1 Constants

Universal Gas Constant $R = 8.314 \frac{J}{mol \cdot K}, R = 0.821 \frac{L \cdot atm}{mol \cdot K}$ Boltzmann Constant $k = 1.38064852 \times 10^{-23} \frac{J}{K}$ Avogadro's Number $N_A = 6.022 \times 10^{23} \frac{units}{mol}$

Stefan-Boltzmann Constant $\sigma = 5.67 \times 10^8 \frac{W}{m^2 K^4}$ Planck's Constant $6.63 \times 10^{-34} J \cdot S$ Planck Temperature $T_P = \frac{m_P c^2}{k} = \sqrt{\frac{\hbar c^5}{G k^2}} \approx 1.416808 \times 10^{32} K$

Specific Heats ($\frac{J}{g^\circ C}$) Water - 4.186; Ice - 2.108; Steam - 2.010; Gold - .129; Lead - .129; Aluminum - .897; Steel - .490; Liquid Ammonia - 4.700; Gaseous Ammonia - 2.060 **Latent Heats**($\frac{J}{g}$) Water: $L_f = 334, L_v = 2,258$; Aluminum: $L_f = 397, L_v = 10,900$; Silicon: $L_f = 1790, L_v = 12,800$ γ=5/3 for ideal monatomic gas, 1.4 for diatomic gas and air.

1.1 Conversions and Temperature

$T_C = \frac{5}{9}(T_F - 32);$ $T_F = \frac{9}{5}T_C + 32;$ $T_K = T_C + 273.15$ $T_R = T_F + 459.67;$ $T_N = \frac{1}{3}T_C;$ $T_{Re} = \frac{4}{5}T_C;$ $T_{Ro} = \frac{21}{40}T_C + 7.5;$ $T_{De} = \frac{3}{2}(100 - T_C)$
1 cal = .001 Cal = 4.184 J = .00397 BTU = 4.184×10^7 ergs = .3238 ft·lb = $1.1628 \times 10^{-6} kWh$ **101.33 J= 1 L · atm**
1 atm= 760 torr= 760 mm Hg = 101.325 kPa = 101325 Pa= 101325 $\frac{N}{m^2}$

2 General

First Law $\Delta U = Q - W$ Thermodynamic Temperature $\tau = kT$ Thermodynamic Beta, Inverse Temperature $\beta = \frac{1}{kT}$ Fundamental thermodynamic relation $dU = TdS - PdV + \sum_{i=1}^{k} \mu_i dN_i$ Internal Energy of a substance: $\Delta U = NC_V \Delta T$ Meyer's Equation $C_P - C_V = nR$

3 Heat Engines and Refrigeration

efficiency $\eta = \left| \frac{W}{Q_H} \right|$ Carnot Efficiency $\eta_c = 1 - \left| \frac{Q_L}{Q_H} \right| = 1 - \frac{T_L}{T_H}$

Refrigeration coefficient of performance $K = \left| \frac{Q_L}{W} \right|$ Carnot Refrigerator $K_C = \frac{|Q_L|}{|Q_H| - |Q_L|} = \frac{T_L}{T_H - T_L}$

$W_C = Q_H - Q_C = \left(1 - \frac{T_C}{T_H} \right) Q_H$ - Carnot work, also equal to total curve area

Otto Cycle: $\eta = 1 - \frac{1}{1 - r^{(\gamma - 1)}} = 1 - \frac{T_4 - T_3}{T_2 - T_1}$

4 Heat Transfer

Heat to raise temp $Q = mC\Delta T$ Latent heat $Q = mL$ heat transfer $q = \frac{Q}{t} = \frac{kA\Delta T}{d}$ linear thermal expansion: $\Delta L = \alpha L_0 \Delta T$, Area: $\Delta A = 2A_0 \alpha \Delta T,$

Volume: $\Delta V = 3V_0 \alpha \Delta T$ coefficient of thermal expansion $\alpha_p = -\frac{1}{V}\left(\frac{\partial V}{\partial P} \right)_{T,N}$ Thermal conduction rate, thermal current, thermal/heat flux, thermal power transfer

$P = \frac{dQ}{dt}$, Thermal Intensity $I = \frac{dP}{dA}$, Thermal/heat flux density (vector analogue of thermal intensity above) (symbol is little q) $Q = \iint q \cdot dSdt$ $C_P = \left(\frac{\partial Q_{rev}}{\partial T} \right)_P = \left(\frac{\partial U}{\partial T} \right)_P + P\left(\frac{\partial V}{\partial T} \right) = \left(\frac{\partial H}{\partial T} \right)_P = T\left(\frac{\partial S}{\partial T} \right)_P$ $C_V = \left(\frac{\partial Q_{rev}}{\partial T} \right)_V = \left(\frac{\partial U}{\partial T} \right)_V = T\left(\frac{\partial S}{\partial T} \right)_V$, Blackbody Radiation: $I = \frac{P}{A} = \sigma T^4$, Real bodies: $I = \frac{P}{A} = \epsilon \sigma T^4$

5 Gas Laws

$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$ - Combined Gas Law $P_1 V_1 = P_2 V_2$ - Boyle's Law $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ - Charles' Law $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ - Gay-Lussac's Law

$(P + \frac{n^2 a}{V^2})(V - nb) = nRT$ - van der Waals' Equation (real gas law) $\ln \frac{P_2}{P_1} = -\frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1} \right)$ - Clausius Clapeyron Equation $\gamma = \frac{C_p}{C_V}$ Adiabatic Index

5.1 Ideal Gases

Ideal Gas Law $PV = nRT = NkT$, $\frac{P_1 V_1}{P_2 V_2} = \frac{n_1 T_1}{n_2 T_2} = \frac{N_1 T_1}{N_2 T_2}$ Pressure $P = \frac{Nm\langle v^2 \rangle}{3V} = \frac{nM_m \langle v^2 \rangle}{3V} = \frac{1}{3}\rho\langle v^2 \rangle$

Quantity	General	Isobaric	Isochoric	Isothermal	Adiabatic
Work W	$\delta W = -pdV$	$-p\Delta V$	0	$-nRT \ln \frac{V_2}{V_1}$ or $-nRT \ln \frac{P_1}{P_2}$	$\frac{PV^\gamma (V_f^{1-\gamma} - V_i^{1-\gamma})}{1 - \gamma} = C_V(T_2 - T_1)$
Heat Capacity C	(same as real gas)	$C_p = \frac{5}{2}nR$ (monatomic) or $C_p = \frac{7}{2}nR$ (diatomic)	$C_V = \frac{3}{2}nR$ (monatomic) or $C_V = \frac{5}{2}nR$ (diatomic)		
Internal Energy ΔU	$\Delta U = C_V \Delta T$	$Q + W$ or $Q_p - p\Delta V$	Q or $C_V(T_2 - T_1)$	0 or $Q = -W$	W or $C_V(T_2 - T_1)$
Enthalpy ΔH	$H = U + PV$	$C_p(T_2 - T_1)$	$Q_V + V\Delta p$	0	$C_p(T_2 - T_1)$
Entropy ΔS	$\Delta S = C_V \ln \frac{T_2}{T_1} + nR \ln \frac{V_2}{V_1}$ $\Delta S = C_p \ln \frac{T_2}{T_1} - nR \ln \frac{P_2}{P_1}$	$C_p \ln \frac{T_2}{T_1}$	$C_V \ln \frac{T_2}{T_1}$	$nR \ln \frac{V_2}{V_1} \frac{Q}{T}$	$C_p \ln \frac{V_2}{V_1} + C_V \ln \frac{P_2}{P1} = 0$
constant		$\frac{V}{T}$	$\frac{P}{T}$	PV	PV^γ

5.2 Statistical Thermodynamics

mean speed $\langle v \rangle = \sqrt{\frac{8kT}{\pi m}}$ Root mean square speed $v_{rms} = \sqrt{\langle v^2 \rangle} = \sqrt{\frac{3kT}{m}}$ most probable speed $v_{mode} = \sqrt{\frac{2kT}{m}}$ Mean free path $\lambda = \frac{RT}{\sqrt{2}\pi d^2 N_A P}$
avg. KE per molecule $KE_{avg} = \frac{3}{2}kT$, per mole: $KE_{avg} = \frac{3}{2}RT$

6 Chem

$\Delta H = U + PV$ - Enthalpy $\Delta_r H^{\Theta} = \Sigma v H^{\Theta}_{products} - \Sigma v H^{\Theta}_{reactants}$ - Standard Enthalpy of Formation

$S = k \log W$, $dS = \dfrac{dQ}{T}$, $\Delta S_{surroundings} = -\dfrac{\Delta H}{T}$ - Entropy $\Delta G = \Delta H - T\Delta S$, $G = U + PV - TS$ - Gibbs Free Energy   **Other Potentials** Helmholtz Free Energy

$F = U - TS$, Landau potential (Landau Free Energy, Grand Potential) $\Omega = U - TS - \mu N$ (μ = chemical potential), Massieu Potential, Helmholtz free entropy $\Phi = S - \dfrac{U}{T}$,

Planck potential, Gibbs free entropy $\Xi = \Phi - \dfrac{PV}{T}$

7 processes

Process	Equations
Isentropic (Adiabatic Reversible)	$\Delta Q = 0$, $\Delta U = -\Delta W$ For an ideal gas: $P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$, $T_1 V_1^{\gamma-1} = T_1 V_2^{\gamma-1}$, $P_1^{\gamma-a} T_1^{\gamma} = P_2^{\gamma-1} T_2^{\gamma}$
Isothermal	$\Delta U = 0$, $\Delta W = \Delta Q$, For an ideal gas: $W = kTN \ln \dfrac{V_2}{V_1}$
Isobaric	$P_1 = P_2$, P =constant, $\Delta W = P\Delta V$, $\Delta q = \Delta U + P\delta V$
Isochoric	$V_1 = V_2$, V =constant, $\Delta W = 0$, $\Delta Q = \Delta U$
Free expansion	$\Delta U = 0$
Work Done by expanding a gas	Process: $$\Delta W = \int_{V_1}^{V_2} PdV$$, Net work in Cyclic processes: $$\Delta W = \oint_{cycle} PdV$$

8 Quantum Properties

$U = NkT^2 \left(\dfrac{\partial \ln Z}{\partial T} \right)_V$ $S = \dfrac{U}{T} + N$, For indistinguishable particles: $S = \dfrac{U}{T} + Nk \ln N + Nk$

Degree of freedom	Partition Function
Translation	$Z_t = \dfrac{(2\pi mkT)^{\frac{3}{2}} V}{h^3}$
Vibration	$Z_v = \dfrac{1}{1 - e^{(\frac{-h\omega}{2\pi kT})}}$
Rotation	$Z_r = \dfrac{2IkT}{\sigma \hbar^2}$, σ=1 for heteronuclear molecules and σ=2 for homonuclear.

9 other

9.1 electricity

resistors - $Q = I^2 Rt = tIV = \dfrac{tV^2}{R}$