Fundamental Constants

$$\begin{aligned}
g &= 9.80 \text{ m s}^{-2}\\
c &= \text{speed of light in vacuum} = 3.00\times 10^{8} \text{ ms}^{-1}\\
e &= \text{charge of electron} = 1.60\times 10^{-19} \text{ C}\\
m_e &= \text{mass of electron} = 9.11\times 10^{-31} \text{ kg}\\
m_n &= \text{mass of neutron or proton} = 1.67\times 10^{-27} \text{ kg}\\
N_A &= \text{Avogadro's number} = 6.022\times 10^{23} \text{ molecules/mol}\\
k_B &= \text{Boltzmann's constant} = 1.38\times 10^{-23}\text{J/K}\\
R &= \text{universal gas constant} = 8.31\frac{\text{J}}{\text{mol K}} = 0.0821\frac{\text{l atm}}{\text{mol K}}\\
c_{\text{W}} &= \text{specific heat of water} = 1 \text{ cal/(g K)]}\\
1 \text{ cal} &= 4.186 \text{ J]}\\
\sigma &= \text{Stefan-Boltzmann constant} = 5.67\times 10^{-8}\,\frac{\text{W}}{\text{m}^2\text{K}^4}
\end{aligned}$$

Energy

kinetic energy $K = \frac{1}{2}mv^2$
graviational potential energy $U_g = mgy$
spring potential energy $U_s = \frac{1}{2}kx^2$
work done by a force $W = F\cdot d$
power $P = \frac{\Delta E}{\Delta t}$

Heat and thermodynamics

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

absolute $T = T_C + 273$

thermal expansion:

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

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: $\frac{1}{2}mv^2_{rms} = \frac{3}{2}k_B T\,, \quad v_{rms} = \sqrt{\frac{3RT}{M}}$
thermal energy of an ideal gas: $\Delta E_{\text{th}} = \frac{3}{2}Nk_B T = \frac{3}{2}nRT$
heat capacity of an ideal gas (monatomic):
$C_V = \frac{3}{2}R = 12.5$ J/mol $\cdot$ K, @ const V
$C_p = \frac{5}{2}R = 20.8$ J/mol $\cdot$ 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)
$\Delta S = mc\ln\left(T_f/T_i\right) + nC\ln\left(V_f/V_i\right)$
second law of thermodynamics: $\Delta S_{\text{total}} \geq 0$

Mechanical properties of matter

stress $\propto$ strain

$$\begin{aligned}
F &= Y\,\frac{\Delta L}{L_0}\,A, &\quad Y &= \text{Young's modulus}\\
F &= S\,\frac{\Delta X}{L_0}\,A, &\quad S &= \text{shear modulus}\\
\frac{F}{A} &= -B\,\frac{\Delta V}{V_0}\,, &\quad B &= \text{bulk modulus}
\end{aligned}$$

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 = $\rho_{\text{X}}/\rho_{\text{H}_2\text{O}}$, $\rho_{\text{H}_2\text{O}} = 1000\,\text{kg/m}^3$

Fluids

hydrostatic pressure: $p = p_0 + \rho gh$
equation of continuity (conservation of mass)

$$\frac{\Delta m}{\Delta t} = \rho Av = \text{const}$$

Bernoulli's equation for an ideal fluid

$$p + \frac{1}{2}\rho v^2 + \rho gy = \text{const}$$

Poiseuille'e equation for a viscous flow

$$Q = \frac{\pi R^4 \Delta p}{8\eta L}\,, \qquad \eta = \text{viscosity}$$

buoyancy

$$F_B = \rho_f V_f g$$

Waves and Sound

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

$$f = 1/T \quad \omega = 2\pi/T = 2\pi f = \sqrt{k/m}$$

$$\begin{cases} x = A\cos\phi = A\cos\omega t,\\ v = -A\omega\sin\omega t\\ a = -A\omega^2\cos\omega t \end{cases}$$

pendulum $\omega = \sqrt{g/L}$
traveling wave

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

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)

$$f = f_s\left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}}\right) \qquad \text{s=source, o=observer}$$

Light and Optics

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

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

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

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

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 $\theta_{\min} \approx 1.22\lambda/D$