UBC Physics 153 Crib Sheet

1 Thermodynamics

Boltzmann's constant $k = 1.381 \times 10^{-23}$ J/K

Calorie 1 cal = 4.184 J

Gas constant $R = 8.314$ J/mol·K

Latent heat

Ice to water	$L_{f,water} = 333.5$ kJ/kg
Water to steam	$L_{v,water} = 2257$ kJ/kg

Specific heat

Ice (−10°C)	$c_{ice} = 2.05$ kJ/kg·K
Water	$c_{water} = 4.18$ kJ/kg·K

Stefan's constant $\sigma = 5.67 \times 10^{-8}$ W/m²·K⁴

1.1 Temperature

Pressure $P = \frac{F}{A}$

Ideal gas $PV = nRT$

van der Waals $\left(P + \frac{an^2}{V^2}\right)(V - bn) = nRT$

Celsius $T_C = T - 273.15$ K

Linear expansion $\frac{\Delta L}{L} = \alpha \Delta T$

Stress $\frac{F}{A} = Y \frac{\Delta L}{L}$

Average translational kinetic energy $K_{av} = \frac{3}{2}kT$

Root-mean-square speed $K_{av} = \frac{1}{2}mv_{rms}^2$

1.2 Heat

Latent heat $Q = mL$ (phase change)

Specific heat $Q = mc\Delta T$

Conduction $I = \frac{dQ}{dt} = kA\frac{\Delta T}{\Delta x}$

Conduction $\Delta T = IR$

Resistance $R = \frac{\Delta x}{kA}$

...In series $R_{eq} = R_1 + R_2 + ...$

...In parallel $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ...$

Radiation $P = e\sigma AT^4$

Heat capacity

Monatomic gas	$C_v = \frac{3}{2}nR$
Diatomic gas	$C_v = \frac{5}{2}nR$
Constant pressure	$C_p = C_v + nR$

1.3 Gas processes

Sign convention ...

Q	+	heat **into** system
W	+	work done **by** system

First law $Q = \Delta U + W$

Work $W = \int P\, dV$

Internal energy $\Delta U = C_v \Delta T$

Adiabatic $Q = 0$; $PV^\gamma =$ constant, $\gamma = \frac{C_p}{C_v}$

Isochoric $\Delta V = 0$; $W = 0$

Isothermal $\Delta U = 0$; $W = nRT \ln \frac{V_f}{V_i}$ (ideal gas)

Isobaric $\Delta P = 0$

1.4 Engines

First law (1 cycle) $W = Q_h - |Q_c|$

Efficiency $\epsilon = \frac{W}{Q_h}$

Refrigerator COP $= \frac{Q_c}{W}$

2 Oscillations and Waves

Speed of sound in air (20°C) 343 m/s

Hearing threshold $I_0 = 1 \times 10^{-12}$ W/m²

2.1 Oscillations

Hooke's law $F_x = -kx$

Simple harmonic motion $a = -\omega^2 x$; $x = A\cos(\omega t + \delta)$

Angular frequency $\omega = 2\pi f$

Period $T = \frac{1}{f}$

2.2 Mass on a spring

Angular frequency $\omega_0 = \sqrt{\frac{k}{m}}$

Potential Energy $U = \frac{1}{2}kx^2$

Mechanical energy $E = K + U$; $E = \frac{1}{2}kA^2$

Damping $E = E_0\, e^{-t/\tau}$

Time constant $\tau = \frac{m}{b}$

Critical damping $b_c = 2m\omega_0$

Quality $Q = \omega_0 \tau$

Resonance $\omega = \omega_0$

Width of resonance $\Delta\omega = \frac{\omega_0}{Q}$

2.3 Waves on a string

Wave number $k = \frac{2\pi}{\lambda}$

Wave speed $v = \frac{\omega}{k} = f\lambda$

Tension $v = \sqrt{\frac{F}{\mu}}$

Power transmitted $P = \frac{1}{2}\mu\omega^2 A^2 v$

Standing waves

Node-node	$L = \frac{n}{2}\lambda_n$	$n = 1, 2, 3, \ldots$
Node-antinode	$L = \frac{n}{4}\lambda_n$	$n = 1, 3, 5, \ldots$

2.4 Sound

Intensity $I = \frac{P_{av}}{A}$

Loudness $\beta = 10 \log \frac{I}{I_0}$ (in dB)

Beat frequency $\Delta f = |f_1 - f_2|$

Doppler shift $f = \frac{1 + u_r/v}{1 - u_s/v} f_0$

Sign convention ...

u_s	+	source approaching
u_r	+	receiver approaching

3 Optics

Refraction index Air $n_{air} = 1$
Water $n_{water} = 1.33$

3.1 Mirrors

Focal length $f = \frac{1}{2}r$

Mirror eq. $\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$

Magnification $m = \frac{y'}{y} = -\frac{s'}{s}$

Sign convention ...

s	+	in front of mirror (real)
s'	+	in front of mirror (real)
r, f	+	concave
m	+	image has same orientation as object

3.2 Refraction

Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Total internal reflection $\theta = 90°$

Malus's law (polarizers) $I = I_0 \cos^2\theta$

Spherical surface $\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{r}$

Sign convention ...

s	+	incident side
s'	+	transmission side
r, f	+	center of curv. on transmission side

3.3 Thin Lenses

Lens-maker's eq. $\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

Thin lens eq. *same as Mirror eq.*

Sign convention *same as Refraction*

Power $P = \frac{1}{f}$ (units: diopters, 1 D = 1/m)

4 Electricity and Magnetism

Coulomb const. $k = 8.99 \times 10^9$ N·m^2/C^2

Fundamental charge $e = 1.60 \times 10^{-19}$ C

Permittivity $\epsilon_0 = 8.85 \times 10^{-12}$ F/m

4.1 Discrete Charges

Coulomb's law $\mathbf{E} = \frac{kQ}{r^2}\hat{\mathbf{r}}$

Force on q $\mathbf{F} = q\mathbf{E}$

Dipole
Moment $\mathbf{p} = q\mathbf{L}$
Torque $\tau = \mathbf{p} \times \mathbf{E}$
Potential Energy $U = -\mathbf{p} \cdot \mathbf{E}$

4.2 Continuous Distribution

Gauss's law $\phi_{net} = \sum_{surfaces} E_\perp \cdot A = \frac{Q_{net}}{\epsilon_0}$

Infinite line $E_r = 2k\frac{\lambda}{r}$

Infinite plane $E_n = 2\pi k\sigma$

4.3 Potential

Point charge $V = \frac{kQ}{r}$

Potential energy of q $U = qV$

Gradient of E $(E_x, E_y, E_z) = -\left(\frac{\partial V}{\partial x}, \frac{\partial V}{\partial y}, \frac{\partial V}{\partial z}\right)$

4.4 Capacitance

Capacitance $C = \frac{Q}{V}$ (units: 1 F = 1 C/V)

Parallel plates $C = \frac{\epsilon_0 A}{s}$

Dielectric
$E = \frac{E}{\kappa}$
$C = \kappa C_0$

Potential energy $U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}QV = \frac{1}{2}CV^2$

...In series $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + ...$

...In parallel $C_{eq} = C_1 + C_2 + ...$

4.5 Circuits

Current $I = \frac{dQ}{dt} = nqAv_d$ $(n = \frac{\#}{V})$

Resistance $R = \frac{V}{I} = \rho\frac{L}{A}$

...In series $R_{eq} = R_1 + R_2 + ...$

...In parallel $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ...$

Power $P = IV = I^2R = \frac{V^2}{R}$

Kirchhoff's #1 around a loop $\sum V = 0$

Kirchhoff's #2 at a branch $\sum I_{in} = \sum I_{out}$

RC circuits
Time constant $\tau = RC$
$Q(t) - Q_0 = (Q_\infty - Q_0)\left(1 - e^{-t/\tau}\right)$
$I(t) - I_0 = (I_\infty - I_0)\left(1 - e^{-t/\tau}\right)$
$V(t) - V_0 = (V_\infty - V_0)\left(1 - e^{-t/\tau}\right)$
(note: need to calculate initial and final values)

Send suggestions/corrections to Rik Blok <rikblok@shaw.ca>.