} = \arcsin\frac{n_2}{n_1}$
polarization by reflection $\theta_{\text{Brewster}} = \arctan\frac{n_2}{n_1}$
spherical mirrors $f = \pm\frac{1}{2}R$
magnification $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$
mirror/lens equation $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
Rayleigh criterion $\theta_{\min} \approx 1.22\lambda/D$

Electricity

Coulomb: $F = k\frac{q_1 q_2}{r^2}$, $\quad k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \text{Nm}^2/\text{C}^2$
$\vec{F} = q\vec{E} \qquad W = -\Delta U = -q\Delta V$
constant electric field: $\Delta V = Ed$
point charge: $E = k\frac{q}{r^2} \quad V = k\frac{q}{r}$
capacitance: $Q = C\Delta V$, $\quad U = \frac{1}{2}C(\Delta V)^2$
parallel plates: $C = \frac{\kappa\varepsilon_0 A}{d}$
current: $I = \frac{q}{\Delta t} \qquad R = \rho\frac{L}{A}$
$\Delta V = IR \quad P = I^2 R = I\Delta V = \frac{(\Delta V)^2}{R}$
series: $R_{eq} = R_1 + R_2 + \cdots \qquad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$
parallel: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \qquad C_{eq} = C_1 + C_2 + \cdots$

Magnetism

long straight wire: $B = \frac{\mu_0 I}{2\pi r}$
centre of loop: $B = N\frac{\mu_0 I}{2r}$
interior of solenoid: $B = N\frac{\mu_0 I}{L}$
force on a moving charge / on a wire of length L:

$$F = qvB\sin\theta \qquad F = ILB\sin\theta$$

torque on a current-carrying loop: $\tau = NIAB\sin\theta$

Electromagnetic Waves

average intensity: $I = \frac{1}{2}\varepsilon_0 E_0^2 c$
energy density: $\frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0}B^2$
$E_0 = cB_0$
polarized light: $I_{out} = I_0 \cos^2\theta$
unpolarized light: $I_{out} = \frac{1}{2}I_0$

Modern Physics

photons: $E = hf$, $p = E/c$, $\lambda = h/p$
photon intensity: $I = \left(\frac{\Delta N}{\Delta t}\right)hf$
photoelectric effect

$$K_{max} = hf - E_0$$

Compton effect

$$\lambda' - \lambda = \frac{h}{mc}(1 - \cos\theta)$$

de Broglie's matter waves: $\lambda = \frac{h}{mv}$
Bohr's quantization of angular momentum:

$$mvr = n\left(\frac{h}{2\pi}\right) \ ,\ n = 1, 2, \dots$$

hydrogen spectrum

$$\Delta E = hf = 13.6 \text{ eV}\left|\frac{1}{n_f^2} - \frac{1}{n_i^2}\right|$$

radioactive decay

$$\frac{\Delta N}{\Delta t} = -\lambda N \qquad N = N_0 e^{-\lambda t} \qquad N = N_0\left(2^{-t/T}\right)$$

$$R = \frac{|\Delta N|}{\Delta t} = \lambda N \qquad R = R_0 e^{-\lambda t}$$

$E = mc^2 \qquad BE = (\Delta m)\,c^2$