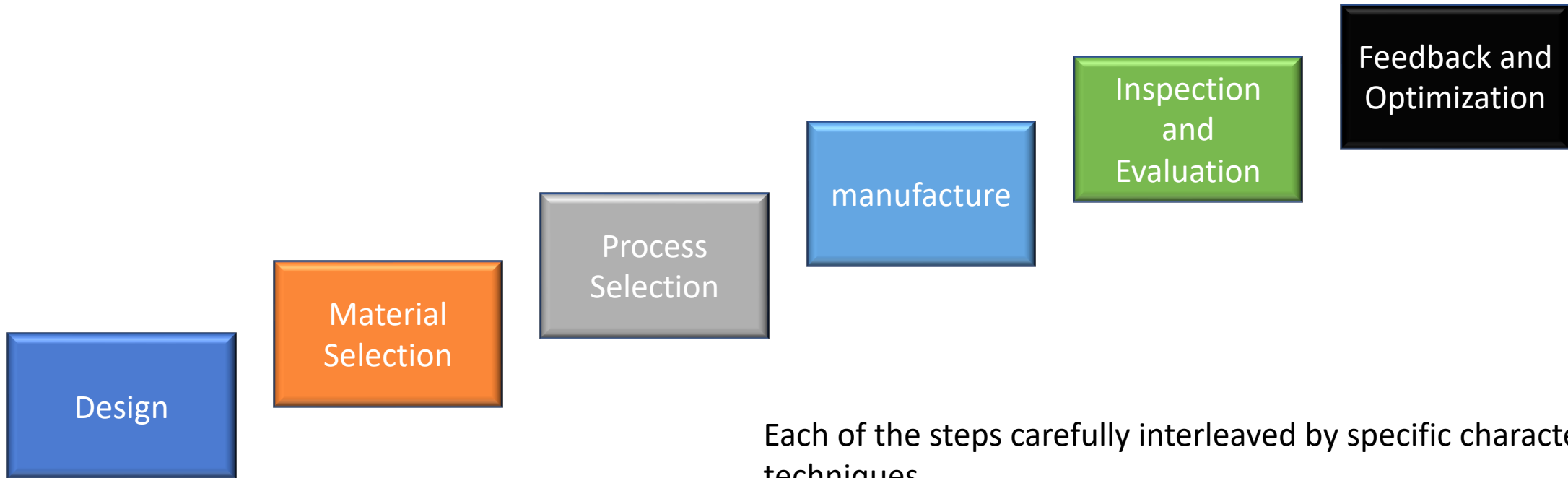


# Material Processing

Primary Processing techniques

Lecture 1

# Stages of Material Processing



Each of the steps carefully interleaved by specific characterization techniques

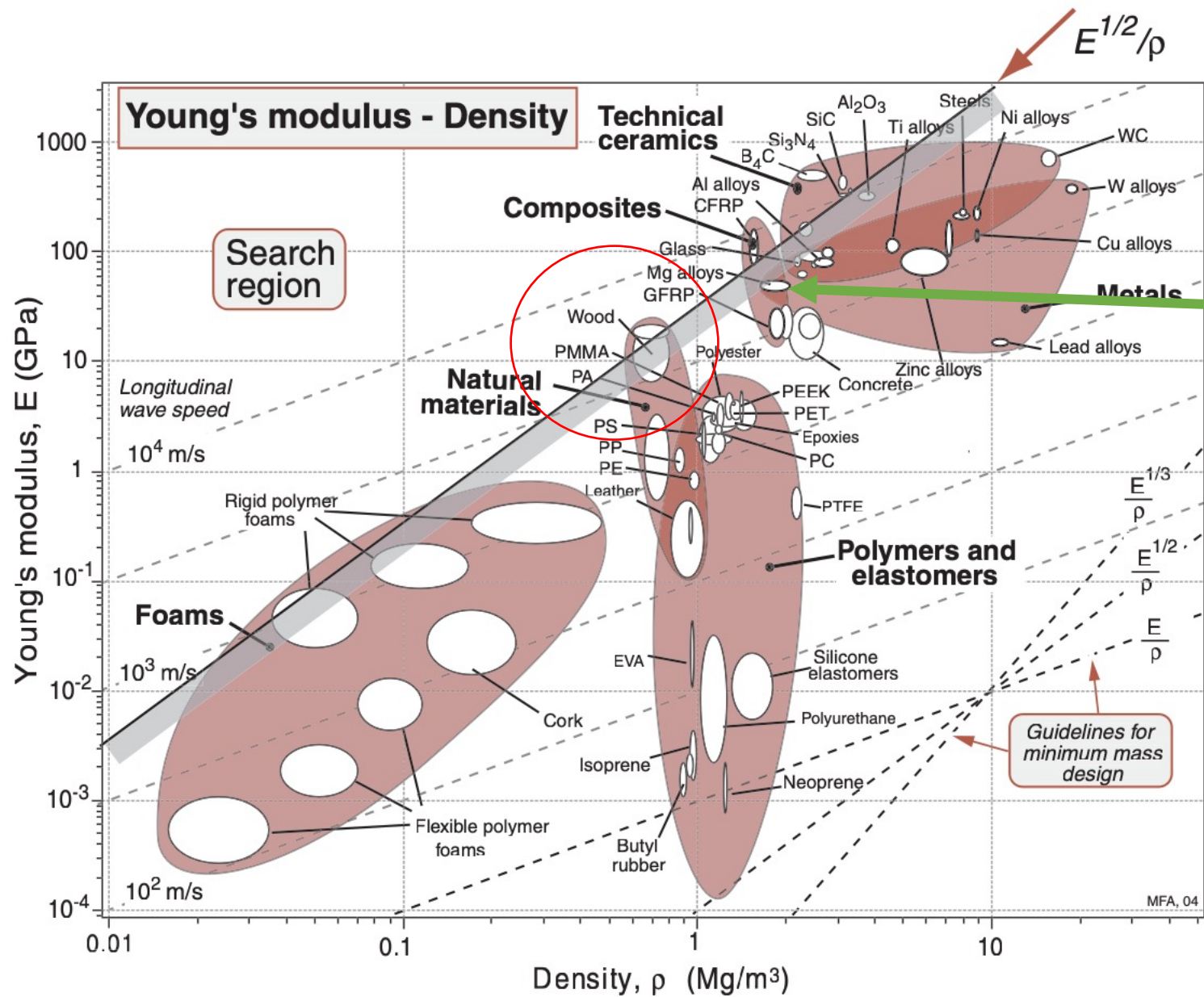
# Case study of an Oar

What are the requirements ?

1. Oar is a beam loaded in bending
2. High stiffness in bending
3. Very light weight
4. Does not get corroded in water
5. Should be sufficiently malleable



Material selection parameter  $M = \frac{\sqrt{E}}{\rho}$



# Some common non ferrous alloys



**FIGURE 7-1** Some common nonferrous metals and alloys, classified by attractive engineering property.

Read about what is specific gravity!

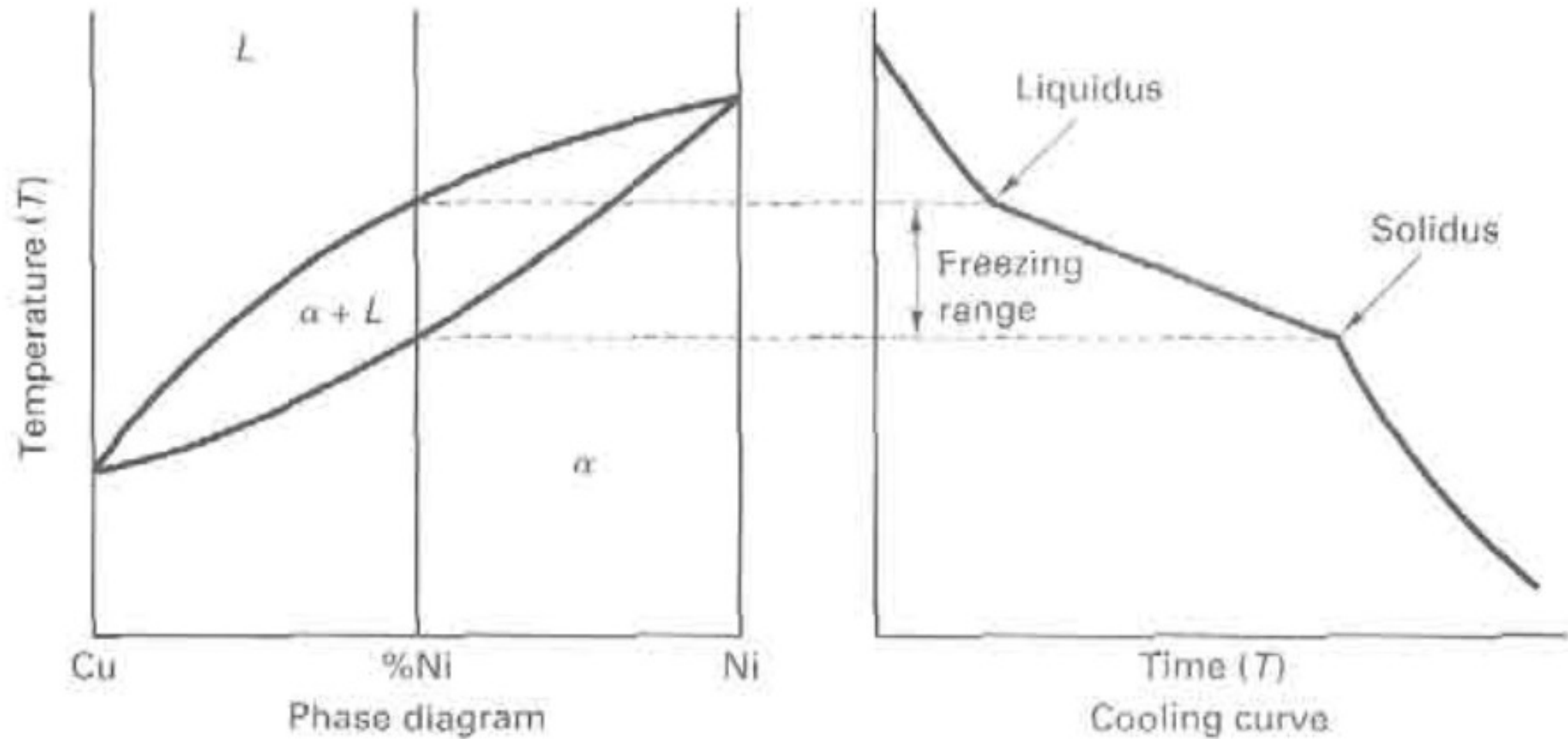
Mg family is the lightest of commercially available alloys. Specific gravity is about 1.74

# Primary Processing

## Step 1: Casting



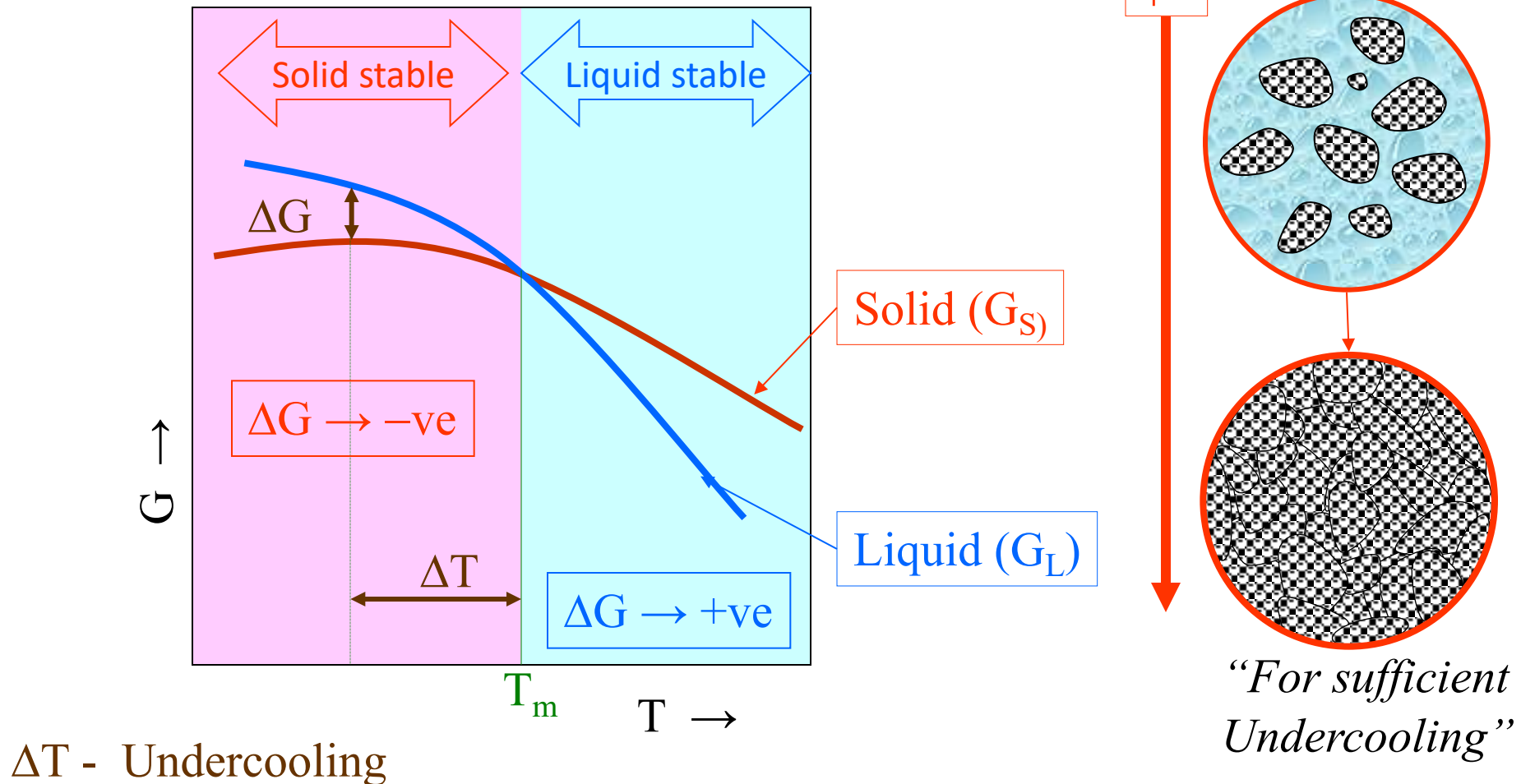
# An example of a cooling transition



Casting is basically

Liquid  $\rightarrow$  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  $T_m$



Solidification

=

Nucleation

+

Growth

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

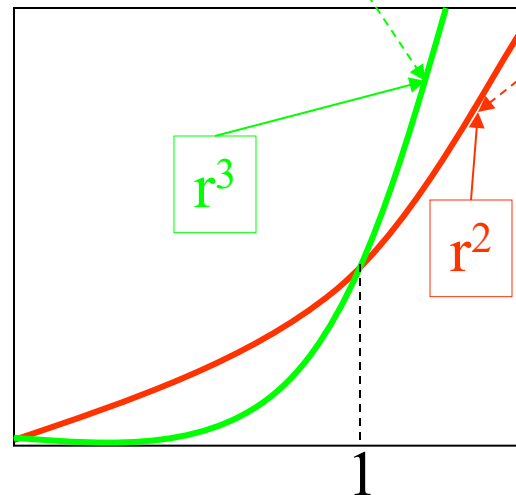
Neglected in L  $\rightarrow$  S transformations

Free energy change on nucleation =

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

$$\Delta G = (\text{Volume}).(\Delta G) + (\text{Surface}).(\gamma)$$

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



$$\Delta G_v = f(\Delta T)$$

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

- 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

$$\frac{d\Delta G}{dr} = 0$$



$$r_1^* = 0$$

Trivial

$$r_2^* = -\frac{2\gamma}{\Delta G_v}$$

As  $\Delta G_v$  is -ve,  $r^*$  is +ve

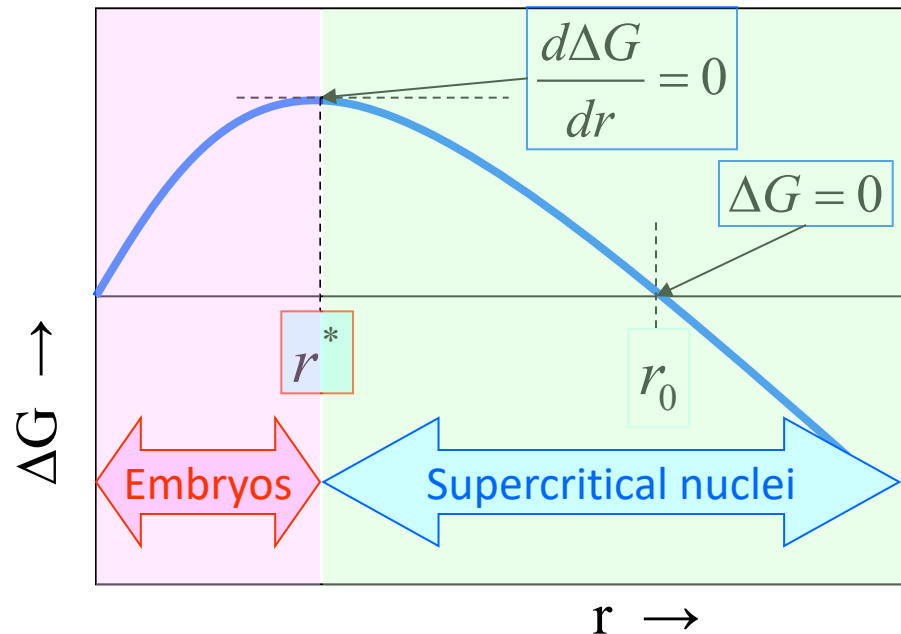
$$r^* = -\frac{2\gamma}{\Delta G_v}$$

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

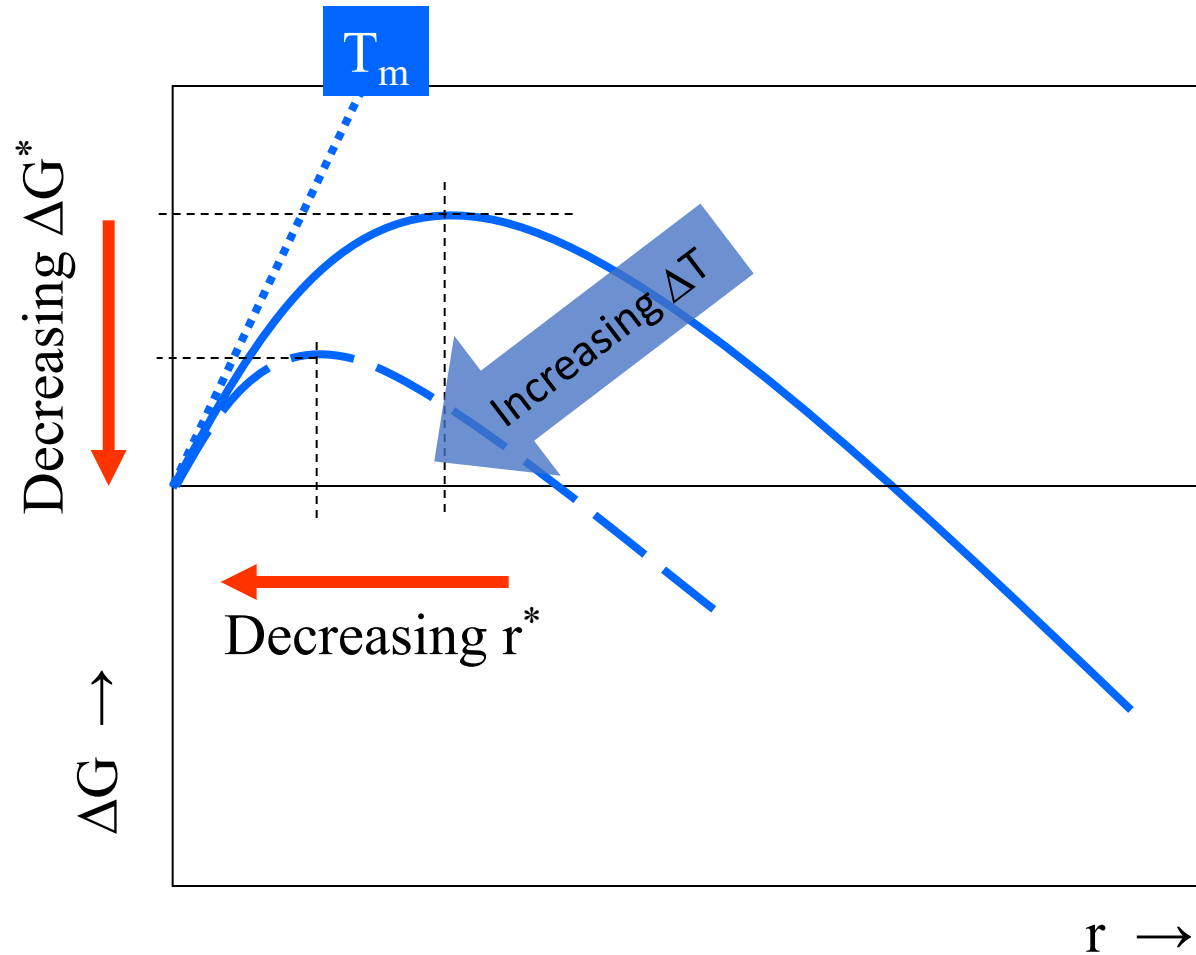
$$\Delta G = 0$$



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



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



Turnbull approximation

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

Rate of nucleation

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

No. of critical sized particles

$\times$

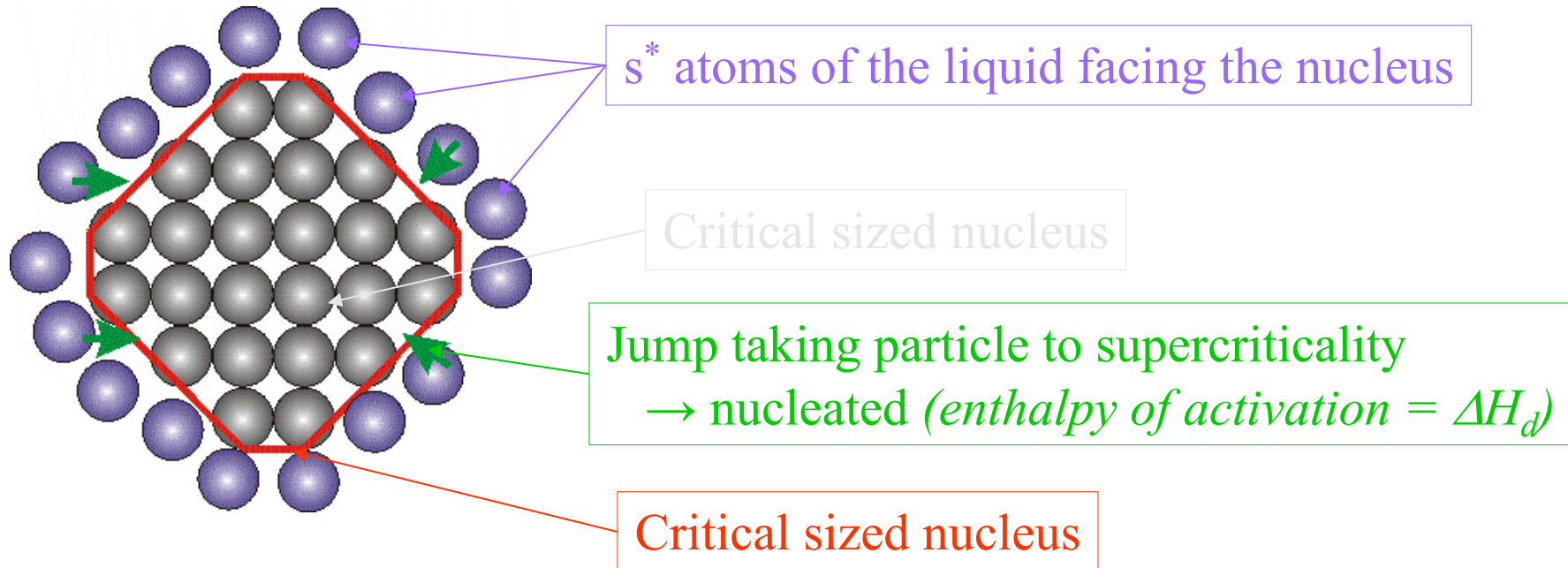
Frequency with which they become supercritical

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

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

No. of particles/volume in L

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



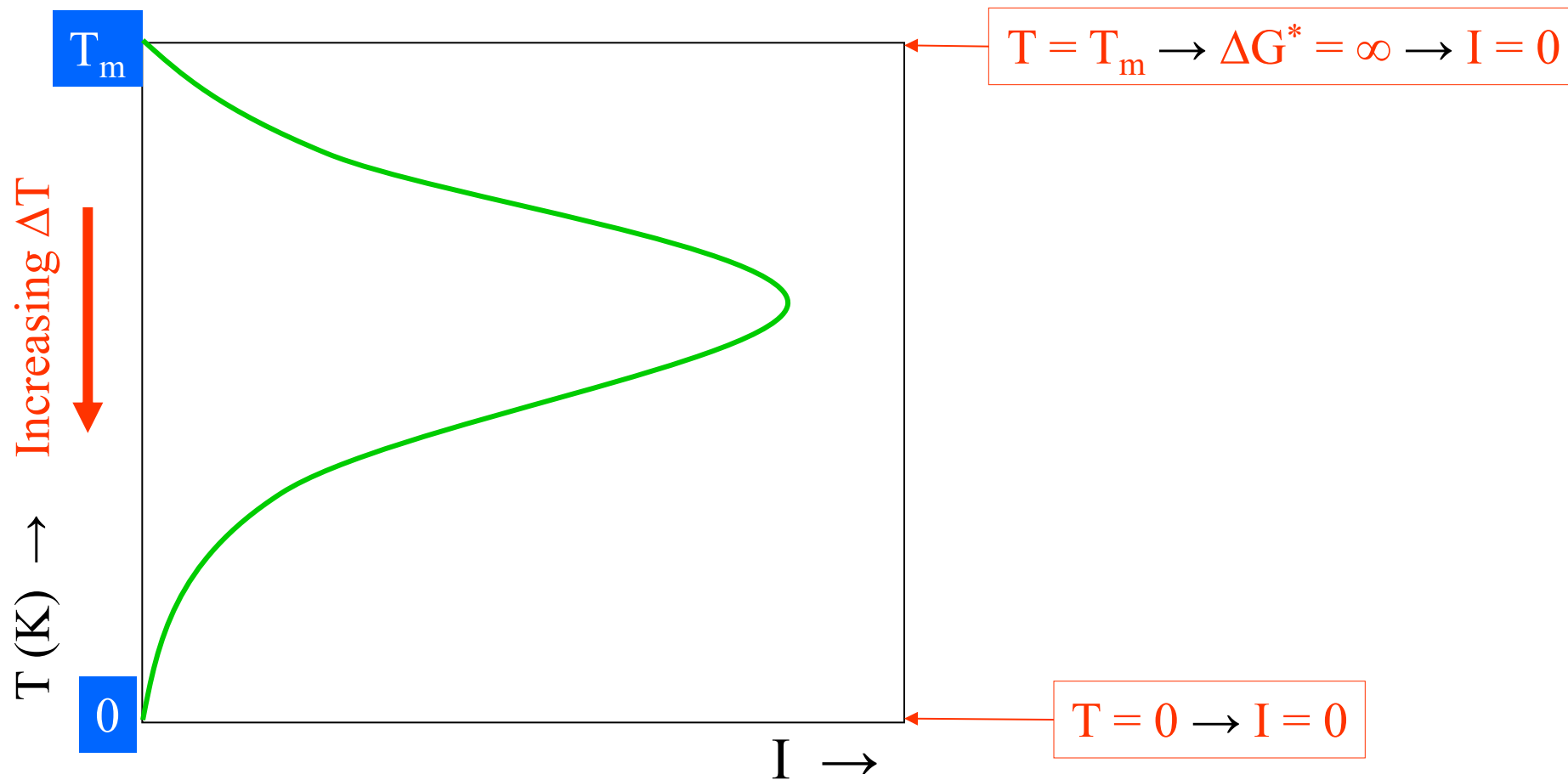
$$I = N_t s^* v e^{-\left(\frac{\Delta G^* + \Delta H_d}{kT}\right)}$$

$\Delta G^*$

$kT$

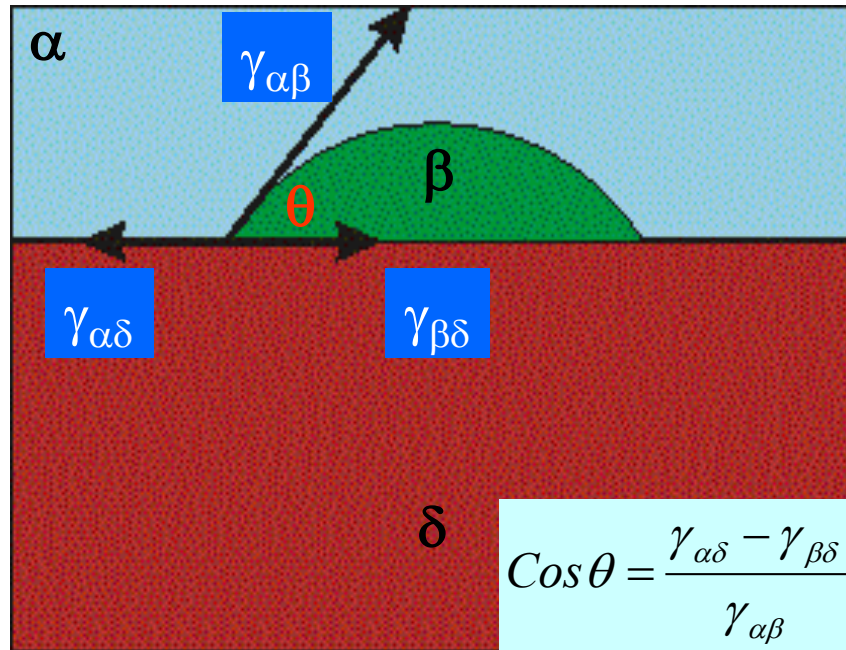
$\blacksquare \Delta G^* \uparrow \Rightarrow I \downarrow$

$\blacksquare T \uparrow \Rightarrow I \uparrow$

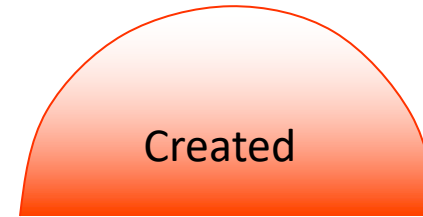


## Heterogeneous nucleation

Consider the nucleation of  $\beta$  from  $\alpha$  on a planar surface of inclusion  $\delta$



### Interfacial Energies



$$A_{\text{lens}} \gamma_{\alpha\beta}$$



$$A_{\text{circle}} \gamma_{\beta\delta}$$



$$A_{\text{circle}} \gamma_{\alpha\delta}$$

Surface tension force balance  $\longrightarrow$

$$\gamma_{\alpha\beta} \cos \theta + \gamma_{\beta\delta} = \gamma_{\alpha\delta}$$

$$\Delta G = (V_{\text{lens}}) \Delta G_v + (A_{\text{lens}}) \gamma_{\alpha\beta} + (A_{\text{circle}}) \gamma_{\beta\delta} - (A_{\text{circle}}) \gamma_{\alpha\delta}$$

$$V_{\text{lens}} = \pi h^2 (3r - h) / 3$$

$$A_{\text{lens}} = 2\pi r h$$

$$h = (1 - \cos \theta) r$$

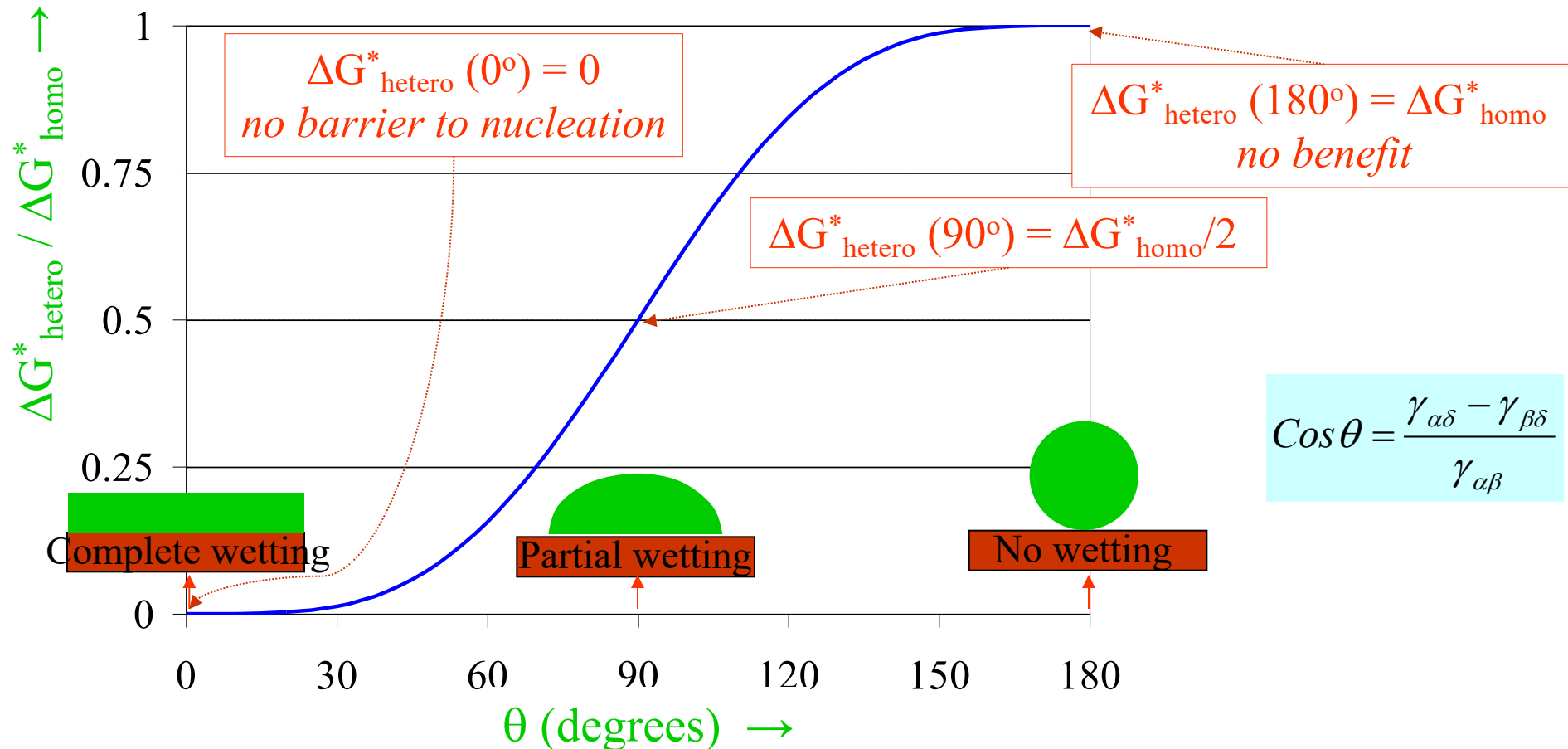
$$r_{\text{circle}} = r \sin \theta$$

$$\frac{d\Delta G}{dr} = 0 \rightarrow$$

$$r_{hetero}^* = -\frac{2\gamma_{\alpha\beta}}{\Delta G_v}$$

$$\Delta G_{hetero}^* = \frac{4}{3}\pi \frac{\gamma_{\alpha\beta}^3}{\Delta G_v^2} (2 - 3\cos\theta + \cos^3\theta)$$

$$\Delta G_{hetero}^* = \frac{1}{4} G_{homo}^* (2 - 3\cos\theta + \cos^3\theta)$$



$$I_{\text{homo}} \propto I_{\text{homo}}^0 e^{-\left(\frac{\Delta G_{\text{homo}}^*}{kT}\right)}$$

$$I_{\text{hetero}} \propto I_{\text{hetero}}^0 e^{-\left(\frac{\Delta G_{\text{hetero}}^*}{kT}\right)}$$

= f(number of nucleation sites)  
 $\sim 10^{42}$

= f(number of nucleation sites)  
 $\sim 10^{26}$

**BUT**  
*the exponential term dominates*

**$I_{\text{hetero}} > I_{\text{homo}}$**

Transformation  
 $\alpha \rightarrow \beta$

=

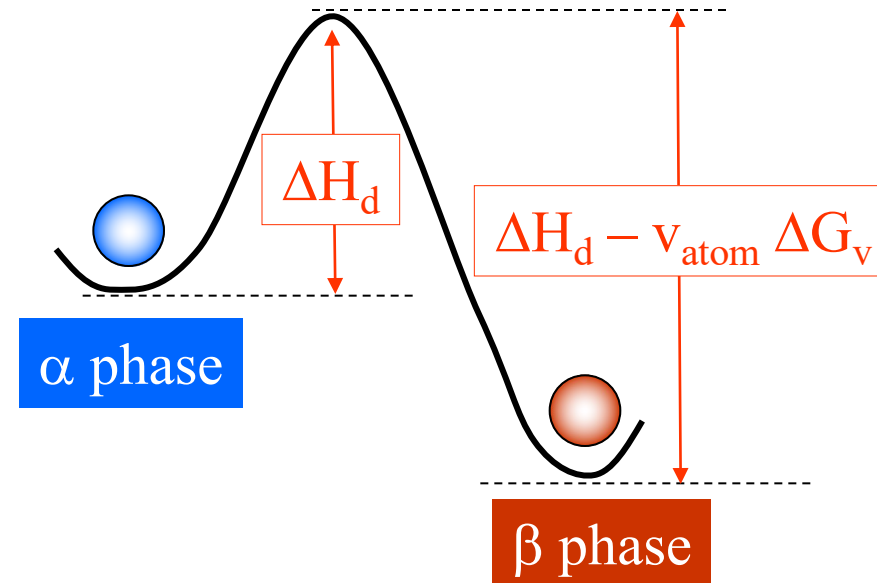
Nucleation  
of  
 $\beta$  phase

+

Growth  
till  
 $\alpha$  is  
exhausted

### Growth

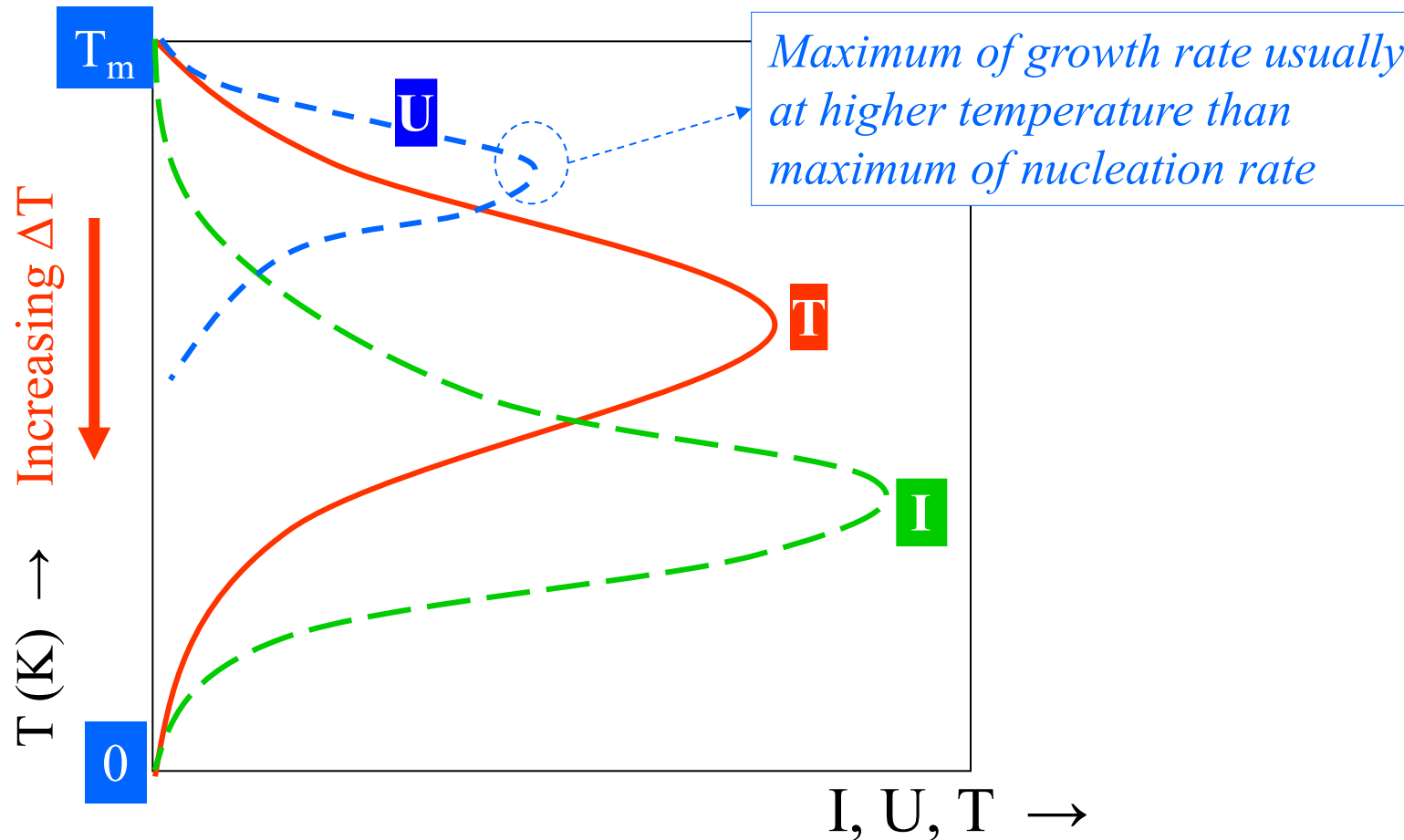
- At transformation temperature the probability of jump of atom from  $\alpha \rightarrow \beta$  (across the interface) is same as the reverse jump
- Growth proceeds below the transformation temperature, wherein the activation barrier for the reverse jump is higher



Transformation rate = f(Nucleation rate, Growth rate)

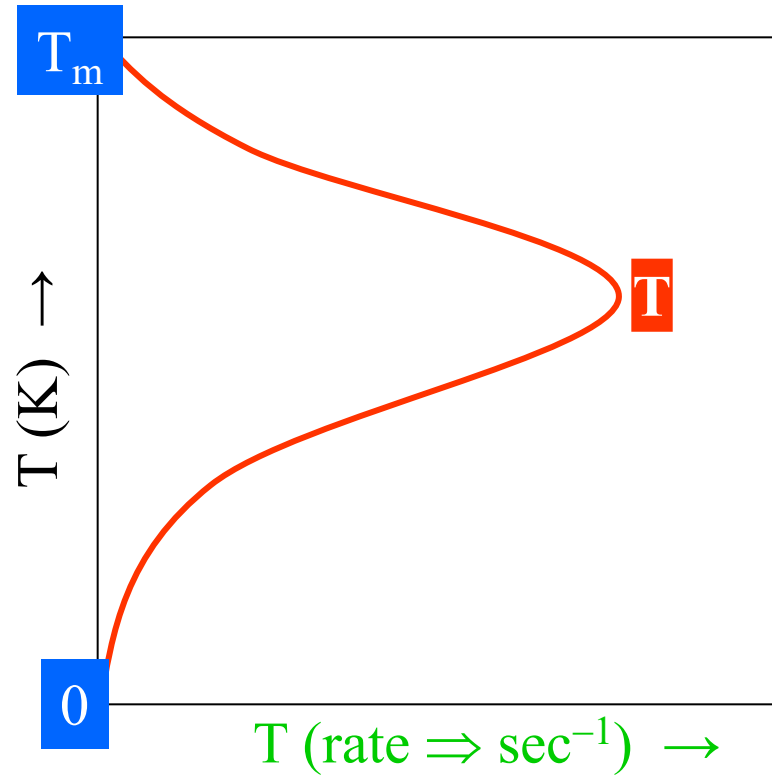
$$T = \frac{dX_{\beta}}{dt} = f(I, U)$$

$$X_{\beta} = 1 - e^{-\left(\frac{\pi I U^3 t^4}{3}\right)}$$

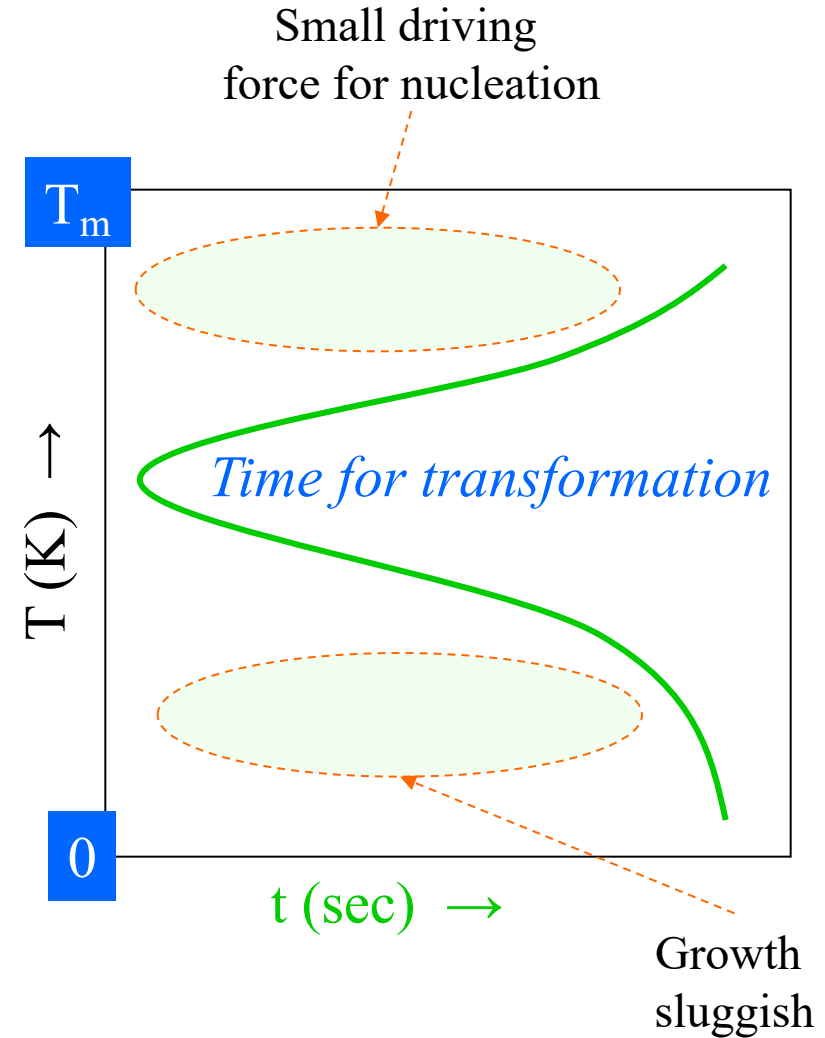


# Time – Temperature – Transformation (TTT) diagrams

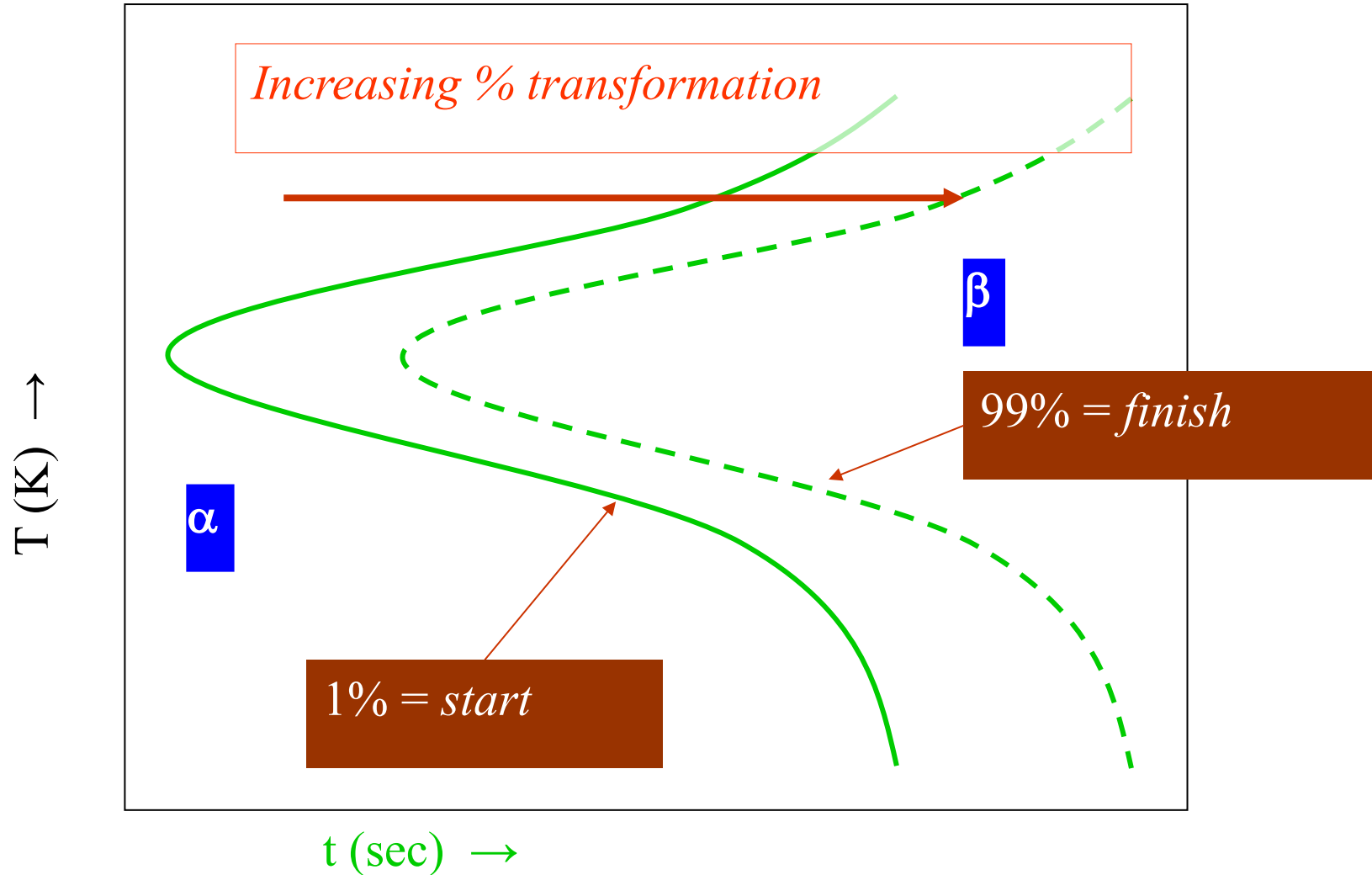
A type of phase diagram



Replot



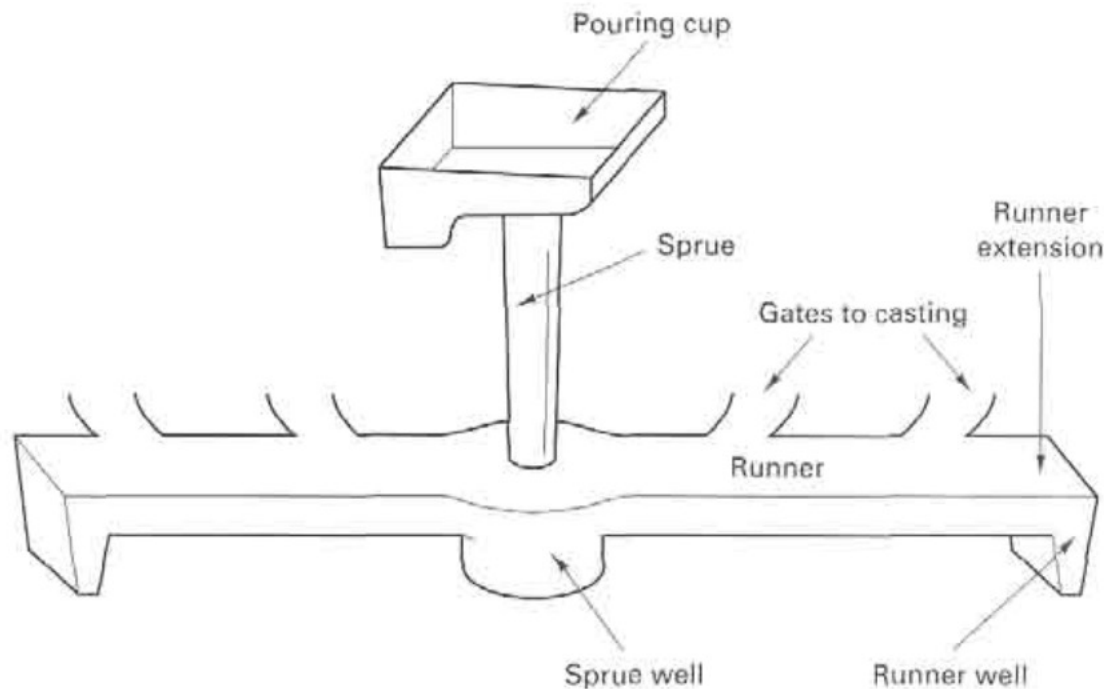
# TTT diagram $\alpha \rightarrow \beta$ phase transformation



# Experimental Casting

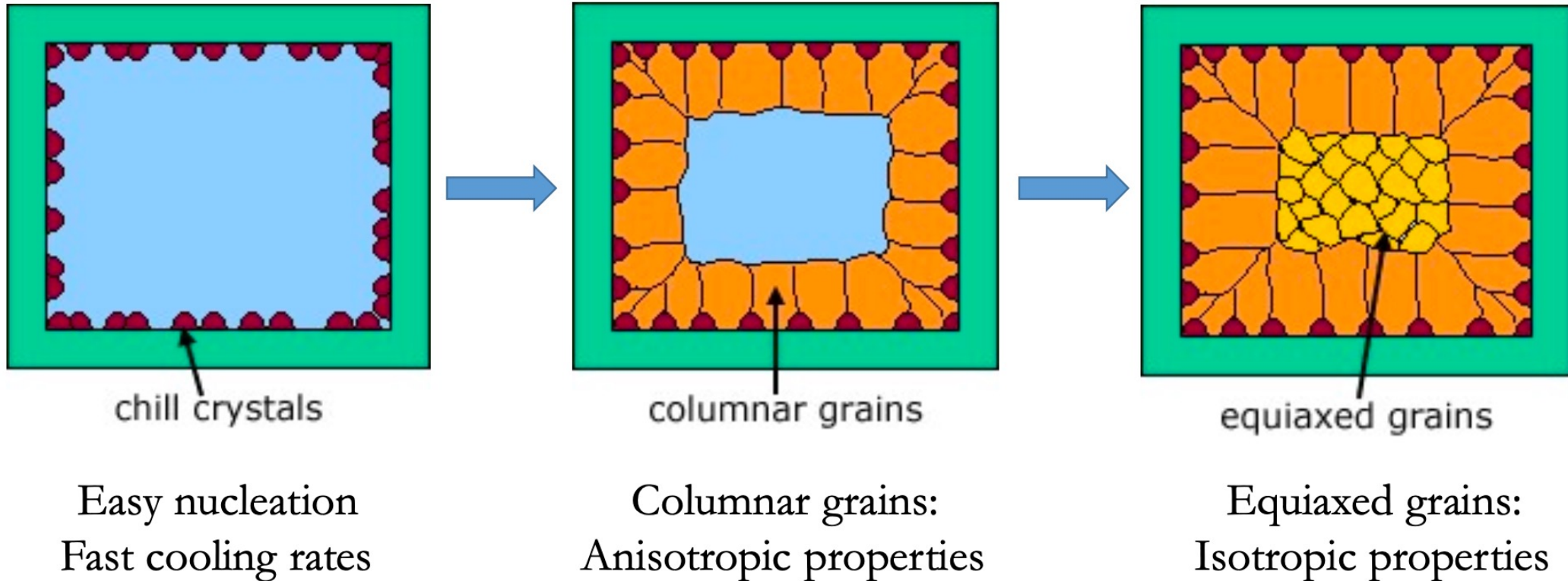
## Problems with molten metal

- Slag: metal reacts with environmental gas leading to oxides and other compounds
- Contamination of the melt from contact surfaces
- Dissolved gases

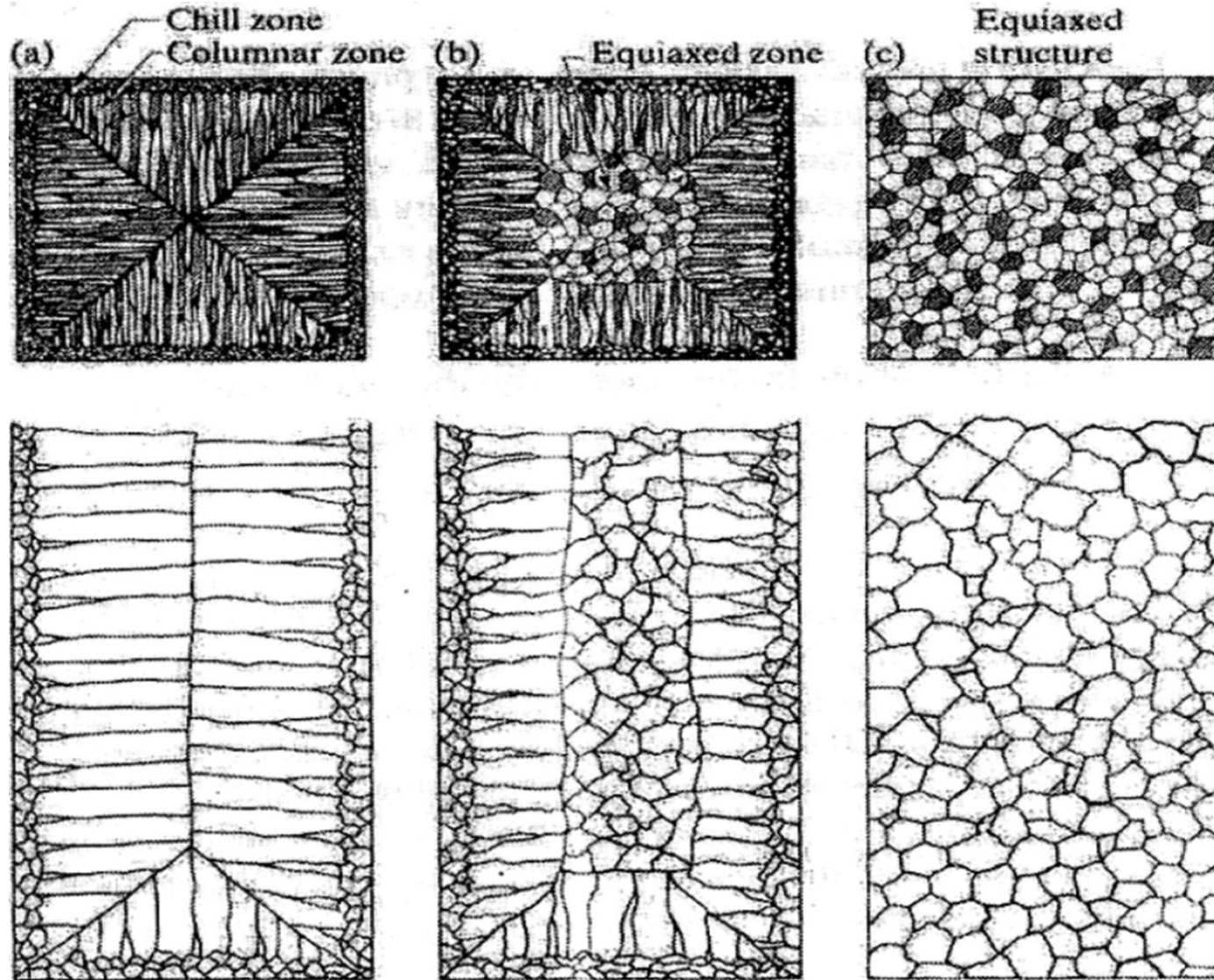


1. Gates designed with suitable filters to remove slag
2. Transfer in controlled ambient
3. Runners and raisers to allow for melt contraction

# Internal structure of a cast



# Grains and Structure of a cast



Section of cast ingot illustrating the microstructure

