

## Fundamental Constants

$g = 9.80 \text{ m s}^{-2}$   
 $c = \text{speed of light in vacuum} = 3.00 \times 10^8 \text{ ms}^{-1}$   
 $e = \text{charge of electron} = 1.60 \times 10^{-19} \text{ C}$   
 $m_e = \text{mass of electron} = 9.11 \times 10^{-31} \text{ kg}$   
 $m_n = \text{mass of neutron or proton} = 1.67 \times 10^{-27} \text{ kg}$   
 $N_A = \text{Avogadro's number} = 6.022 \times 10^{23} \text{ molecules/mol}$   
 $k_B = \text{Boltzmann's constant} = 1.38 \times 10^{-23} \text{ J/K}$   
 $R = \text{universal gas constant} = 8.31 \frac{\text{J}}{\text{mol K}} = 0.0821 \frac{\text{l atm}}{\text{mol K}}$   
 $c_W = \text{specific heat of water} = 1 \text{ cal/(g K)}$   
 $1 \text{ cal} = 4.186 \text{ J}$   
 $\sigma = \text{Stefan-Boltzmann constant} = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2\text{K}^4}$   
 $\mu_0 = \text{permeability of space} = 4\pi \times 10^{-7} \text{ WbA}^{-1}\text{m}^{-1}$   
 $\epsilon_0 = \text{permittivity of space} = 8.85 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{m}^{-2}$   
 $k = \text{Coulomb's constant} = 8.99 \times 10^9 \text{ Nm}^2\text{C}^{-2}$   
 $G = \text{Newton's constant} = 6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2}$   
 $h = \text{Planck's constant} = 6.63 \times 10^{-34} \text{ Js}$

## Mechanics

constant acceleration:

$$v = v_0 + at, \quad d = v_0t + \frac{1}{2}at^2, \quad v^2 = v_0^2 + 2ad$$

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  $P = \frac{\Delta E}{\Delta t}$ ; 1 hp = 746 W

## Fluids

hydrostatic pressure:  $p = p_0 + \rho gh$

equation of continuity (conservation of mass)

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

$$\text{Bernoulli: } p + \frac{1}{2}\rho v^2 + \rho gy = \text{constant}$$

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

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

## Mechanical properties of matter

stress  $\propto$  strain

$$F = Y \frac{\Delta L}{L_0} A, \quad Y = \text{Young's modulus}$$

$$F = S \frac{\Delta X}{L_0} A, \quad S = \text{shear modulus}$$

$$\frac{F}{A} = -B \frac{\Delta V}{V_0}, \quad B = \text{bulk modulus}$$

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

## Heat and thermodynamics

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

absolute  $T = T_C + 273$

thermal expansion:

$$\text{length (1D): } \Delta L = \alpha L_0 \Delta T$$

$$\text{volume (3D): } \Delta V = \beta V_0 \Delta T$$

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:  $\frac{\Delta Q}{\Delta t} = e\sigma A (T^4 - T_{\text{surround}}^4)$

ideal gas law:  $\frac{pV}{T} = k_B N = nR$

Maxwell distribution:  $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_B T$ ,  $v_{rms} = \sqrt{\frac{3RT}{M}}$

thermal energy of an ideal gas:  $\Delta E_{th} = \frac{3}{2}Nk_B T = \frac{3}{2}nRT$

heat capacity of an ideal gas (monatomic):

$C_V = \frac{3}{2}R = 12.5 \text{ J/mol} \cdot \text{K}$ , @ const  $V$

$C_P = \frac{5}{2}R = 20.8 \text{ J/mol} \cdot \text{K}$ , @ 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  $L$ )

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

sound intensity

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

point source

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

Doppler (upper sign = approach, lower = recede)

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

## 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 ( $\lambda_{film} = \lambda/n$ ;  $v = c/n$ )

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

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

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

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

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

reflection  $\theta_i = \theta_r$ , refraction  $n_1 \sin \theta_1 = n_2 \sin \theta_2$

index of refraction of a medium  $m$

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

total internal reflection  $\theta_{critical} = \arcsin \frac{n_2}{n_1}$

polarization by reflection  $\theta_{Brewster} = \arctan \frac{n_2}{n_1}$

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:  $F = k \frac{q_1 q_2}{r^2}$ ,  $k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{Nm}^2/\text{C}^2$

$\vec{F} = q\vec{E}$   $W = -\Delta U = -q\Delta V$

constant electric field:  $\Delta V = Ed$

point charge:  $E = k \frac{q}{r^2}$   $V = k \frac{q}{r}$

capacitance:  $Q = C\Delta V$ ,  $U = \frac{1}{2}C(\Delta V)^2$

parallel plates:  $C = \frac{\kappa\epsilon_0 A}{d}$

current:  $I = \frac{q}{\Delta t}$   $R = \rho \frac{L}{A}$

$\Delta V = IR$   $P = I^2 R = I\Delta V = \frac{(\Delta V)^2}{R}$

series:  $R_{eq} = R_1 + R_2 + \dots$   $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$

parallel:  $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$   $C_{eq} = C_1 + C_2 + \dots$

## 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  $L$ :

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

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

## Electromagnetic Waves

average intensity:  $I = \frac{1}{2}\epsilon_0 E_0^2 c$

energy density:  $\frac{1}{2}\epsilon_0 E^2 + \frac{1}{2\mu_0} B^2$

$E_0 = cB_0$

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:

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

hydrogen spectrum

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

radioactive decay

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

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

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