Phase Diagrams

melting / production process / alloying (strength, T_m...)
heat treatment

microstructure ⟷ material properties

system (e.g. Cu-Ni)

components (pure substances or compounds)

phases (uniform physical/chemical characteristic)

solid solution – solvent + solute

solubility limit=> precipitation

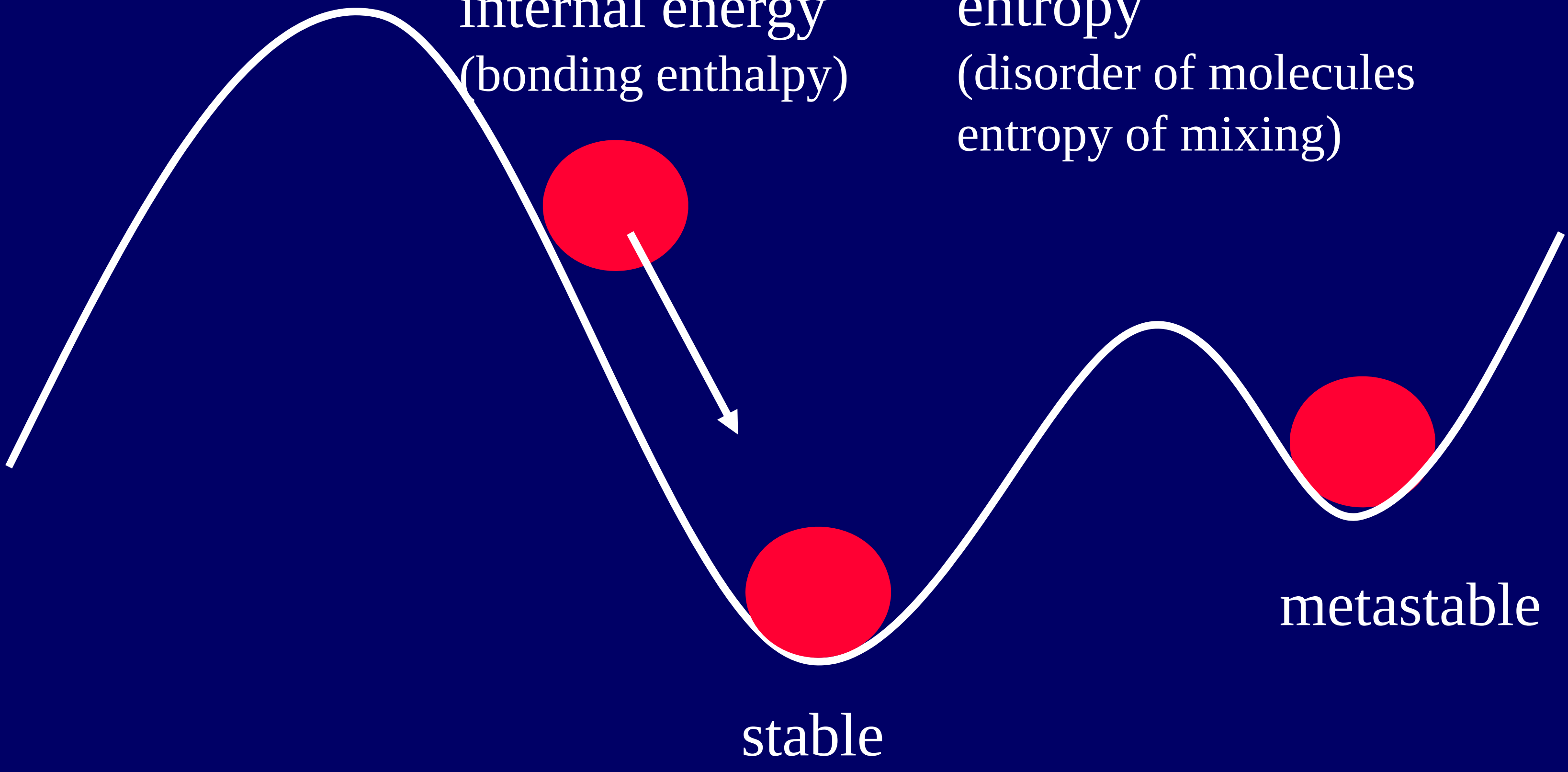
pure materials – 2 phases: liquid + solid

Phase Equilibria G=min

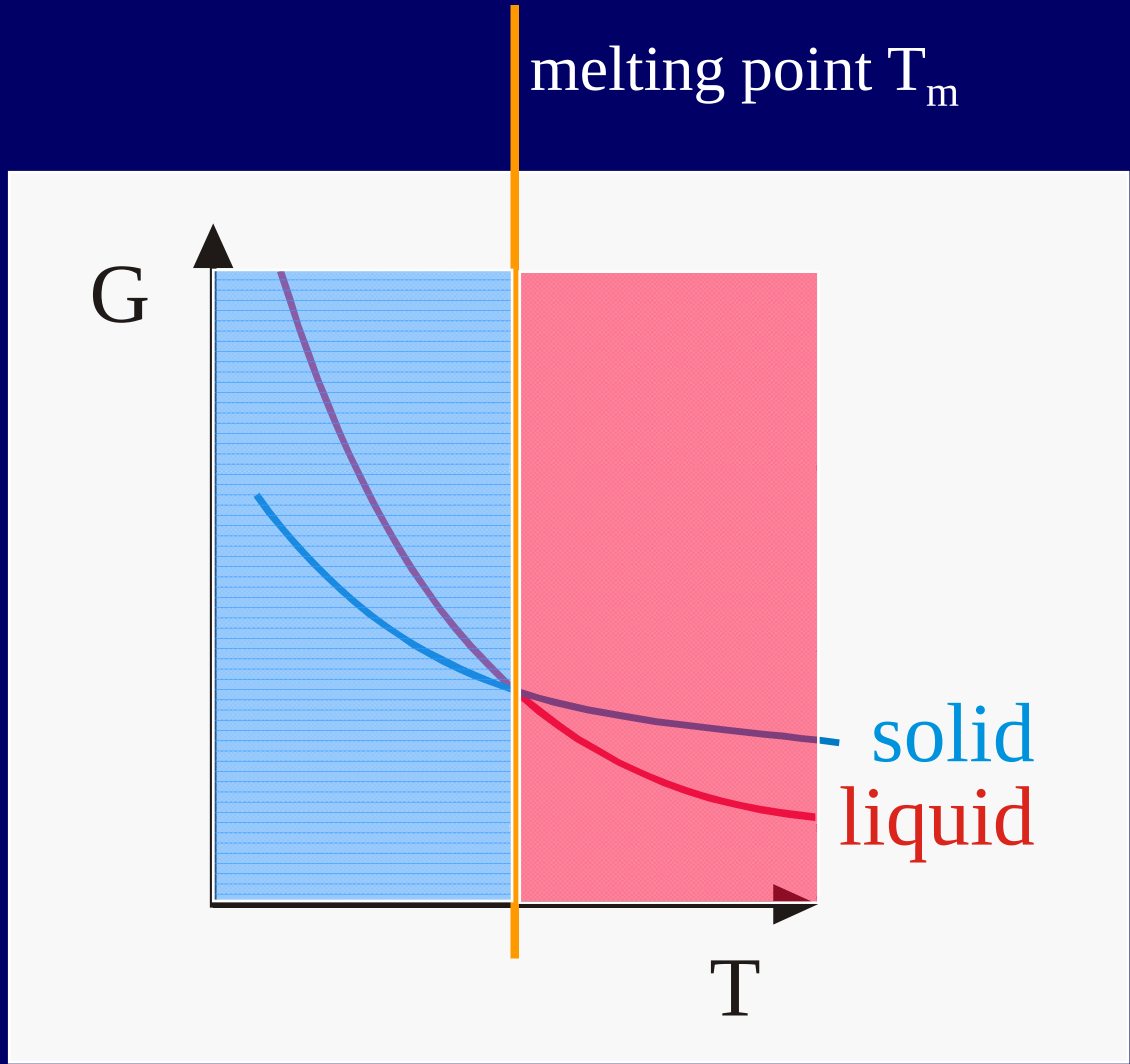
Gibbs free energy: $\boxed{G=H-TS}$ $=f(T,c,p)$ $\boxed{=\min}$

internal energy
(bonding enthalpy)

entropy
(disorder of molecules
entropy of mixing)



Phase Equilibrium

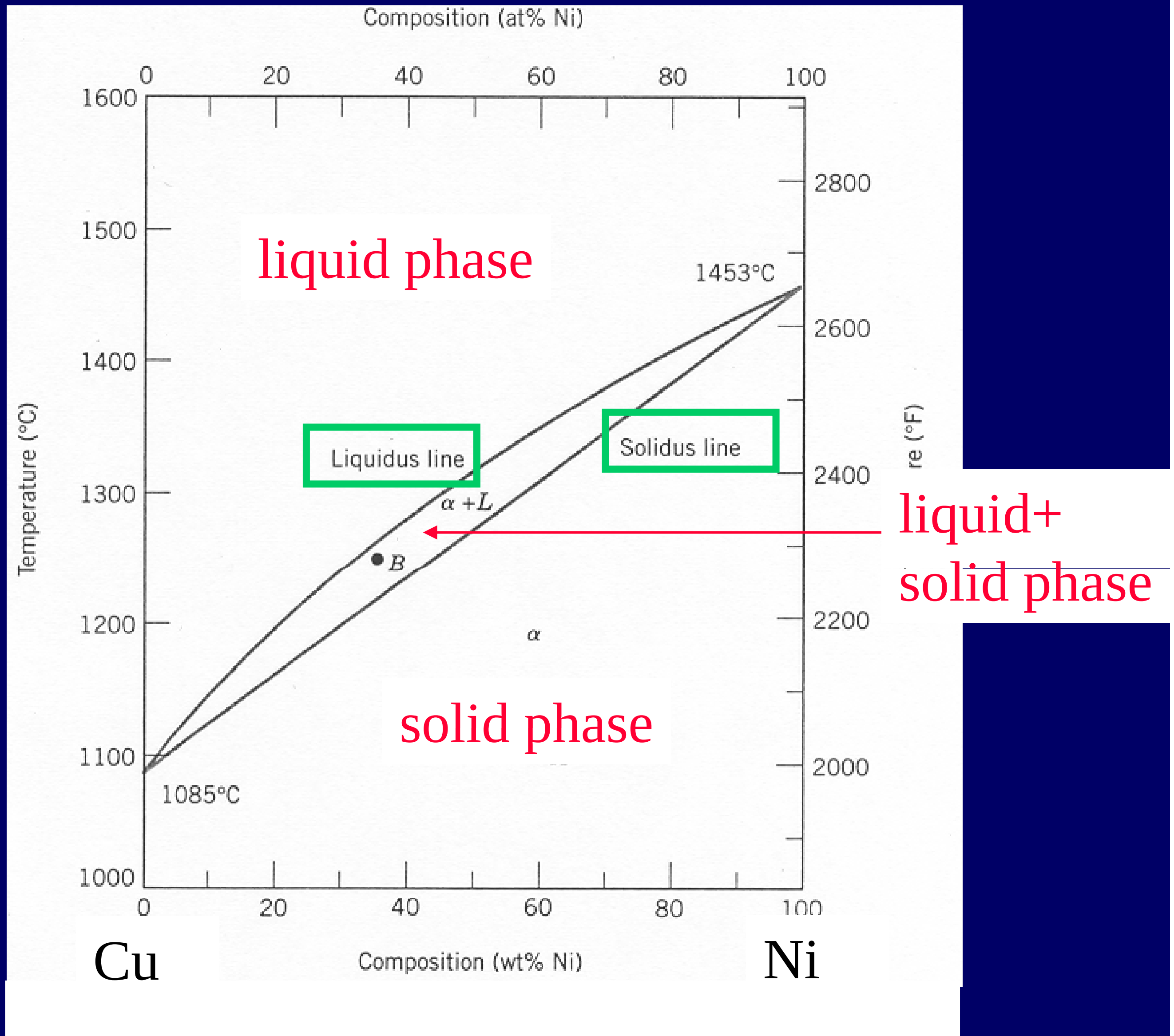


phase composition <=> G minimization

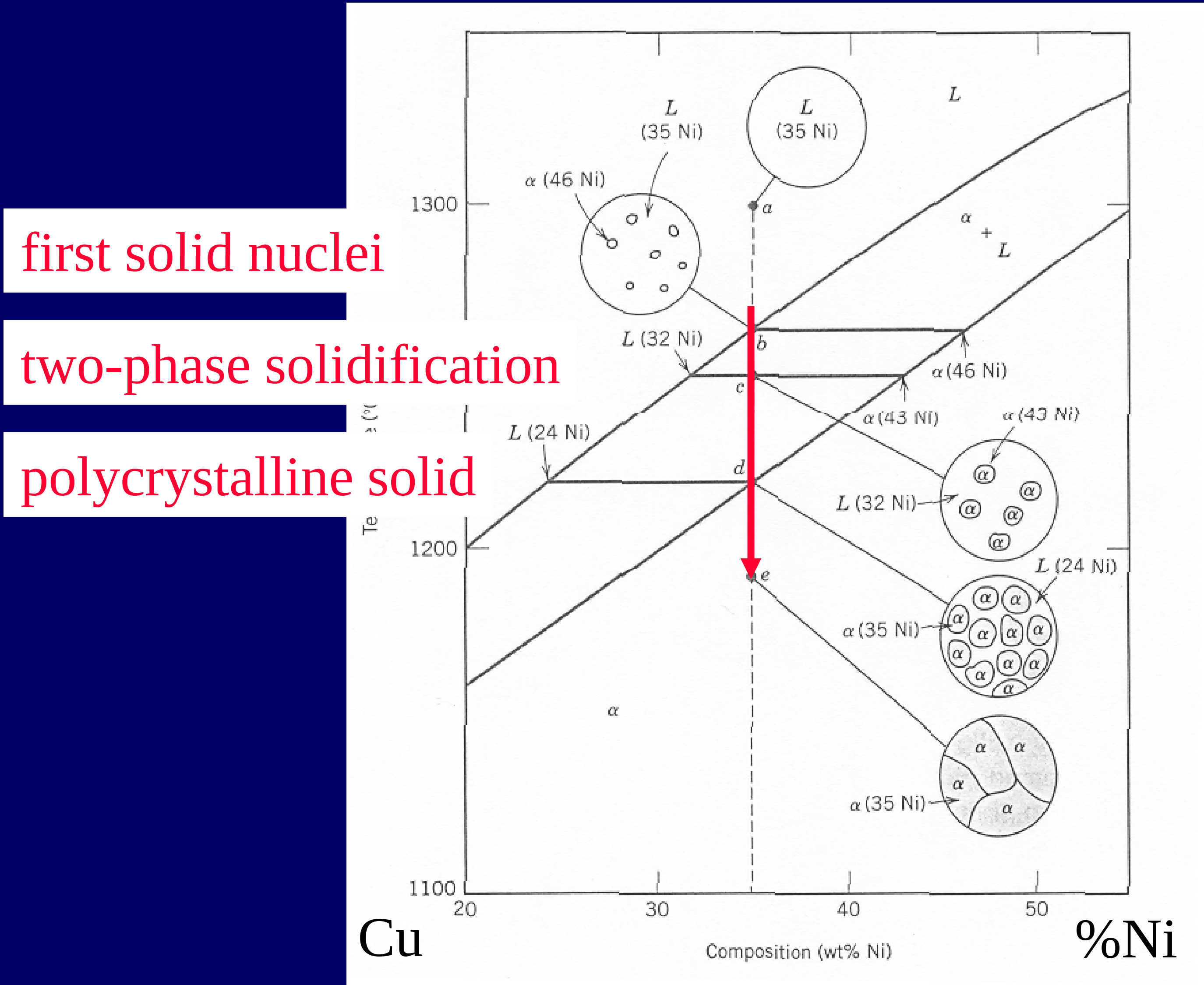
Cu-x%Ni Phase Diagram (p=const) isomorphous

phase composition =f (T,c)

Gibbs phase rule
F=K-P+2
(F degrees of freedom depends on number of components K and number of phases P)

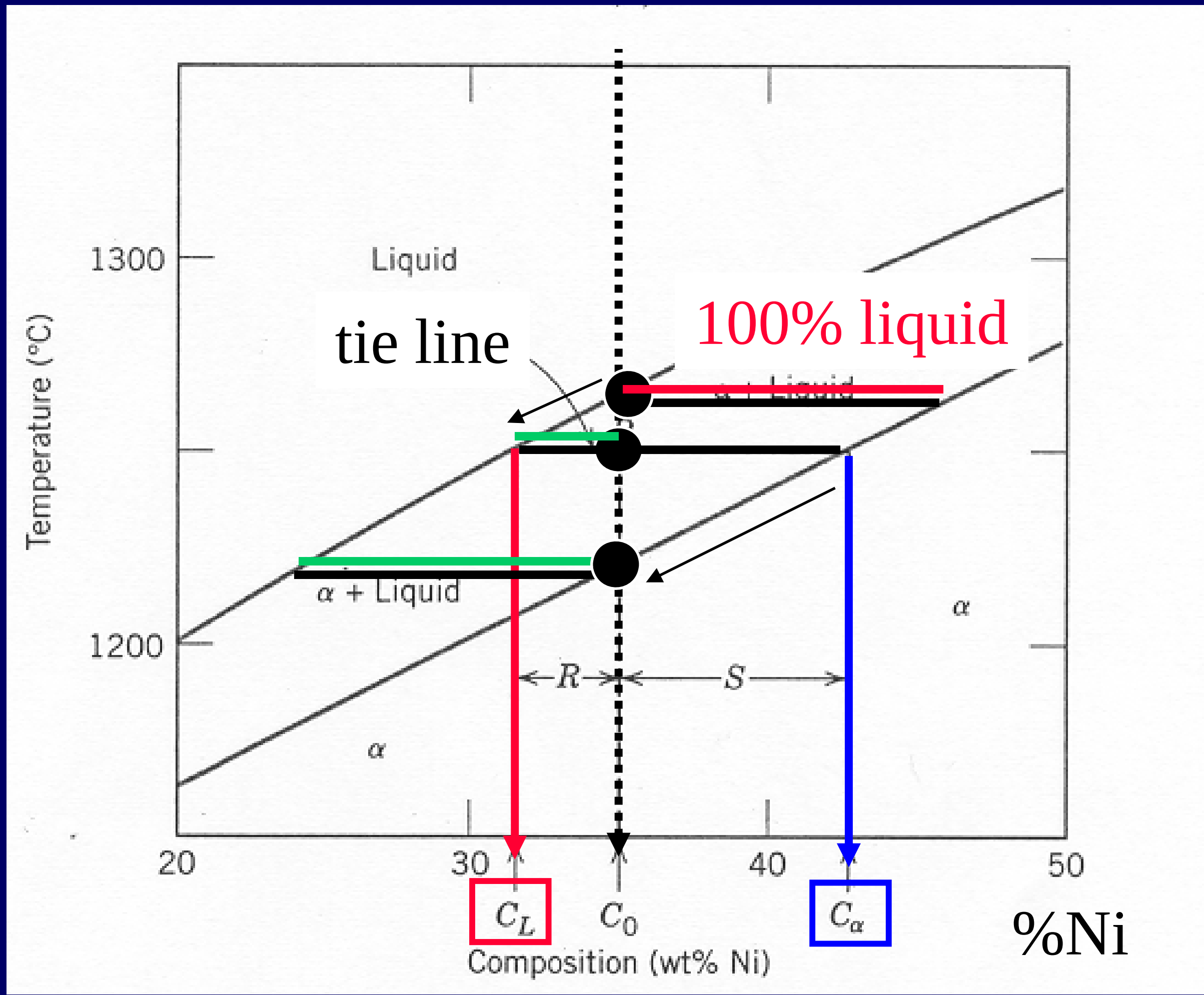


Equilibrium Cooling



Phase Amounts W

W_{Solid}=W_{α}:
length of tie line
from C_L to C_o
divided by
length of tie line

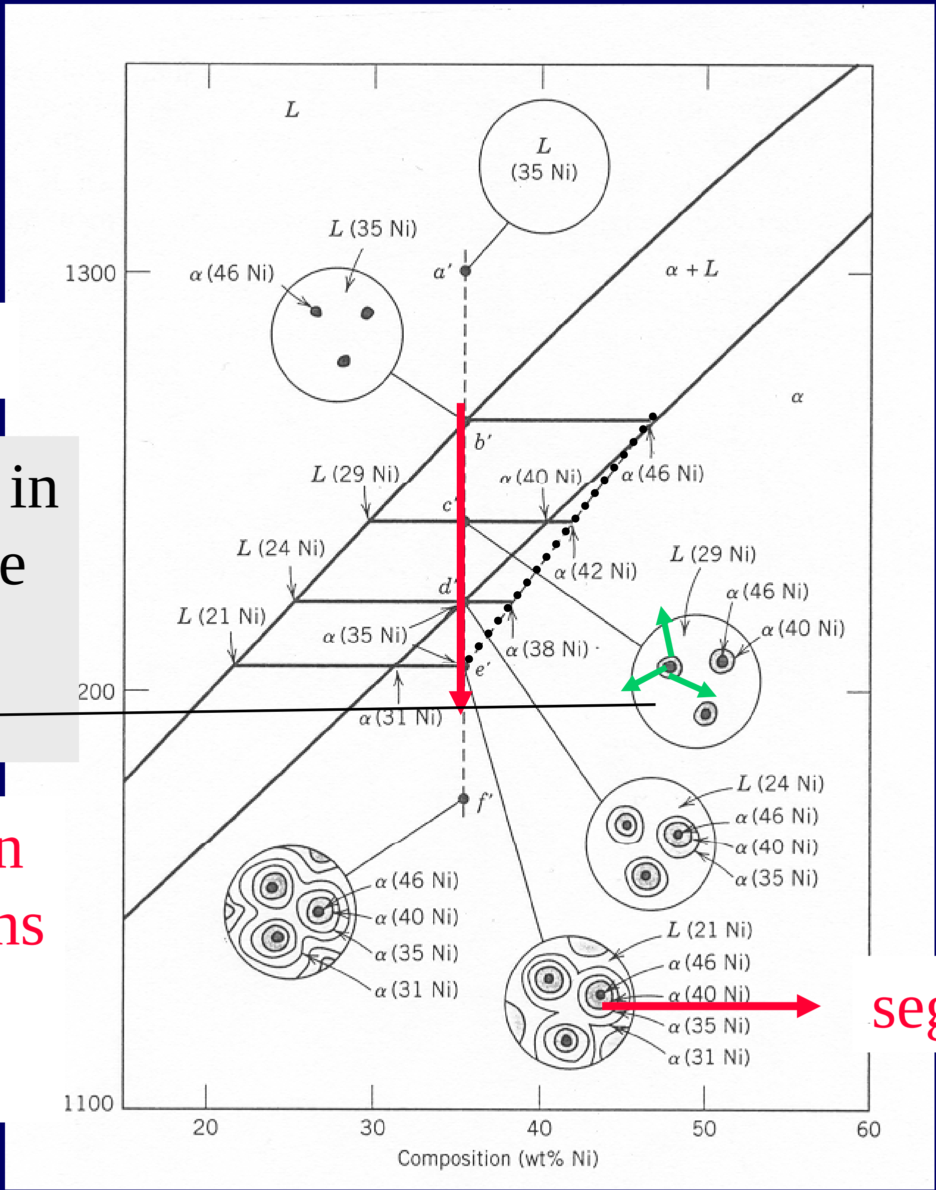


Non-Equilibrium Cooling

first solid nuclei

concentration changes in solid AND liquid phase required!!
by **diffusion**

Ni concentration in solid nuclei remains high: ·········
low D_{solid}

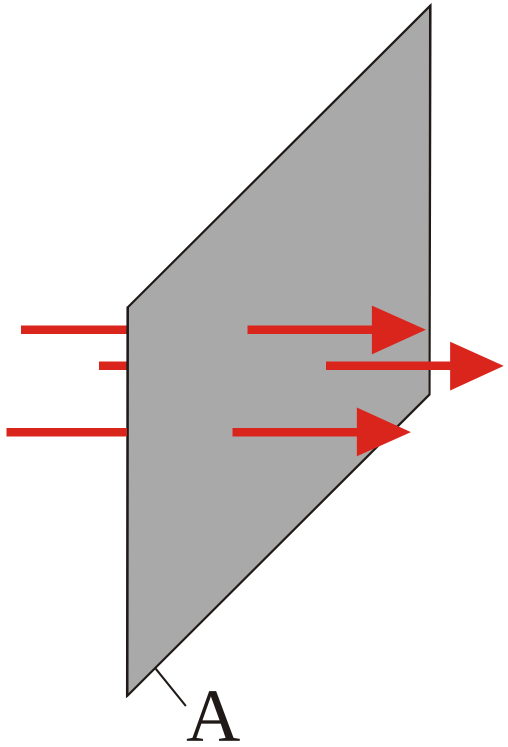


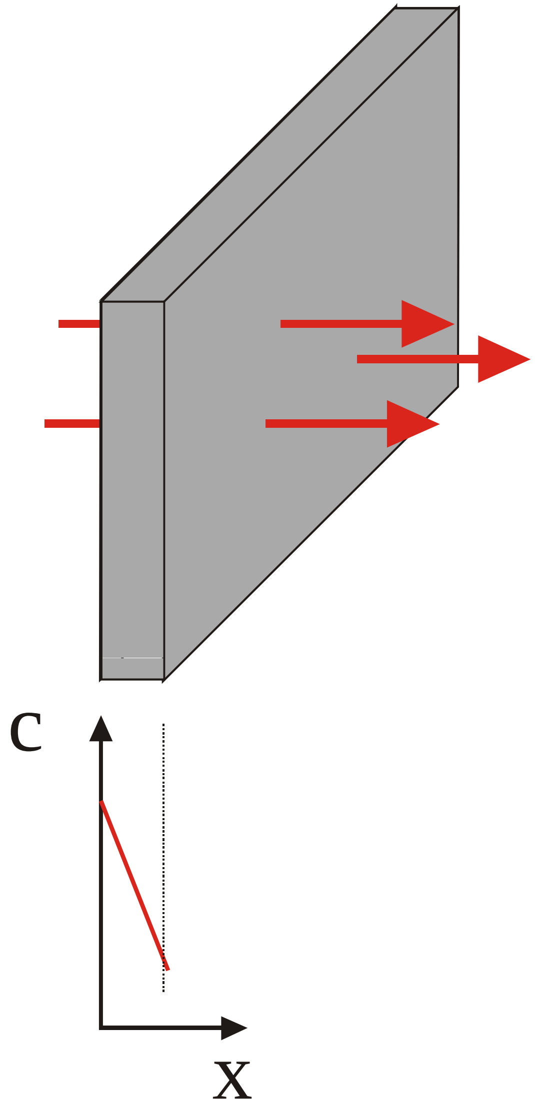
segregation

Diffusion

flux

$$J = \frac{1}{A}\frac{dN}{dt}$$



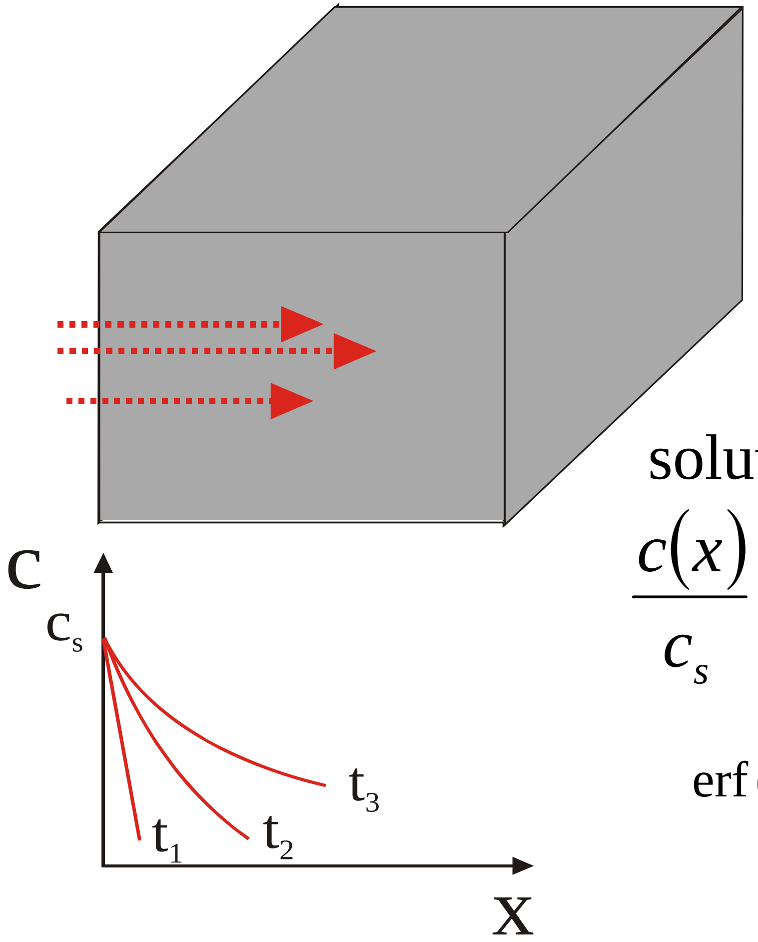


steady state diffusion

$$J = -D\frac{dc}{dx}$$

Non-Steady-State Diffusion
Ficks‘s 2nd Law

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}$$



solution (c(0)=0):

$$\frac{c(x)}{c_s} = 1 - \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\mathrm{erf}\,(z) = \frac{2}{\sqrt{\pi}} \int_0^z \exp(-z')dz'$$

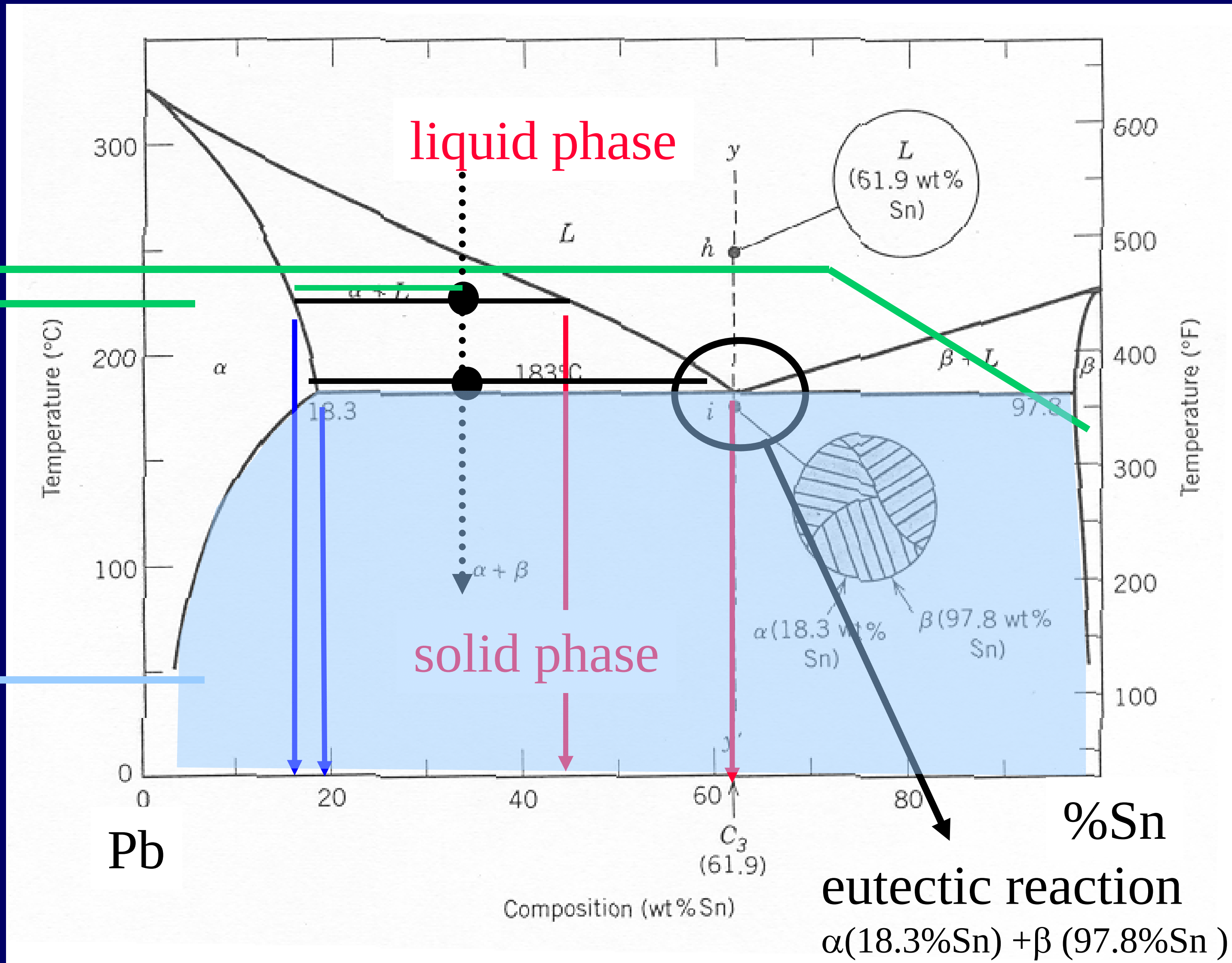
diffusion coefficient:

$$D = D_0 \exp\left(-\frac{Q_D}{RT}\right)$$

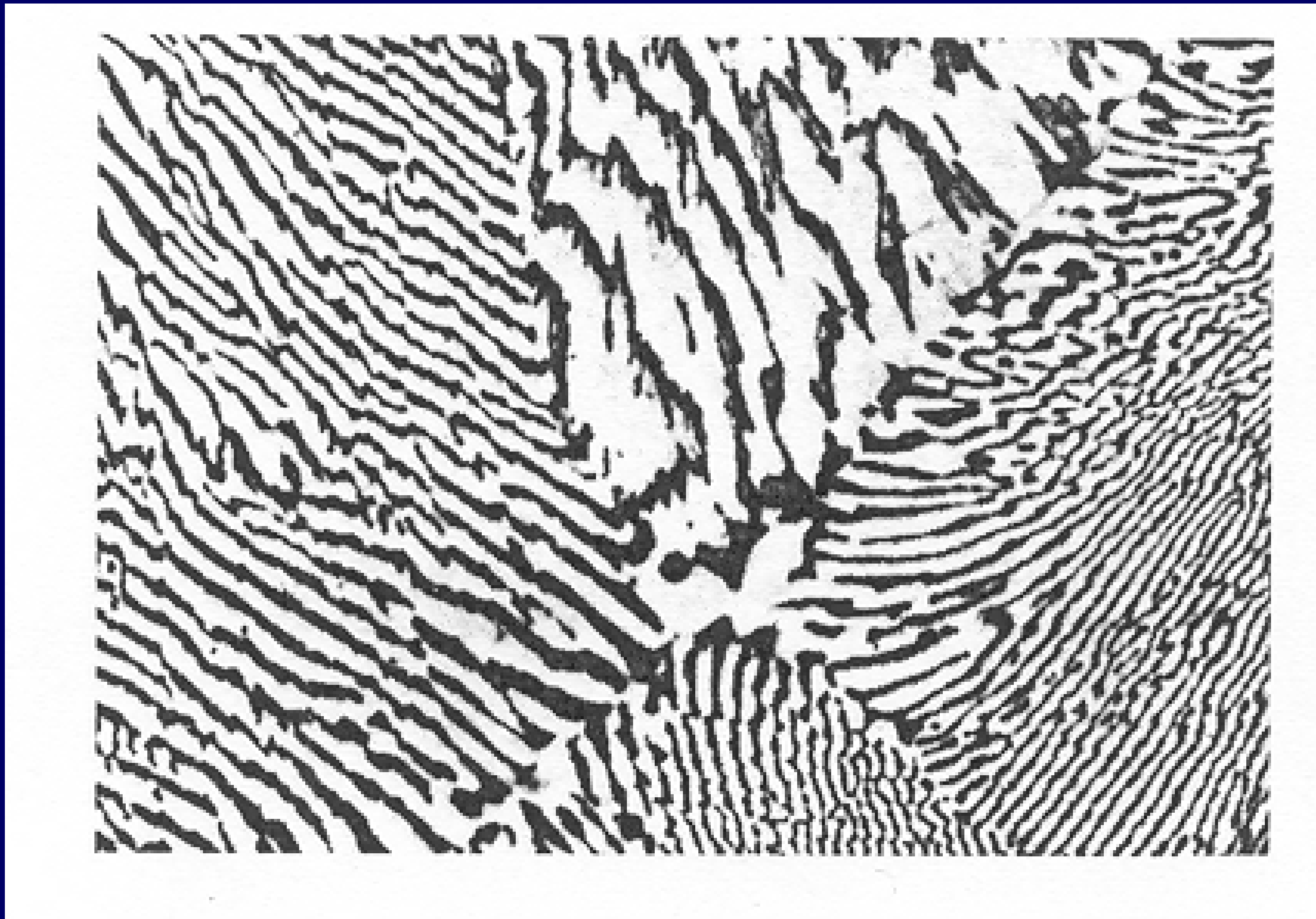
Binary Eutectic Phase Diagrams (Pb-Sn)

α and β
solid solution

limited
solubility



Lamellar Eutectic Microstructure

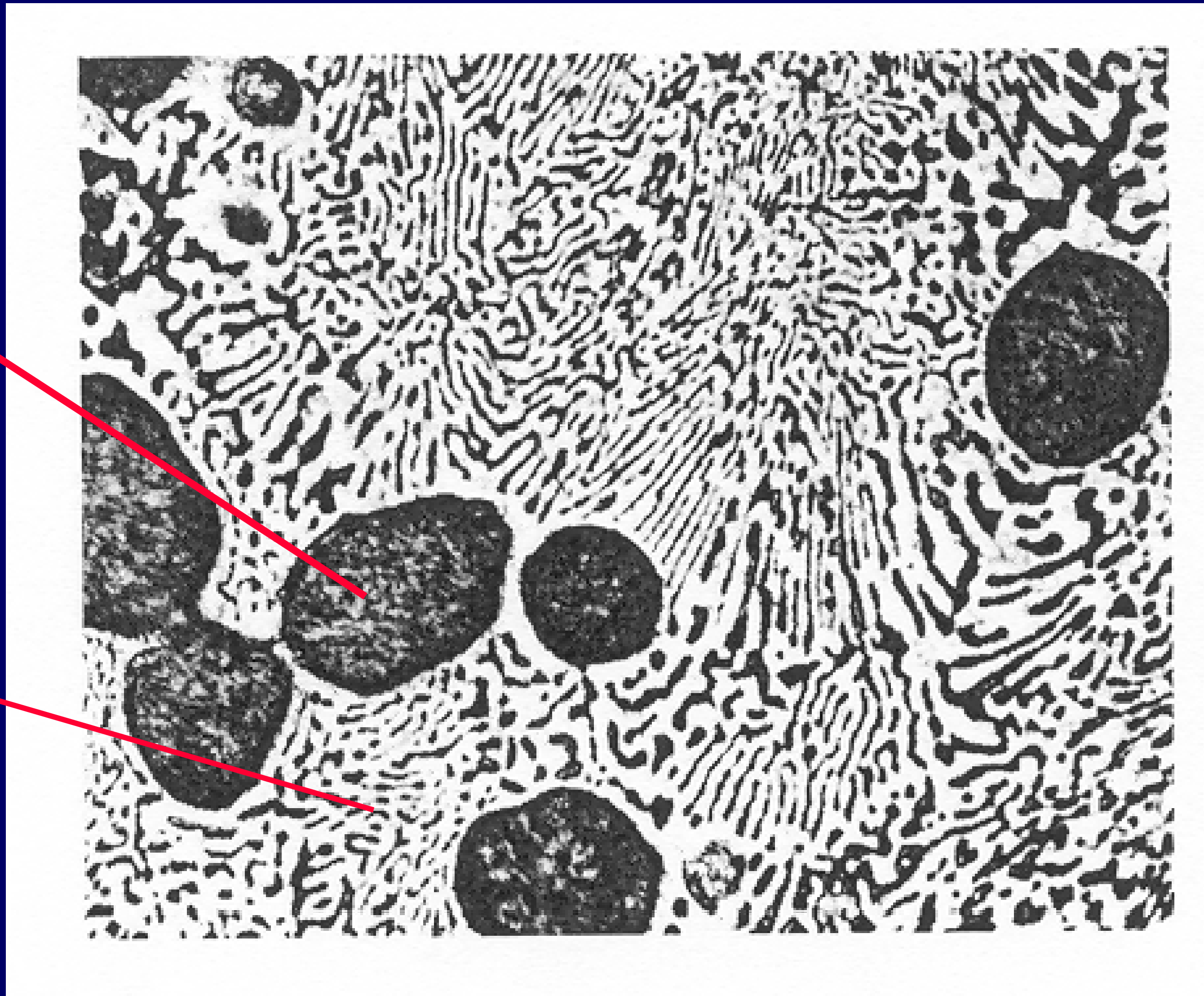


T_m, similar to pure components, but: two phases!!

Sub-Eutectic Microstructure

lead-rich
α phase

eutectic:
white β
dark α



Microstructural Examination - Metallography

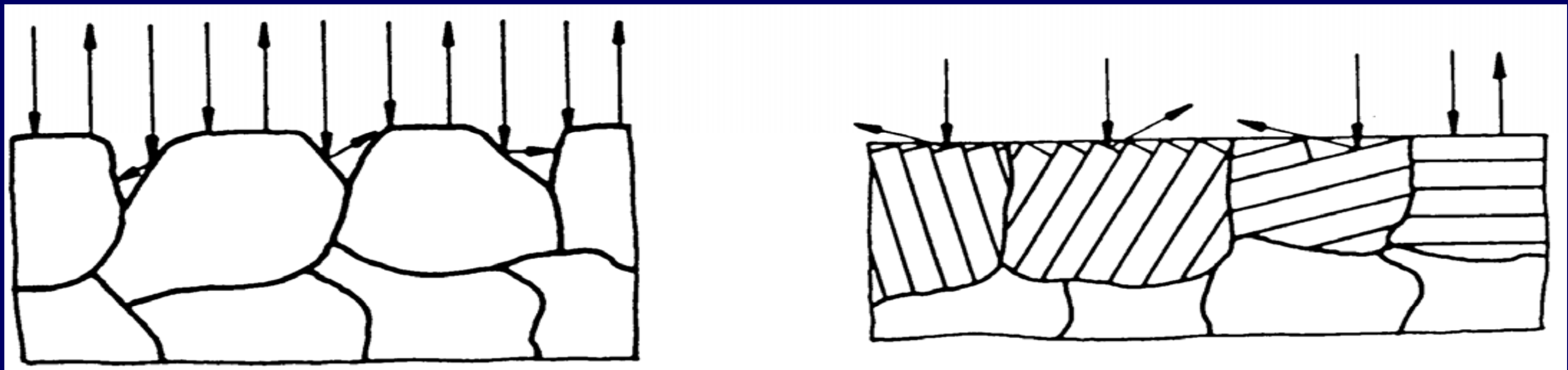
preparation of cross section

-cutting

-grinding (SiC paper)

-polishing (e.g. 1µm diamond suspension)

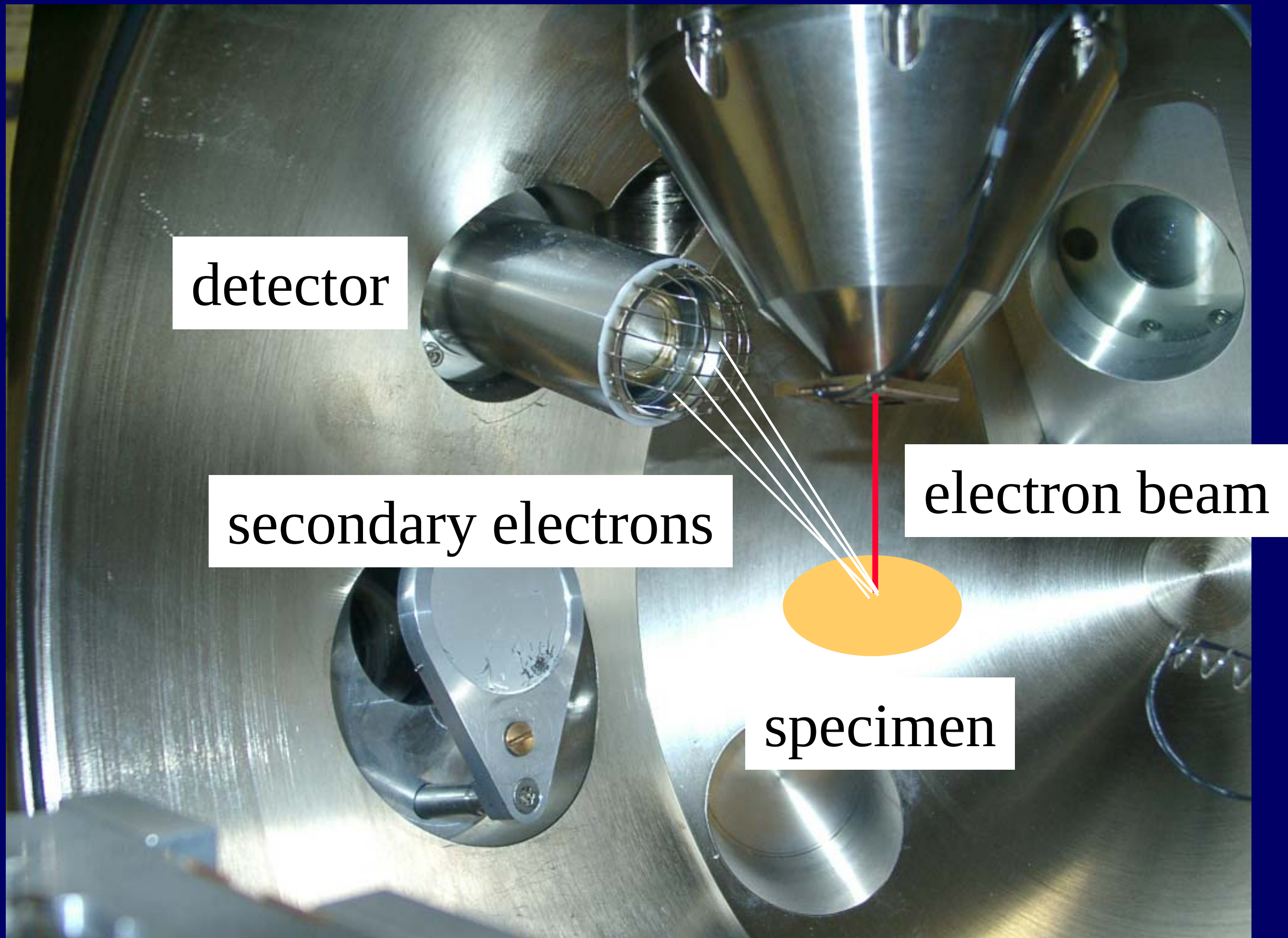
-etching (selective chemical attack of grains/grain boundaries)



optical microscopy

electron microscopy (transmission (TEM) or scanning (SEM))

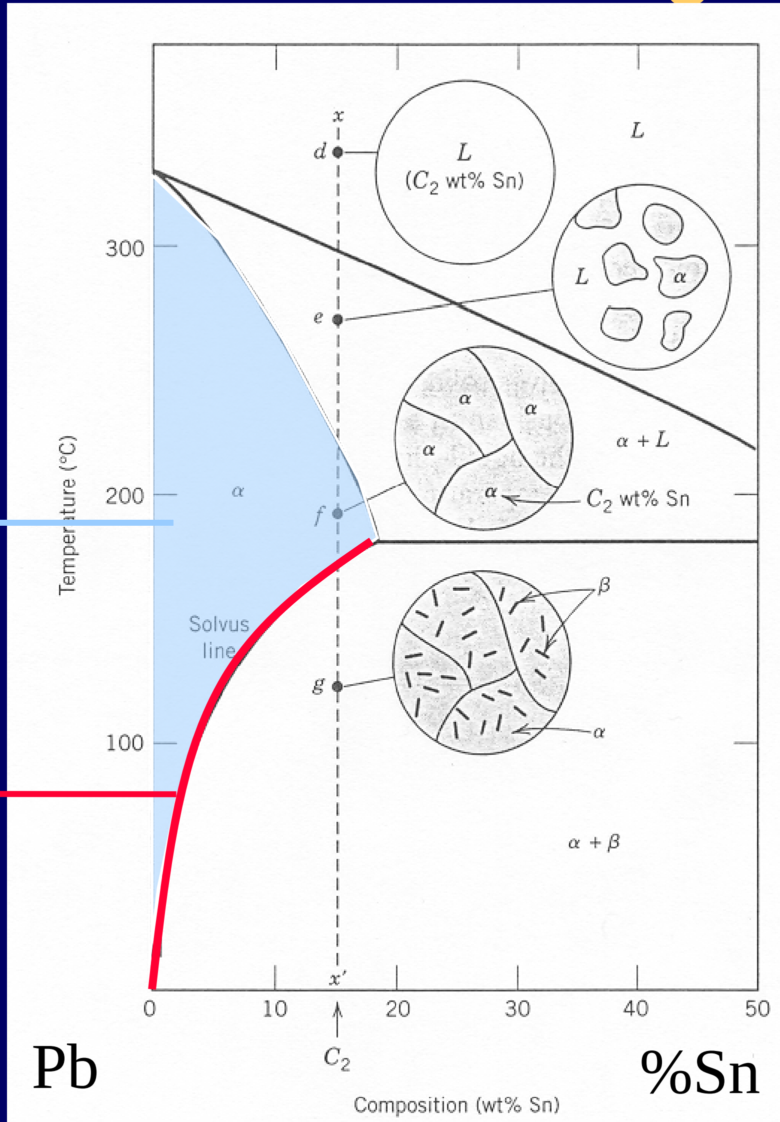
Metallography (SEM)



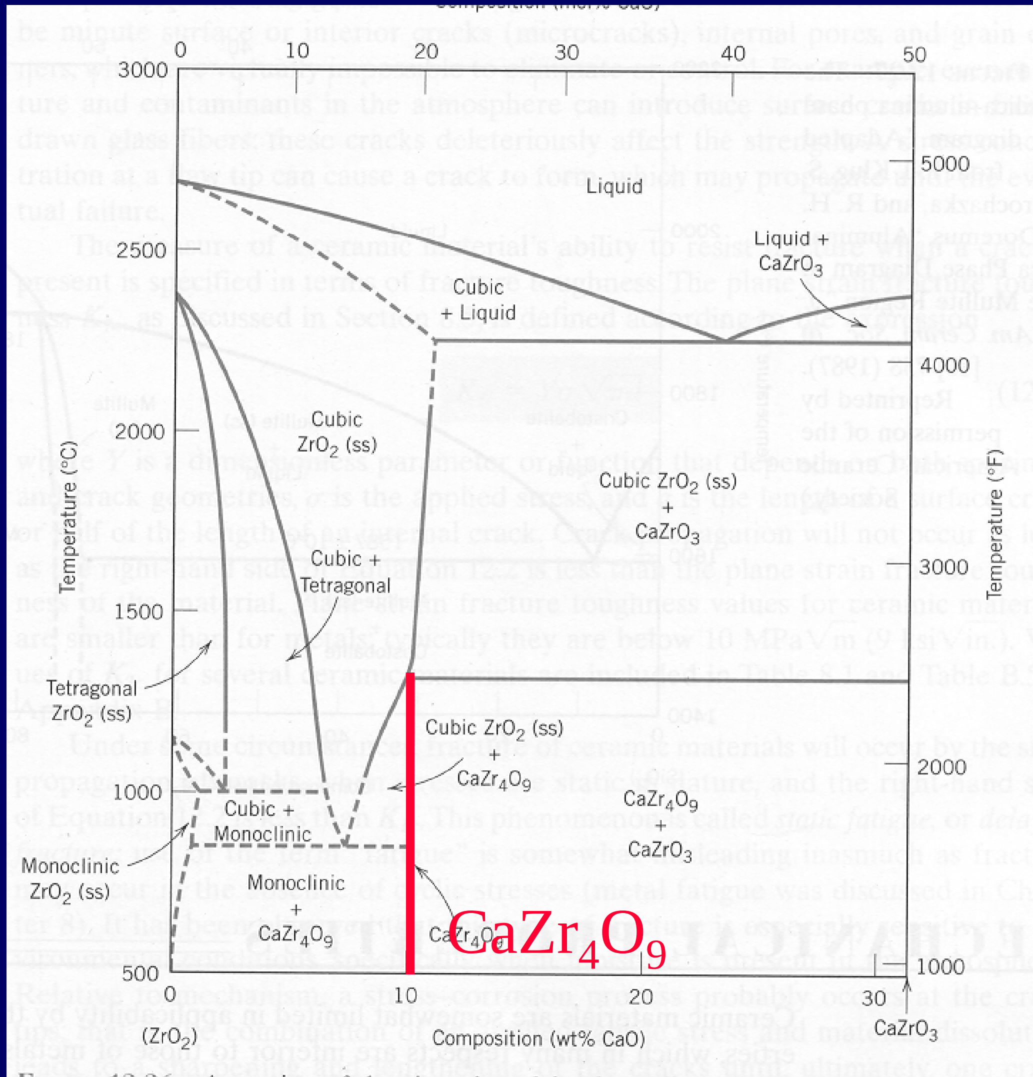
Binary Eutectic Phase Diagrams

α phase

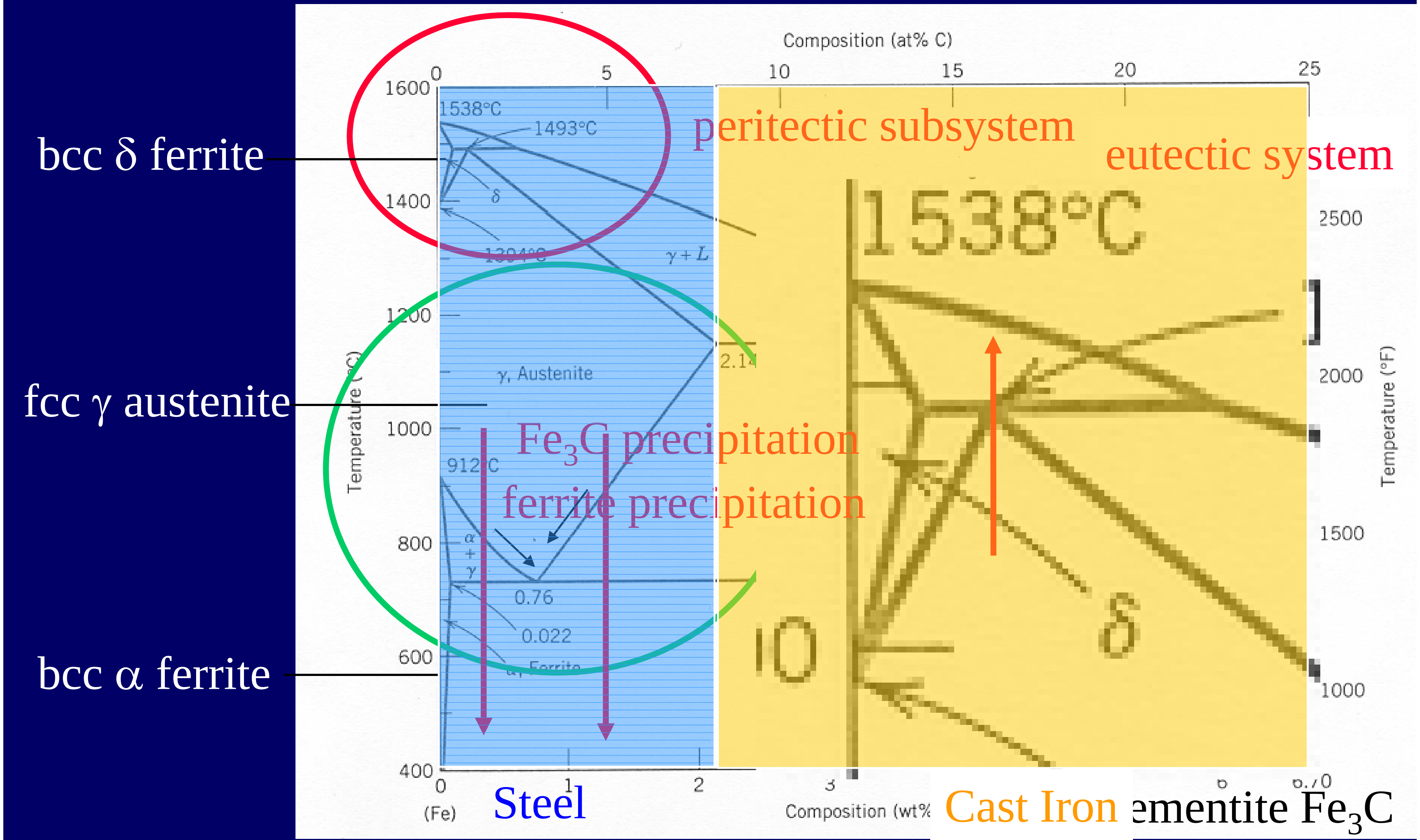
solvus line:
precipitation
of β phase



Intermetallic Phases/Compounds (e.g. ceramics)



The Iron-Carbon Phase Diagram

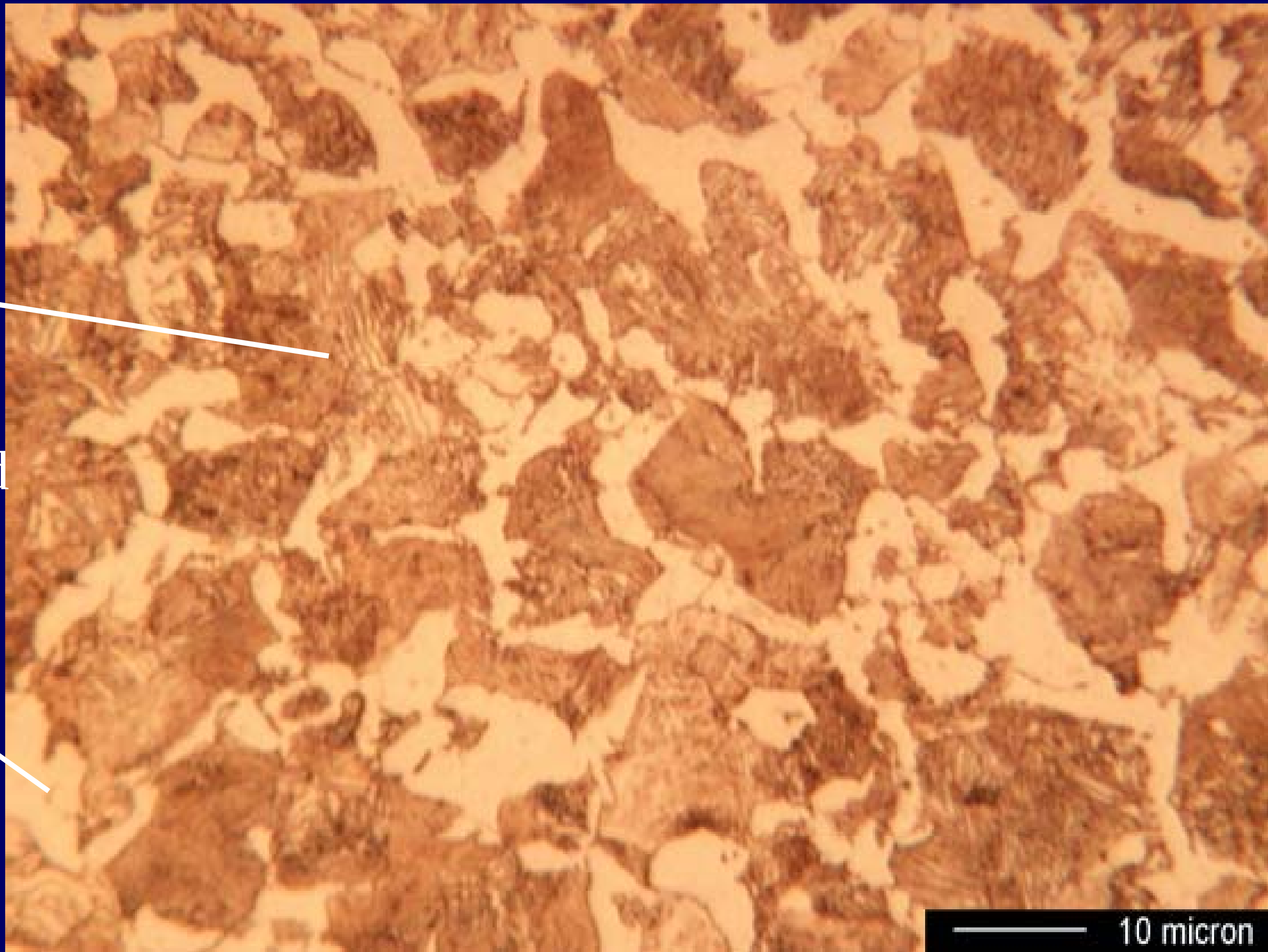


Hypoeutectoid Steels (C_C<0.76%)
(⇔ hypereutectoid)

Ck45
Cc=0.45%

dark
pearlite:
lamellae
of Fe_3C and
ferrite

light
α ferrite



Hypoeutectoid Steels (C_C<0.76%)
(⇔ hypereutectoid)

Ck15
Cc=0.15%

dark
pearlite:

light
α ferrite