Thermodynamics Formula Sheet

(see back for additional constants)

Constants

1 atm = 1.01 x 10^5 Pa (where 1 Pa = 1 N/m^2)

$T = T_c + 273$, where T_c is in Celsius

1 cal = 4.186 J

k = 1.38 x 10^{-23} J/K

N_A = 6.02 x 10^{23}/mol

R = 8.31 J/mol•K = 0.0821 (L•atm)/(mol•K)

1 L · atm = 101 J

Nk = nR; $n = N/N_A$; $R = N_A k$

Ideal gas equation of state

PV = NkT = nRT

adiabatic process:

$PV^{\gamma} = \text{const}$; $P_iV_i^{\gamma} = P_fV_f^{\gamma}$

$TV^{\gamma-1} = \text{const}$; $T_iV_i^{\gamma-1} = T_fV_f^{\gamma-1}$

$\gamma = C_p/C_v = 5/3$ (= 1.67) (monatomic)

$= 7/5$ (=1.40) (diatomic)

$$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}} \quad \left(v_{rms} = \sqrt{(v^2)_{avg}}\right)$$

Specific heat

$Q = mc\Delta T = nc'\Delta T$

$dQ = mc\,dT = nc'\,dT$

Heat capacity of ideal gasses:

monatomic: $c_V' = \frac{3}{2}$ R; $c_P' = (\frac{3}{2} + 1)$ R

diatomic: $c_V' = \frac{5}{2}$ R; $c_P' = (\frac{5}{2} + 1)$ R

Thermal conductivity

$$P_{cond} = \frac{kA\Delta T}{L} \quad \text{or} \quad P_{cond} = \frac{A\Delta T}{\sum_{i=1}^{n} \frac{L_i}{k_i}}$$

First law of thermodynamics

$\Delta E_{int} = Q - W_{by}$

$\Delta E_{int} = Q + W_{on}$ where $W_{on} = -W_{by}$

equipartition theorem

$E_{int} = \frac{3}{2}$ nRT = $\frac{3}{2}$ NkT monatomic gas

$E_{int} = \frac{5}{2}$ nRT = $\frac{5}{2}$ NkT diatomic gas

$\Delta E_{int} = n c_V' \Delta T$

Work

$$W_{by} = +\int_{V_1}^{V_2} P\,dV$$

isothermal

$$W_{by} = +NkT \ln\frac{V_2}{V_1} = +nRT \ln\frac{V_2}{V_1}$$

Second law of thermodynamics

$\Delta S_{system+surroundings} = 0$ [reversible process]

$\Delta S_{system+surroundings} > 0$ [irreversible]

Entropy

$$dS = \frac{dQ}{T}$$

$$\Delta S = \int_i^f dS = \int_i^f \frac{dQ}{T}$$

Thermodynamic efficiency

ε = (Work By Engine)/Q_{Hot} where Q_{Hot} is the heat put into the engine

$\varepsilon = (Q_{hot} - Q_{cold})/Q_{Hot}$ where Q_{cold} is the absolute value of the heat out of the engine

Carnot efficiency

$$\varepsilon_{carnot} = 1 - \frac{T_C}{T_H}$$

Normal Melting Point (MP), Latent Heat of Fusion (L_f), Normal Boiling Point (BP), and Latent Heat of Vaporization (L_v) for Various Substances at 1 atm

Substance	MP, K	L_f, kJ/kg	BP, K	L_v, kJ/kg
Alcohol, ethyl	159	109	351	879
Bromine	266	67.4	332	369
Carbon dioxide	—	—	194.6†	573†
Copper	1356	205	2839	4726
Gold	1336	62.8	3081	1701
Helium	—	—	4.2	21
Lead	600	24.7	2023	858
Mercury	234	11.3	630	296
Nitrogen	63	25.7	77.35	199
Oxygen	54.4	13.8	90.2	213
Silver	1234	105	2436	2323
Sulfur	388	38.5	717.75	287
Water	273.15	333.5	373.15	2257
Zinc	692	102	1184	1768

† These values are for sublimation. Carbon dioxide does not have a liquid state at 1 atm.

Specific Heats and Molar Specific Heats of Some Solids and Liquids

Substance	c, kJ/kg·K	c, kcal/kg·K or Btu/lb·F°	c', J/mol·K
Aluminum	0.900	0.215	24.3
Bismuth	0.123	0.0294	25.7
Copper	0.386	0.0923	24.5
Glass	0.840	0.20	—
Gold	0.126	0.0301	25.6
Ice (−10°C)	2.05	0.49	36.9
Lead	0.128	0.0305	26.4
Silver	0.233	0.0558	24.9
Tungsten	0.134	0.0321	24.8
Zinc	0.387	0.0925	25.2
Alcohol (ethyl)	2.4	0.58	111
Mercury	0.140	0.033	28.3
Water	4.18	1.00	75.2