Equations 4

T conversion: \[ T_K = 273 + T_c \quad \text{T}_F = \frac{9}{5} T_c + 32^\circ \]
Heat capacity: \[ Q = m c \Delta T = C \Delta T \]
Two objects coming to thermo. eq: \[ m_1 c_1 \Delta T_1 + m_2 c_2 \Delta T_2 = 0 \]
Conductive heat flow: \[ H = -k a \Delta T \], thermal resistance: \[ R = \frac{\Delta x}{k a} \quad \text{and} \quad 1/R = \frac{k}{\Delta x} \]
Radiative heat transfer: \[ P = e c a A T^4 \], \( e = \text{emissivity} \) and \( a = 5.67 \times 10^{-8} \ \text{W/m}^2\cdot\text{K}^4 \)

Ideal gas law: \[ pV = nRT = N k_B T \quad \text{where} \quad R = 8.314 \ \text{J/mol} \cdot \text{K} \quad \text{or} \quad k_B = 1.38 \times 10^{-23} \ \text{J/K} \]

Micro/macro connection for monatomic gas: \[ \frac{1}{2} m v^2 = \frac{3}{2} k_B T \quad \text{and} \quad v_{rh} = \sqrt{3 k_B T/m} \]

Phase transformations: \[ Q = m L \quad ; \quad N_A = 6.02 \times 10^{23} \ \text{particles/mol} \quad ; \quad 1L = 10^{-3} \ \text{m}^3 \]
Thermal expansion: solids: \( \alpha \Delta T = \Delta L/L \); liquids and gases: \( \beta \Delta T = \Delta V/V \)

Zeroth law of thermo: statement of thermodynamic equilibrium
First law of thermo: \( \Delta U = W + Q \)

Definition of work: \( \Delta W = -p \Delta V \) or in integral form \[ W = -\int p \, dV \]

\( \Delta U = n C_v \Delta T \); for ideal gas: \( C_v = 3 R/2 \) (monatomic) \quad ; \quad C_v = 5 R/2 \) (diatomic)
\( C_p = C_v + R \) with \( C_v/C_v = \gamma = 1.67 \) (monatomic) \quad ; \quad \gamma = 1.4 \) (diatomic)

**ISOTHERMAL**

- \( T = \text{constant} \)
- \( Q = -W \)
- \( W = -nRT \ln \left( \frac{V_2}{V_1} \right) \)
- \( \rho V = \text{constant} \)

**CONSTANT-VOLUME**

- \( V = \text{constant} \)
- \( Q = \Delta U \)
- \( W = 0 \)
- \( Q = n C_v \Delta T \)

**ISOBARIC**

- \( p = \text{constant} \)
- \( Q = \Delta U - W \)
- \( W = -p(V_2 - V_1) \)
- \( Q = n C_p \Delta T \)
- \( C_p = C_v + R \)

**ADIABATIC**

- \( Q = 0 \)
- \( \Delta U = W \)
- \( W = \frac{p_2 V_2 - p_1 V_1}{\gamma - 1} \)
- \( p V^\gamma = \text{constant} \)
- \( T V^\gamma = \text{constant} \)

Second law of thermo: It is impossible to construct a heat engine operating in a cycle that extracts heat from a reservoir and delivers an equal amount of work.

1 cycle of engine \( (\Delta U)_{net} = 0 \) \quad 1 cycle work done by engine \( W_{out} = Q_{net} = Q_h - Q_c \)

Definition of efficiency: \( e = \frac{W_{out}}{Q_h} = 1 - \frac{Q_c}{Q_h} \); Carnot efficiency: \( e_c = 1 - \frac{T_c}{T_h} \)

Second law of thermo: It is impossible to construct a refrigerator operating in a cycle whose sole effect is to transfer heat from a cooler object to a hotter one.

Refrigerator: \( \text{COP}_R = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q_c} = \frac{T_c}{T_h - T_c} \); Heat pump: \( \text{COP}_{HP} = \frac{Q_h}{W} = \frac{Q_h}{Q_h - Q_c} = \frac{T_h}{T_h - T_c} \)

Entropy change: \( \Delta S_{12} = \int_1^2 dQ/T \); Energy unavailable for work: \( E = T_{min} \Delta S \)