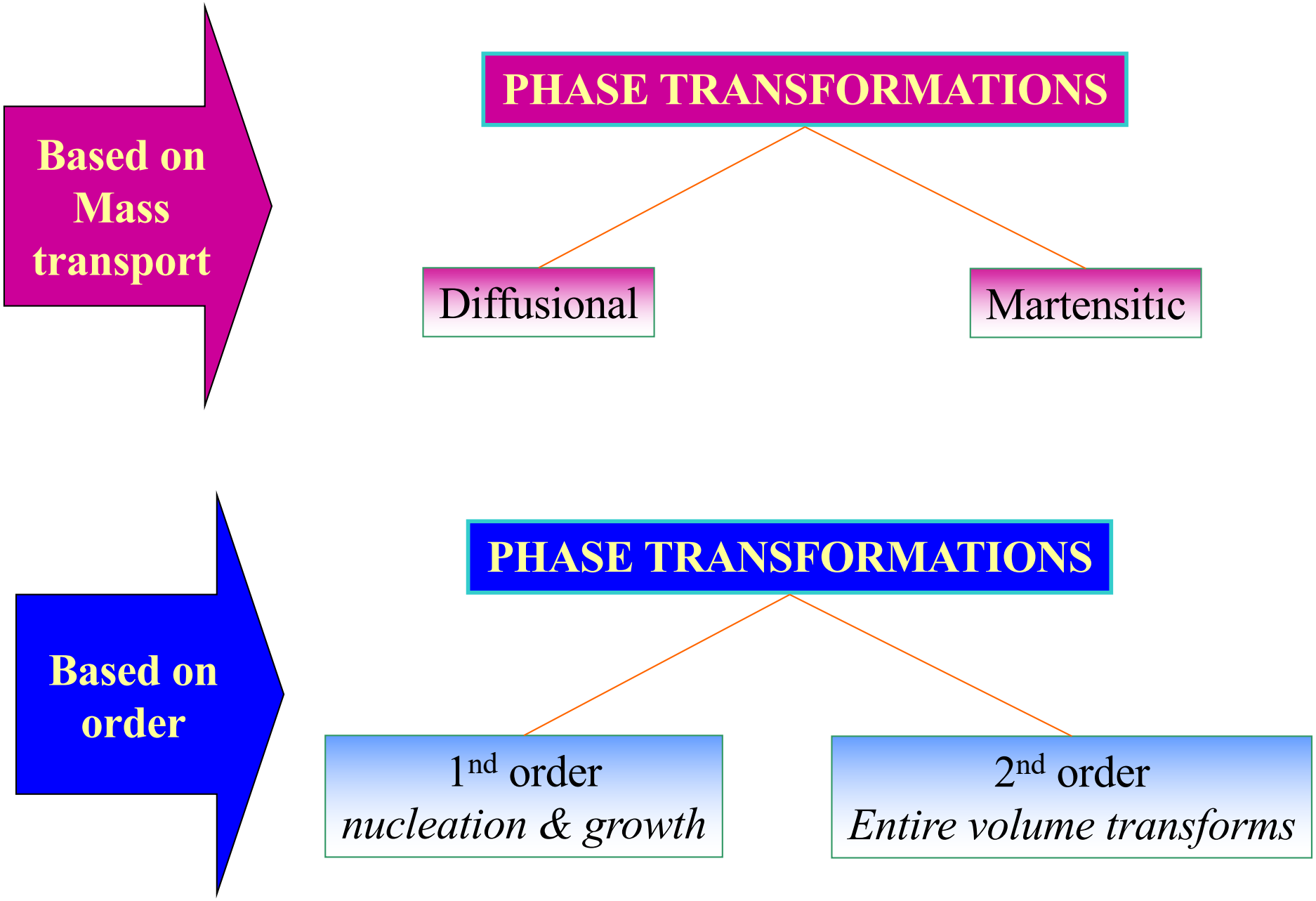
PHASE TRANSFORMATIONS

- Nucleation
- Growth
- APPLICATIONS
  - Transformations in Steel
  - Precipitation
  - Solidification & crystallization
  - Glass transition
  - Recovery, Recrystallization & Grain growth

Phase Transformations in Metals and Alloys

David Porter & Kenneth Esterling

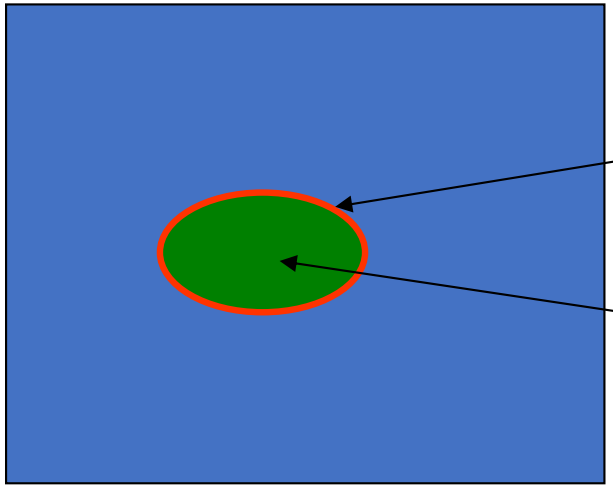
Van Nostrand Reinhold Co. Ltd., New York (1981)


Based on Mass transport
PHASE TRANSFORMATIONS
Diffusional
Martensitic
Based on order
PHASE TRANSFORMATIONS
1nd order
nucleation & growth
2nd order
Entire volume transforms

Energies involved

- Bulk Gibbs free energy ↓
- Interfacial energy ↑
- Strain energy ↑

Solid-solid transformation



❑ The concepts are illustrated using solidification of a metal

1nd order
nucleation & growth

Trasformation

$\alpha \rightarrow \beta$

=

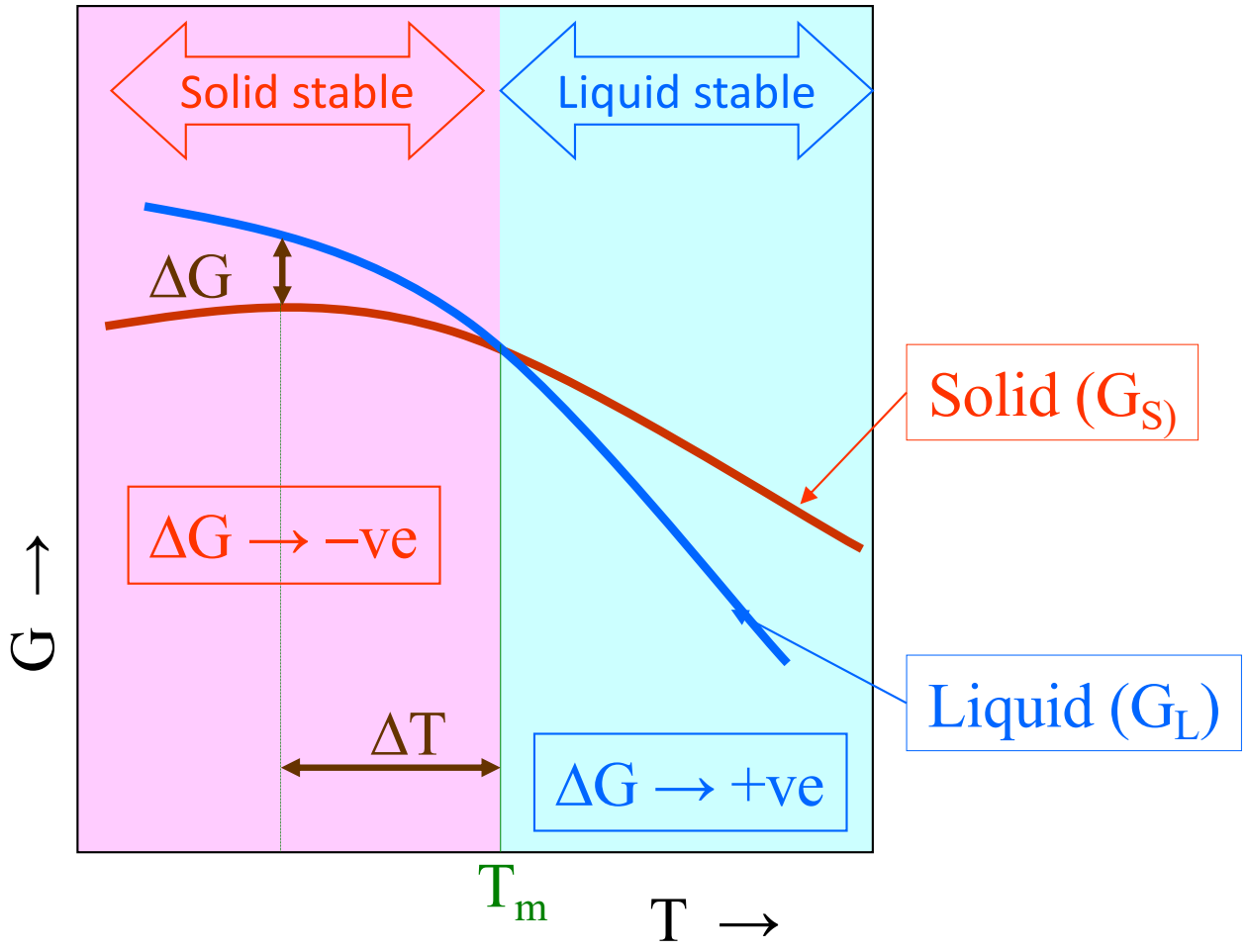
Nucleation of β phase

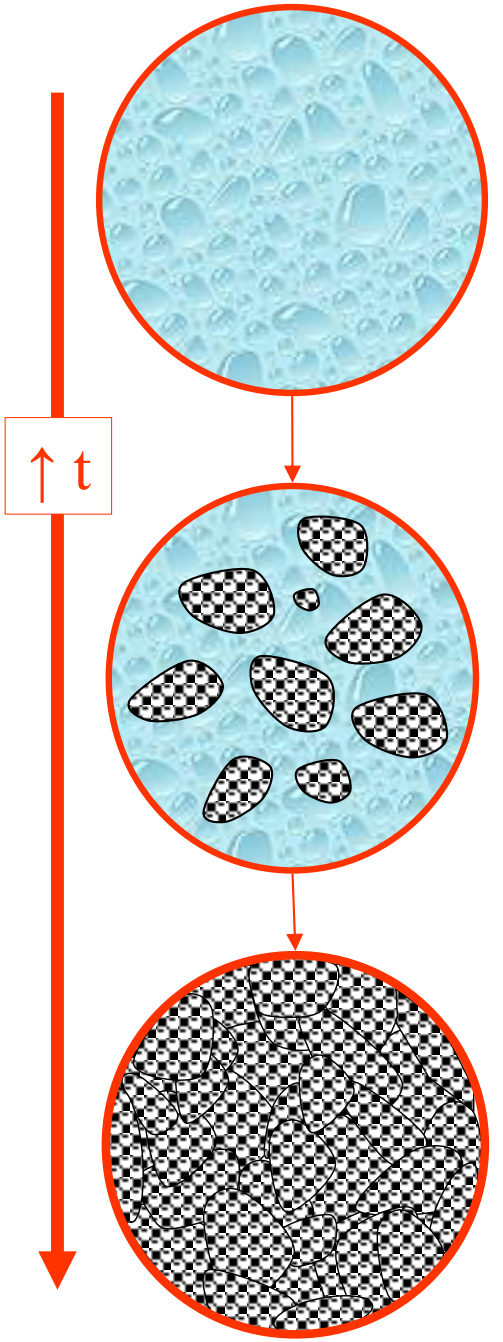
+

Growth till α is exhausted

Liquid → Solid phase transformation

- On cooling *just* below T_m solid becomes stable
- *But* solidification does not start
- E.g. liquid Ni can be undercooled 250 K below T_m





"For sufficient Undercooling"

ΔT - Undercooling

Solidification = Nucleation + Growth

Nucleation

Nucleation → Homogenous

Nucleation → Heterogenous

- Liquid → solid
  walls of container, inclusions
- Solid → solid
  inclusions, grain boundaries, dislocations, stacking faults

- The probability of nucleation occurring at point in the parent phase is same throughout the parent phase
- In heterogeneous nucleation there are some preferred sites in the parent phase where nucleation can occur

Homogenous nucleation

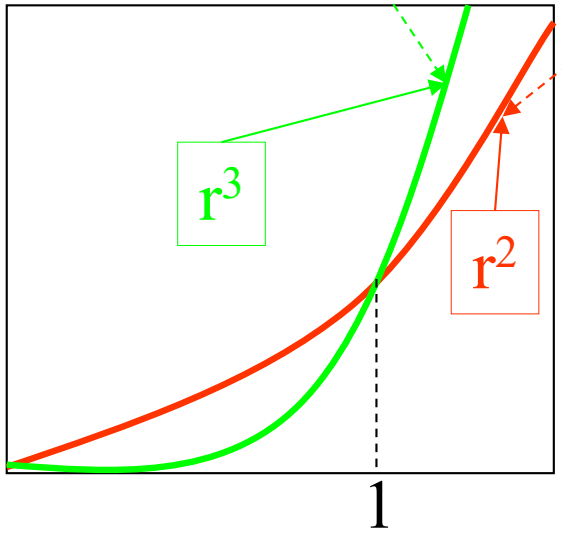
Neglected in L → S transformations

Free energy change on nucleation □

Reduction in bulk free energy □ increase in surface energy □ increase in strain energy

$$\Delta G \;\square\; (\text{Volume}).(\Delta G) \;\square\; (\text{Surface}).(\gamma)$$

$$\Delta G \;\square\; \left(\frac{4}{3}\pi r^3\right).(\Delta G_v) \;\square\; 4\pi r^2.(\gamma)$$



$$\Delta G_v \;\square\; f(\Delta T)$$

$$\Delta G = \left(\frac{4}{3}\pi r^3\right).(\Delta G_v) + 4\pi r^2.(\gamma)$$

- By setting $d\Delta G/dr = 0$ the critical values (corresponding to the maximum) are obtained (denoted by superscript *)
- Reduction in free energy is obtained only after r_0 is obtained

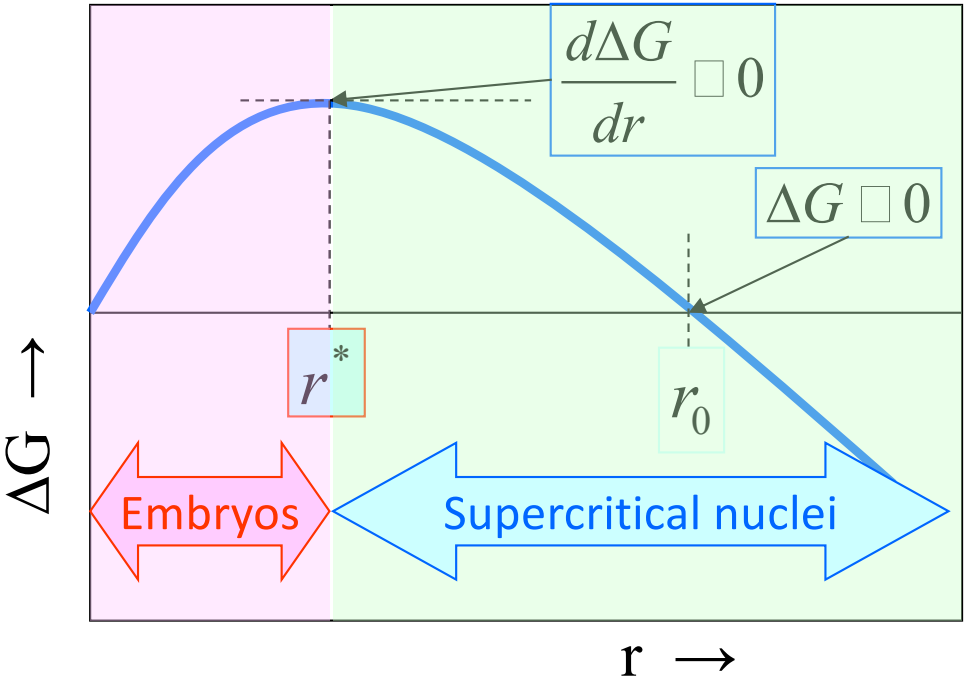
$$\frac{d\Delta G}{dr} = 0 \Rightarrow r_1^* = 0 \text{ (Trivial)}, \quad r_2^* = -\frac{2\gamma}{\Delta G_v}$$

As ΔG_v is –ve, r^* is +ve

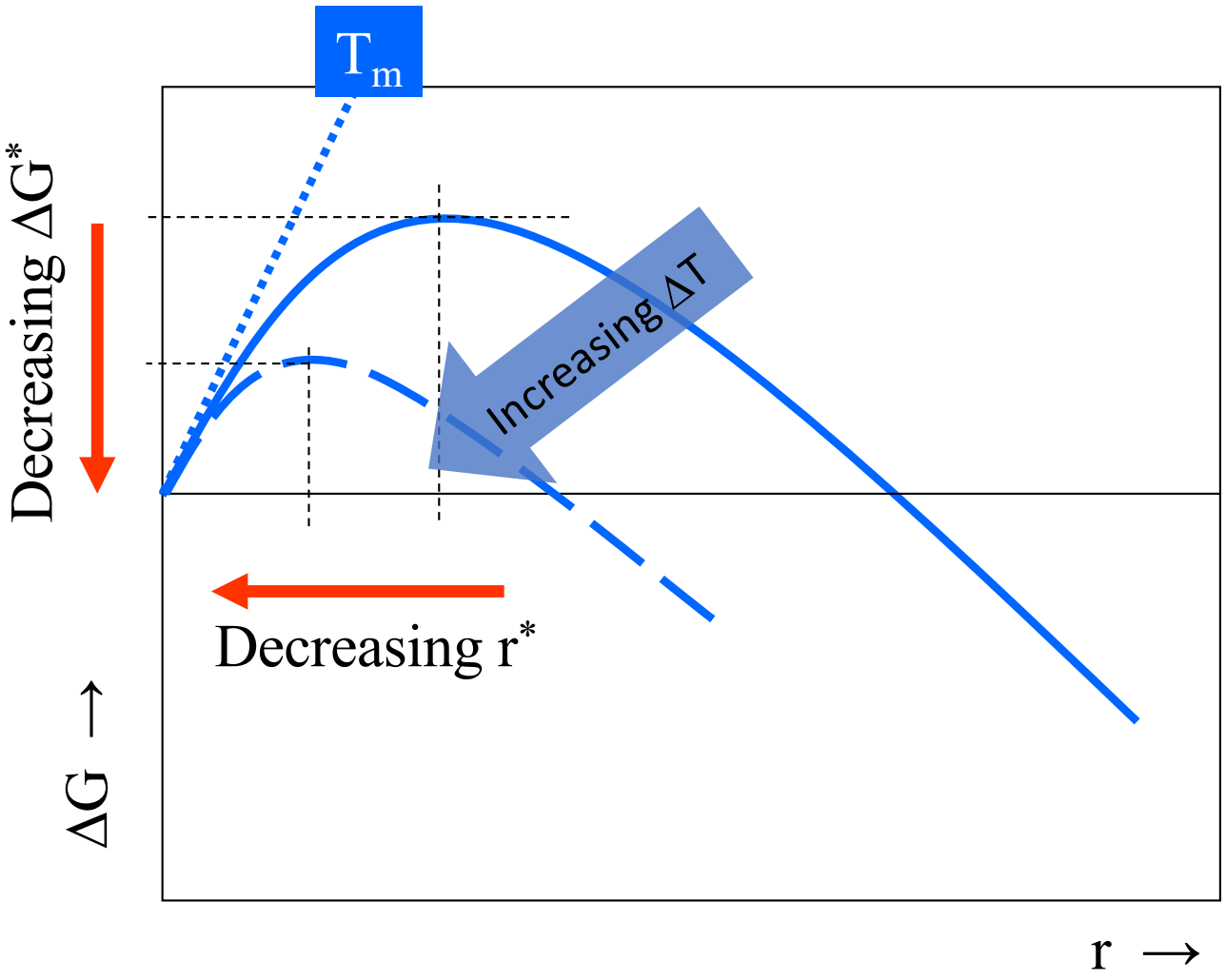
$$r^* = -\frac{2\gamma}{\Delta G_v}$$

$$\Delta G^* = \frac{16}{3}\pi\frac{\gamma^3}{\Delta G_v^2}$$

$$\Delta G = 0 \Rightarrow r_0 = -\frac{3\gamma}{\Delta G_v}$$



$\Delta G_v \square f(\Delta T)$ The bulk free energy reduction is a function of undercooling



Turnbull approximation

$$\Delta G^* \square \frac{16}{3}\pi\gamma^3 \frac{T_m^2}{\Delta T^2\ \Delta H^2}$$

Rate of nucleation = No. of critical sized particles x Frequency with which they become supercritical

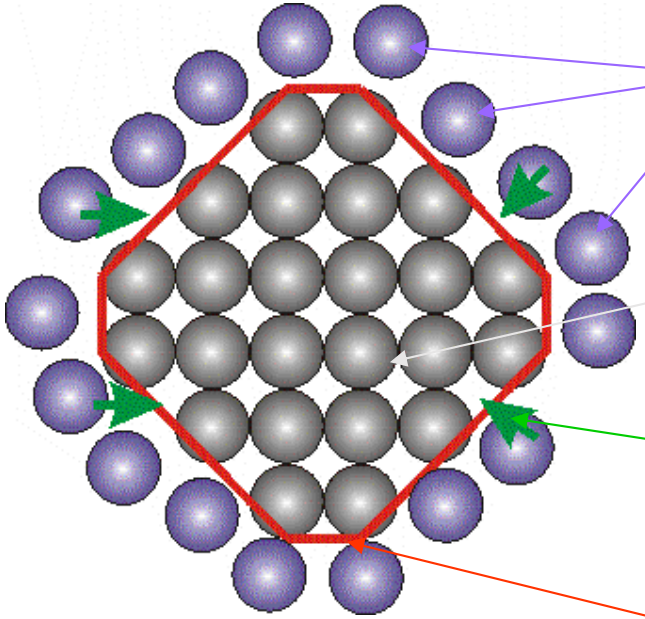
$$I \equiv \frac{dN}{dt}$$

$$N^* \equiv N_t \, e^{\left(-\frac{\Delta G^*}{kT}\right)}$$

$$\nu' \equiv s^* \nu \, e^{\left(-\frac{\Delta H_d}{kT}\right)}$$

No. of particles/volume in L

$\nu \rightarrow$ lattice vibration frequency ($\sim 10^{13}$ /s)



s^* atoms of the liquid facing the nucleus

Critical sized nucleus

Jump taking particle to supercriticality
→ nucleated *(enthalpy of activation = ΔH_d)*

Critical sized nucleus