EMA5001 Lecture 14
Growth of Alloys from Liquid

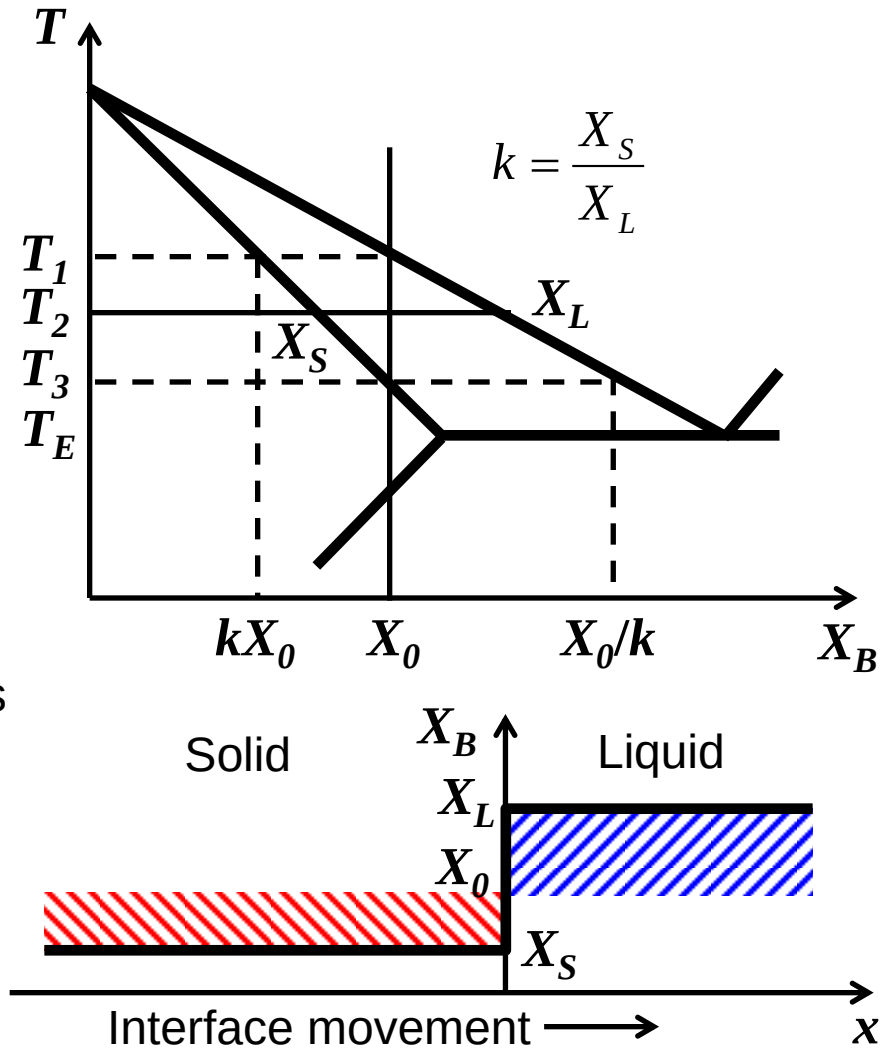
FLORIDA INTERNATIONAL UNIVERSITY

Solidification of Single Phase Alloys (1)

- **Most commercial metals contain alloy elements**
- **Systems to be examined**
  - Single phase
  - Eutectic alloy
  - Peritectic alloy

- **<u>Case #1</u> Equilibrium solidification of single phase alloys**

  Assuming straight solidus and liquidus lines
  - Infinitely slow cooling
  - Liquid and solid phase uniform
  - Average liquid composition follow liquidus line
  - Average solid composition follows solidus line



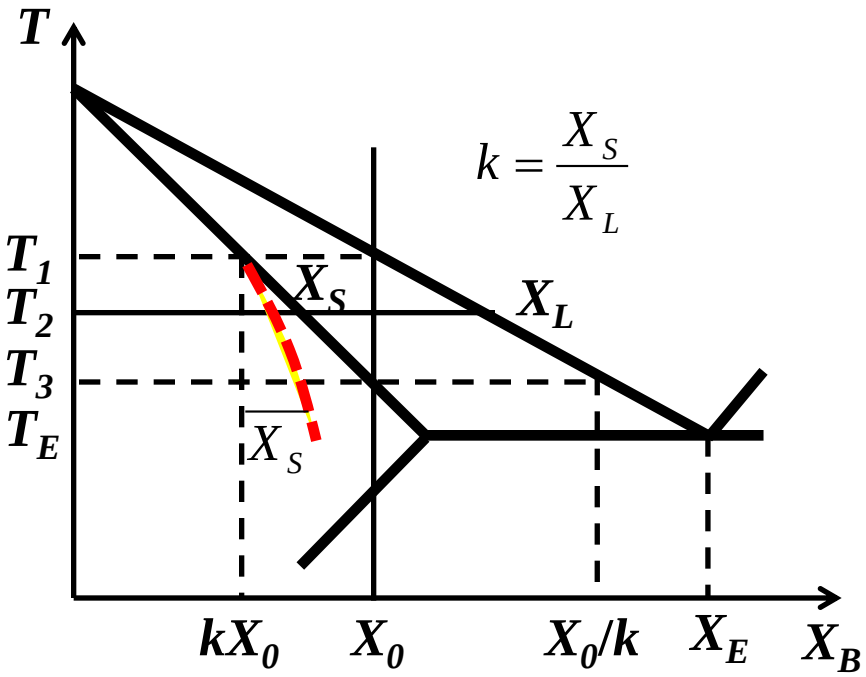
Solidification of Single Phase Alloys (2)

- **Case #2 No diffusion in solid, perfect mixing in liquid**

  Example

  Fast cooling with efficient **stirring** in liquid

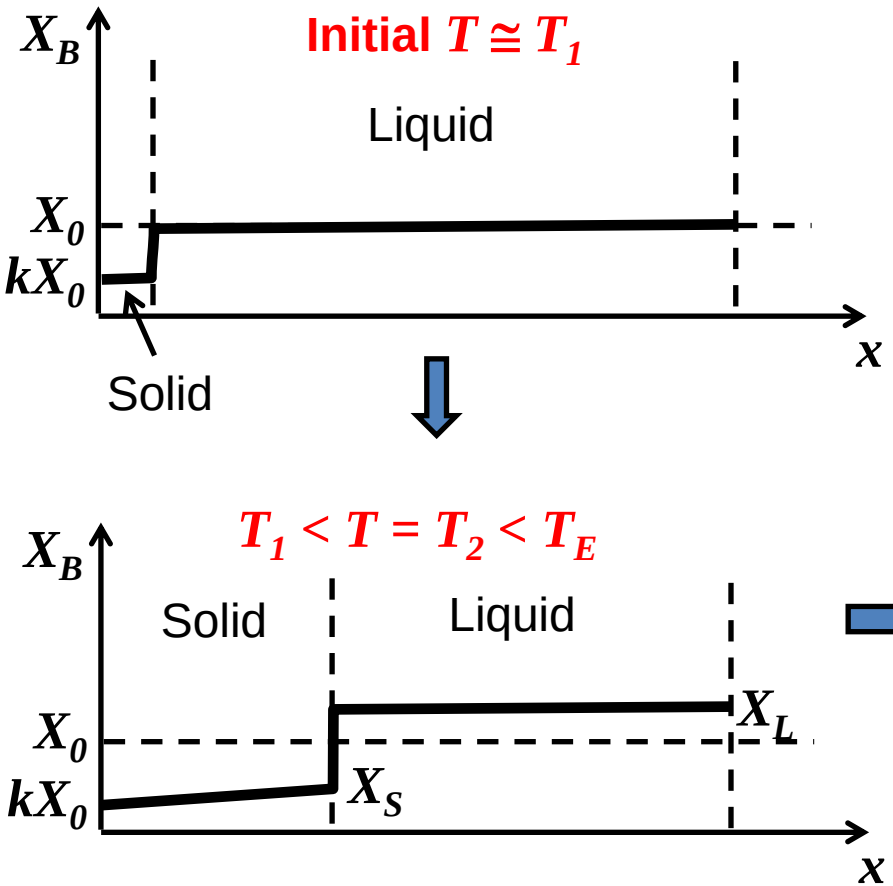
  - Uniform liquid composition at any time
  - Local equilibrium at the solid-liquid interface
  - Liquid composition follow liquidus line
  - Solid composition changes with position as a result of solidification at decreasing temperature with no diffusion in solid
  - Average solid composition lower (in solute concentration) than solidus line
  - Always reaches eutectic point

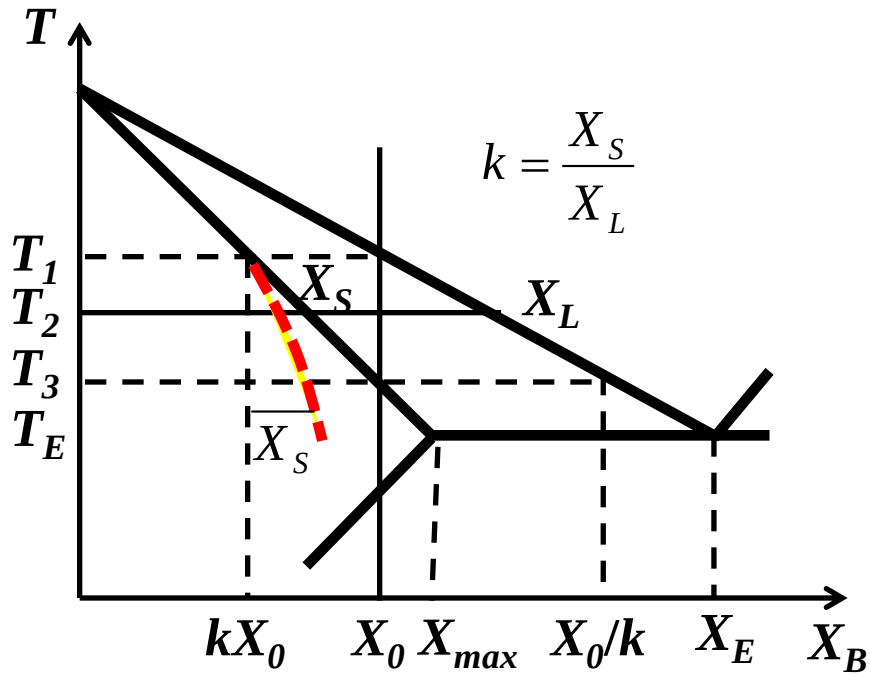


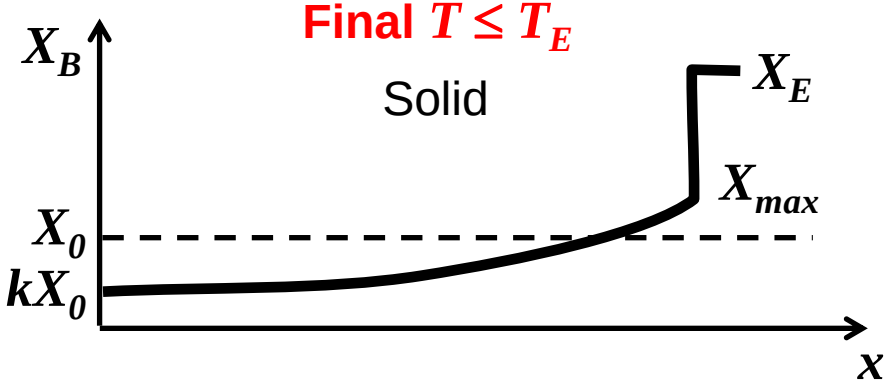
Solidification of Single Phase Alloys (3)

❑ **Continue from p.3**

Evolution of composition profile

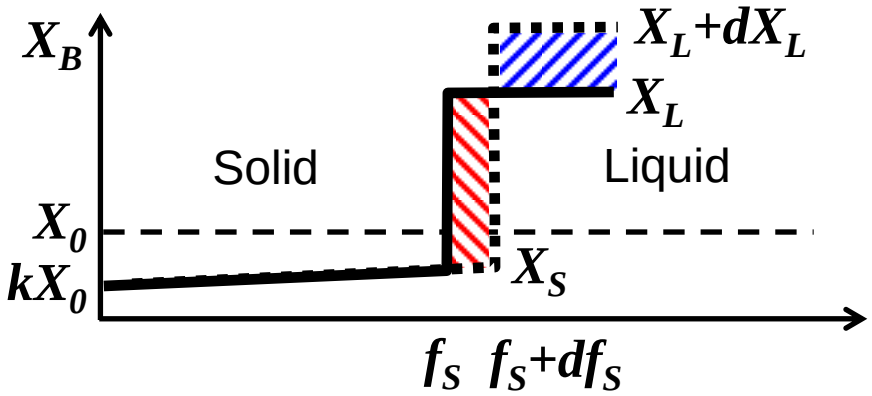






Solidification of Single Phase Alloys (4)

❑ **Continue from p.4**



At any given extent of solidification

X_L Liquid composition (uniform)

X_S Solid composition at the interface

f_S Total weight fraction of solid

$f_L=1-f_S$ Total weight fraction of liquid

df_S Small increase in solid weight fraction due to continued solidification

dX_L Small increase in liquid composition due to solute diffusion from solid to liquid

We have: $(X_L - X_S)df_S \approx (1-f_S)dX_L$ $\quad \frac{df_S}{1-f_S} = \frac{dX_L}{X_L - X_S}$

Consider $k = \frac{X_S}{X_L}$, we have $-\frac{df_L}{f_L} = \frac{1}{1-k}\cdot\frac{dX_S}{X_S}$

Integral and consider when $f_S = 0$, $X_S = kX_0$, we have $X_S = \frac{kX_0}{(1-f_S)^{1-k}}$ $\quad X_L = \frac{X_0}{f_L^{1-k}}$

Implication: the system will always contain some eutectics

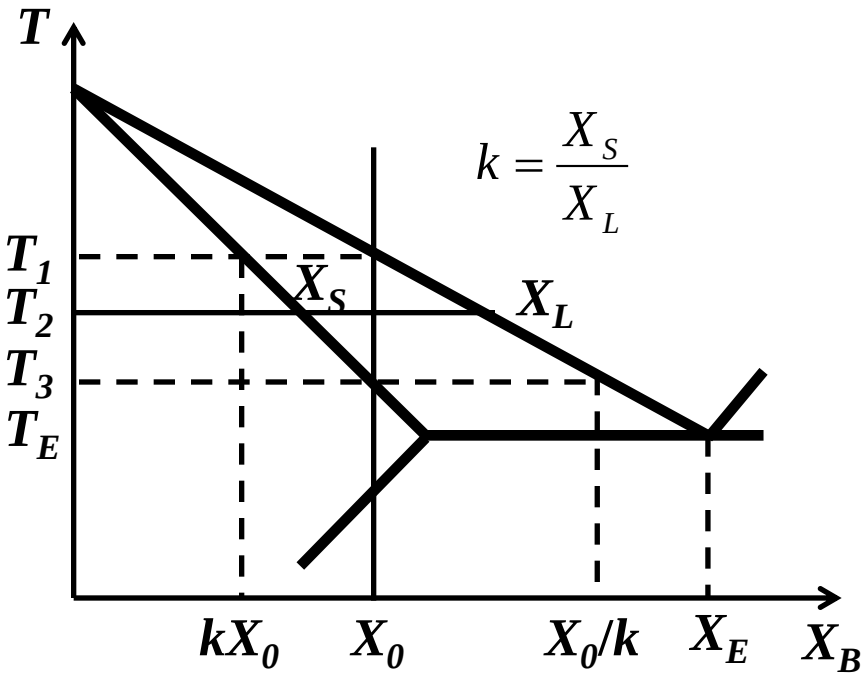
Solidification of Single Phase Alloys (5)

- **Case #3 No diffusion in solid, diffusional mixing in liquid**

  Assumption:

  After initial stage, system can reach steady state with stable solidification rate

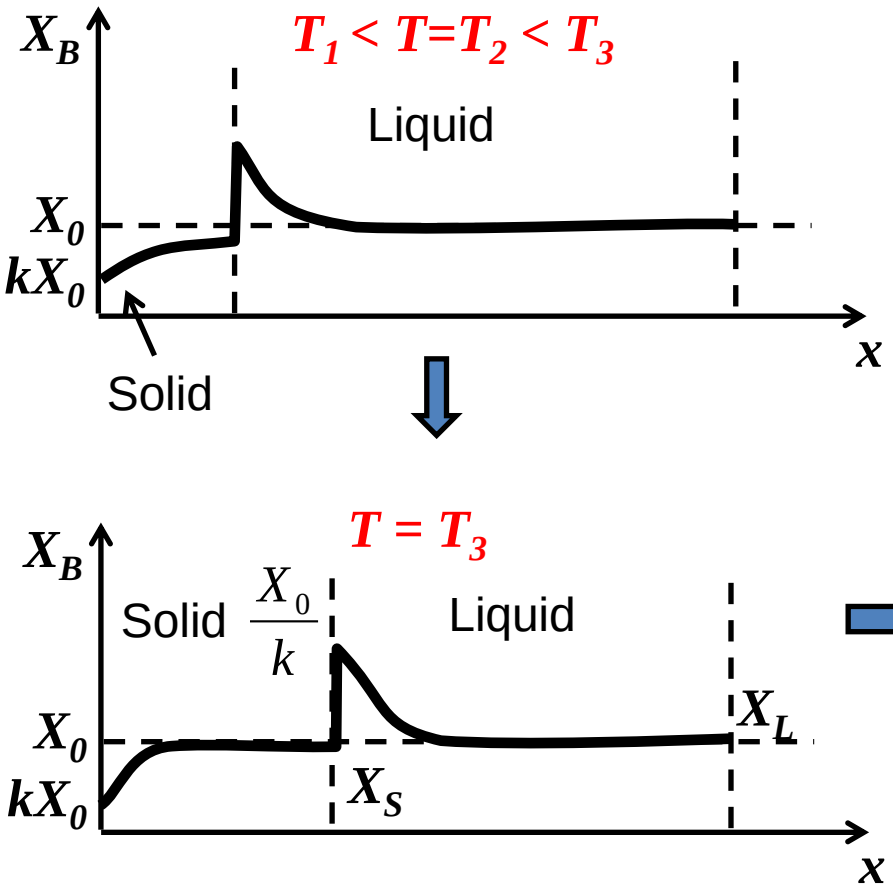
  - Liquid composition decreases from liquidus line to bulk concentration
  - Local equilibrium at the solid-liquid interface
  - System can reaches steady state: balance of diffusion and cooling/solidification process
  - Always reaches eutectic point

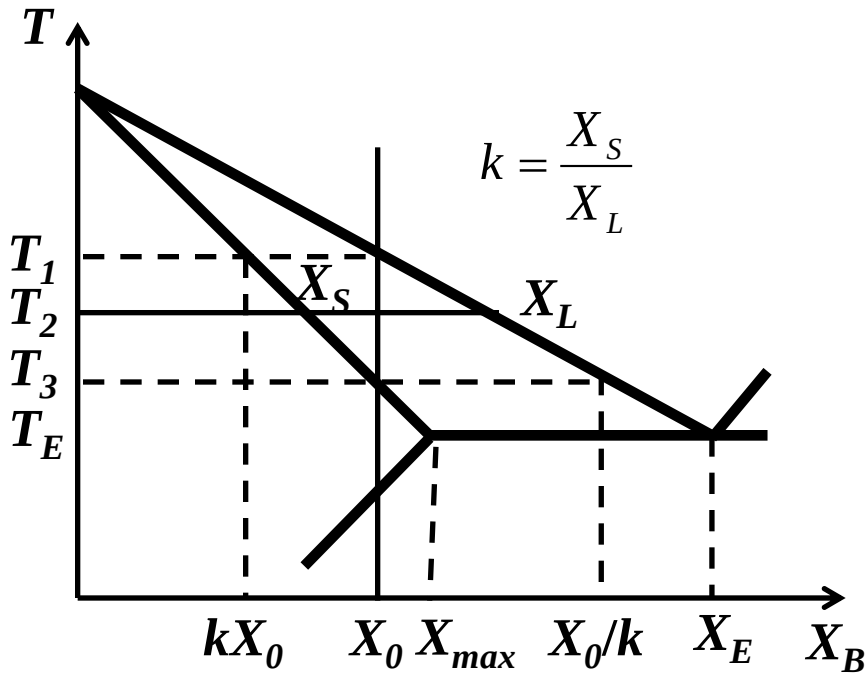


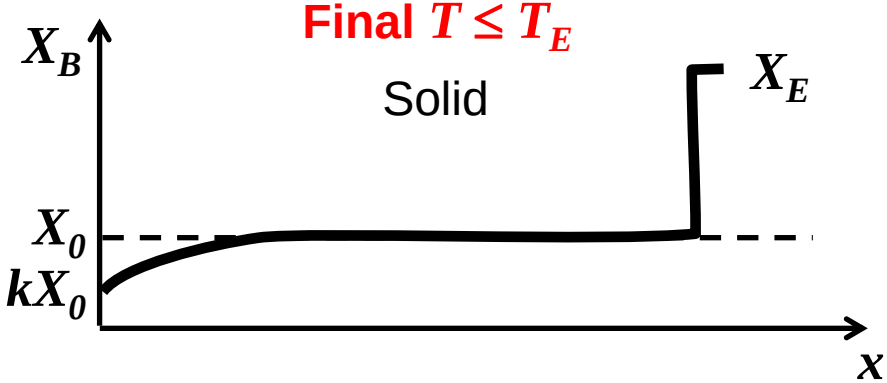
Solidification of Single Phase Alloys (6)

❑ **Continue from p.6**

Evolution of composition profile







Constitutional Supercooling

- **Solidification of an alloy with solid grows into <u>superheated</u> liquid**
  - Example: Solidification of liquid alloy in a mold w/ wall colder is than liquid
  - "Equilibrium" temperature T_{Eq} changes as liquid composition changes near the interface