2-6-2012

SOLIDIFICATION & GRAIN SIZE STRENGTHENING

Solidification of Pure materials

Nucleation

Solidification requires
1. Nucleation
2. Growth

Atmospheric Pressure
= 1 atm = 101.325 kPa
= 760 mm. Hg
= ρgh
ρ = 13595 kg/m³ g = 9.807 m/s²

→ Nucleation means formation of tiny solid particles.

Growth ⇒ ~~atta~~ continuous attachment ~~of~~ and formation of bigger solid particles from liquids till no liquid remains.

when liquid releases energy and solidifies below freezing temperature the solid aquires more stable condition and has less free energy as compared with liquid

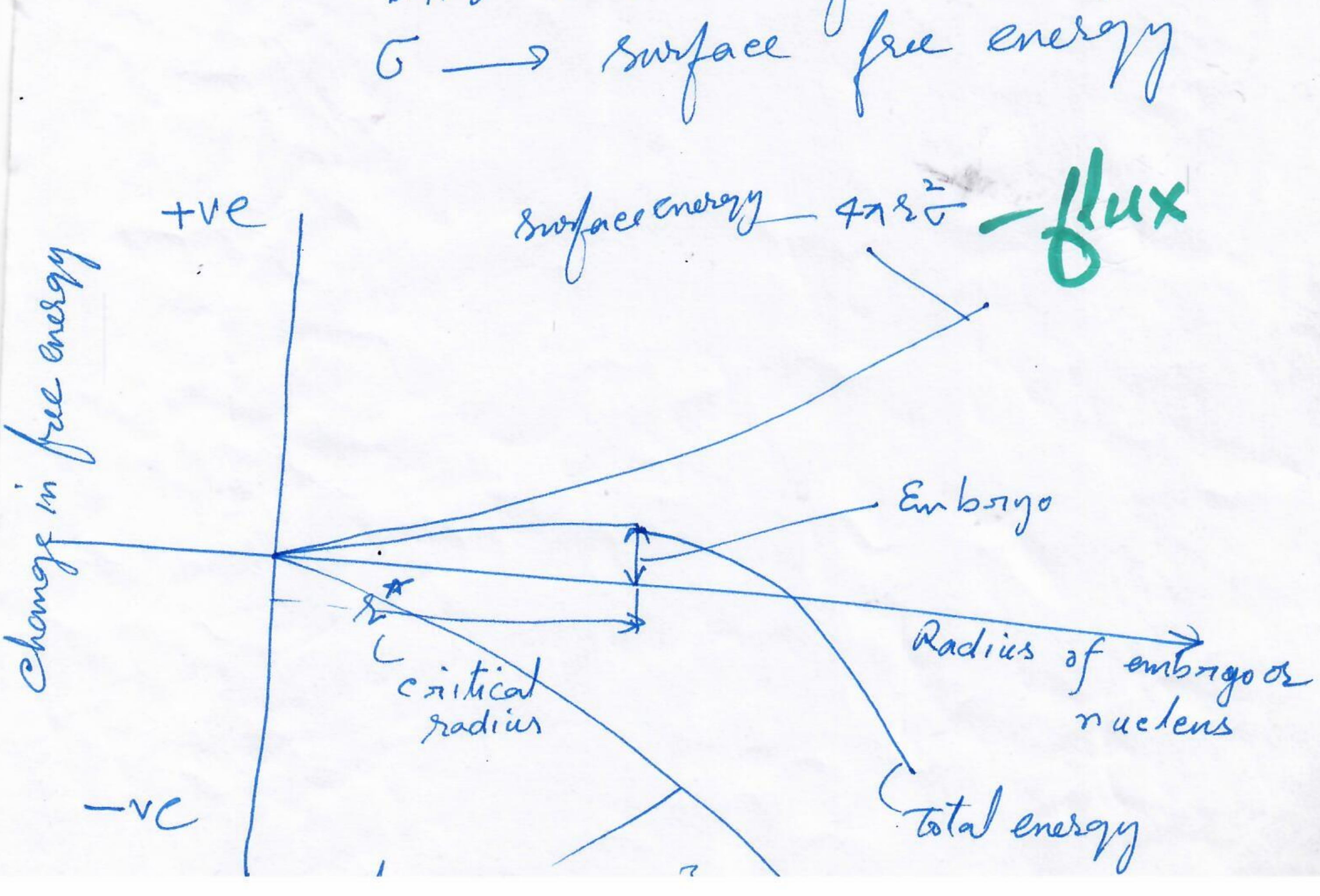
Small particle is called embryo

Total change in free energy of embryo formation

$$\Delta F = \frac{4}{3}\pi r^3 \, \Delta F_v \text{/volume} + 4\pi r^2 \sigma \text{/sur. area}$$

$\Delta F_v \rightarrow$ Volume free energy

$\sigma \longrightarrow$ Surface free energy



Critical radius of nucleus

$$\frac{d}{dr}(\Delta F) = \frac{d}{dr}\left(\frac{4}{3}\pi r^3 \Delta F_v + 4\pi r^2 \sigma\right) = 0$$

$$\rightarrow r^* = \frac{-2\sigma}{\Delta F_v}$$

and $$\Delta F_v = \frac{-\Delta H_f \, \Delta T}{T_m}$$

$\Delta H_f \rightarrow$ latent heat of fusion

T_m = equilibrium freezing temp. in °K

$\Delta T = T_m - T$

$\longrightarrow$ under cooling temp.

$T \rightarrow$ liquid temp.

$$\therefore r^* = \frac{2\sigma T_m}{\Delta H_f \, \Delta T}$$

where $\Delta T = T_m - T$ is the under cooling)

Homogeneous nucleation occurs when

$$\Delta T = 0.2\, T_m (°K)$$

EXAMPLE

The freezing temperature of pure copper is 1085°C. Estimate the undercooling required for homogeneous nucleation.

$$\Delta T = 0.2\, T_m = 0.2\,(1085 + 273)$$
$$= 272^\circ C$$

EXAMPLE

Calculate the size of the critical radius and the number of atoms in the critical nucleus when solid copper forms by homogeneous nucleation.

Solution:

$\Delta T = 0.2\, T_m = 272^\circ C$, $T_m = 1358^\circ K$

ΔH_f = Latent heat of fusion

$= 1628 \times 10^6\ J/m^3$

$$r^* = \frac{2\sigma T_m}{\Delta H_f \Delta T} = \frac{2\times(177\times10^{-3})(1358)}{(1628\times10^{6})(272)}$$ P-5

$$= 10.85\times10^{-10} m$$

The lattice parameter for FCC copper is

$a_0 = 3.615 A^o (\times 10^{-10} m)$

$V_{unit\ cell} = (a_0)^3 = (3.615\times10^{-8})^3$

$= 47.24\times10^{-30} m^3$

$V_{r^*} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(10.85\times10^{-8} m^3)^3$

$= 5350\times10^{-30} m^3$

The number of unit cells in the critical nucleus is

$$\frac{5350\times10^{-24\ -30}}{47.24\times10^{-24\ -30}} = 113 \text{ unit cell}$$

Since there are 4 – atoms in each unit cell of FCC metals, the number of atoms in the critical nucleus must be