# Lecture 2-Thermo state, reversible process, ideal gas

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**State Variable (or state function):** is an independent variable of a state function, it only depends on the state (P, V, T) of the system, but not the path the system takes to change from state 1 to state 2. No matter what path the system takes to change from state 1 to state 2. the difference of a state variable is the same. For example, internal energy (U), enthalpy (H), temperature (T), pressure (P), volume (V) and entropy (S).

$\int dU = \Delta U = U_2 - U_1 \qquad \int dQ = Q \qquad \int dW = W$

**Process variable:** however, its exact value depends on the particular path taken between the start and end points of the process. Example include **heat** and **work**.

**Reversible Process:**

1. Frictionless
2. Follow exactly the same path
3. Always at equilibrium, takes an infinite amount of time
4. Not possible in practice (because friction always exists)
5. A quasi-static process can be considered as a reversible process in the exam.

$P_{sys} = P_{ext}$

$W = -\int_{V_1}^{V_2} P_{ext}\,dV = -\int_{V_1}^{V_2} \frac{RT}{V}\,dV = -RT\ln\left(\frac{V_2}{V_1}\right) = -RT\ln\left(\frac{P_1}{P_2}\right)$ Reversible process

$W = -\int_{V_1}^{V_2} P_{ext}\,dV = P_{ext}(V_2 - V_1) = P_{ext}\left(\frac{RT}{P_{ext}} - \frac{RT}{P_0}\right) = RT\left(1 - \frac{P_{ext}}{P_0}\right)$ irreversible process

**Isochoric (constant V) and reversible:**

$dW = 0, \quad \Delta U = Q$

**Isobaric (constant P) and reversible:**

$dQ = dU - dW = dU + PdV = d(U + PV)$

$H \equiv U + PV$ (Enthalpy) 焓

$dQ = dH$

(5) Other important notes, Page 83

For monatomic i.g : γ=5/3 (molecule only has one atmo (Ne, Ar))

For diatomic i.g: γ=7/5 (two atmos (H2, N2))

For other simple polyatomic gases, such as $CO_2$, $SO_2$, $NH_3$, $CH_4$ : γ=1.3

And we know $C_p^{ig} - C_V^{ig} = R$, so

For monatomic i.g : $C_P^{ig}$ =5R/2, $C_V^{ig}$ =3R/2

For diatomic i.g: $C_P^{ig}$ =7R/2, $C_V^{ig}$ =5R/2

For other simple polyatomic gases, such as $CO_2$, $SO_2$, $NH_3$, $CH_4$: $C_P^{ig}$ =13R/3, $C_V^{ig}$ =10R/3

**Heat capacity**

**C represents how much heat is required to increase 1K of temperature.**

**Constant V:**

$\left(\frac{\partial U}{\partial T}\right)_V = C_V, \quad \Delta U = \int_{T_1}^{T_2} C_V^{ig}\,dT$

**Constant P:**

$\left(\frac{\partial H}{\partial T}\right)_P = C_P, \quad \Delta H = \int_{T_1}^{T_2} C_P^{ig}\,dT$

$R = 8.314\ [J/(mol\cdot k)]$ $[m^3/mol]$

**Ideal Gas PV=RT:**

1. No interaction between gas molecules
2. Gas molecules have negligible molecular volume

**High temp. and low pressure**, a gas behaves more like a ideal gas.

$U^{ig} = U(T)$ (only relate to T), $H^{ig} = H(T)$

$\Delta U^{ig} = \int_{T_1}^{T_2} C_V^{ig}\,dT \qquad \Delta H^{ig} = \int_{T_1}^{T_2} C_P^{ig}\,dT$ (any process)

$C_P^{ig} - C_V^{ig} = R$

**Ideal Gas reversible processes, closed system, only PV work**:

1. **Isothermal process (constant T):**

$\Delta H^{ig} = \Delta U^{ig} = 0$

$Q = -W = \int_{V_1}^{V_2} P\,dV = RT\ln\left(\frac{V_2}{V_1}\right) = RT\ln\left(\frac{P_1}{P_2}\right)$

2. **Isobaric process (constant P):**

$\Delta U^{ig} = \int_{T_1}^{T_2} C_V^{ig}\,dT \qquad Q = \Delta H^{ig} = \int_{T_1}^{T_2} C_P^{ig}\,dT$

$W = -P(V_2 - V_1) = -R(T_2 - T_1)$

3. **Isochoric process (constant V):**

$W = 0, \quad U = Q = \Delta U^{ig} = \int_{T_1}^{T_2} C_V^{ig}\,dT$

$\Delta H_{ig} = \int_{T_1}^{T_2} C_P^{ig}\,dT$

1. **Adiabatic process (constant Q):**

$\gamma = \frac{C_P^{ig}}{C_V^{ig}}$

$TV^{\gamma-1} = Const. \qquad TP^{\frac{1-\gamma}{\gamma}} = Const. \qquad PV^{\gamma} = Const.$

$dW = dU = C_V^{ig}\,dT$

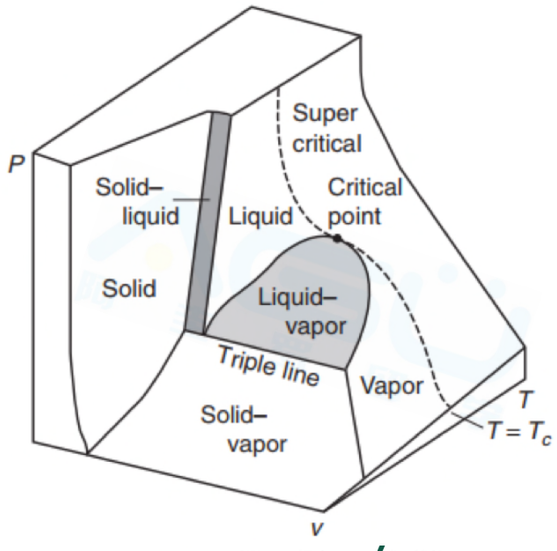
$W = \frac{R(T_2 - T_1)}{\gamma - 1} = \frac{P_2V_2 - P_1V_1}{\gamma - 1}$

$\Delta H^{ig} = \int_{T_1}^{T_2} C_P^{ig}\,dT$

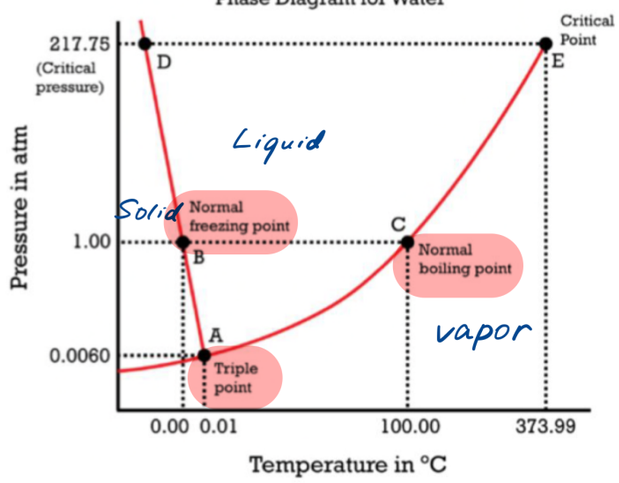
# Lecture 3-Efficiency, phase diagram, EOS, compressibility

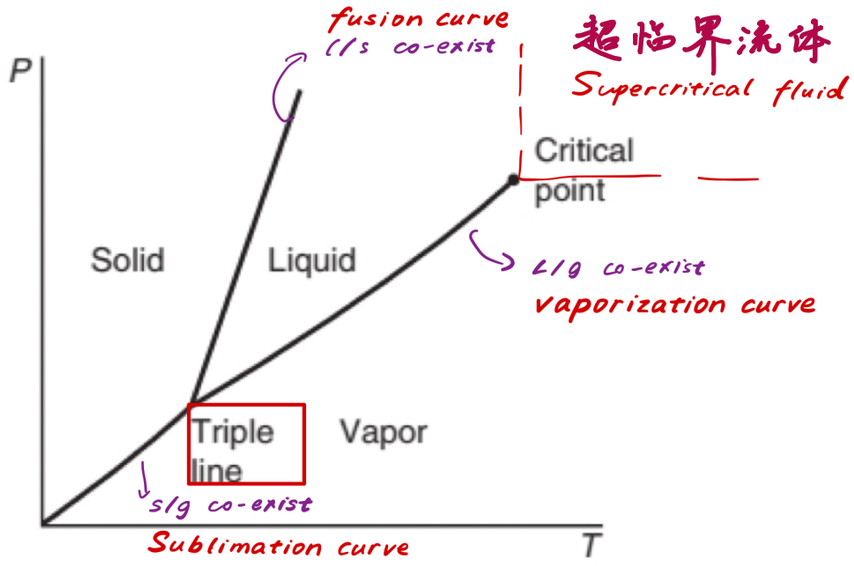
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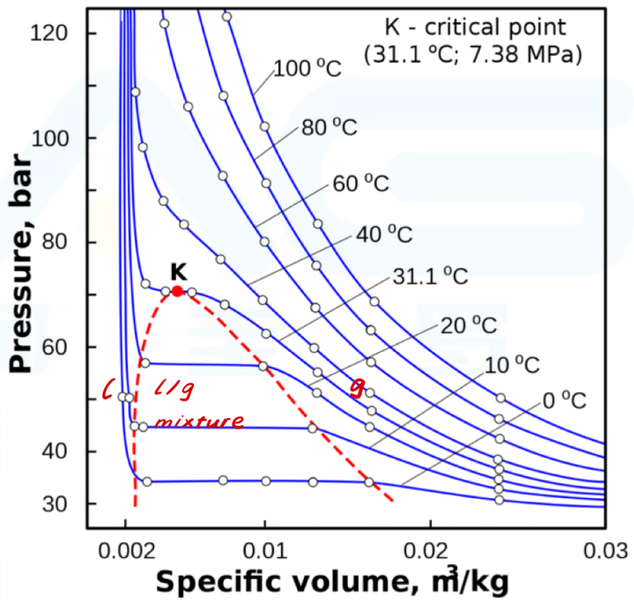
**PVT relations for pure substances:**




Phase Diagram for Water




$CO_2$ P-V diagram

