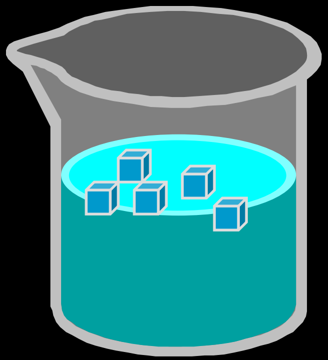
PHASE DIAGRAMS

THEORY AND APPLICATIONS

Some basic concepts

- Phase
  - A homogeneous region with distinct structure and physical properties
  - In principle, can be isolated
  - Can be solid, liquid or gas



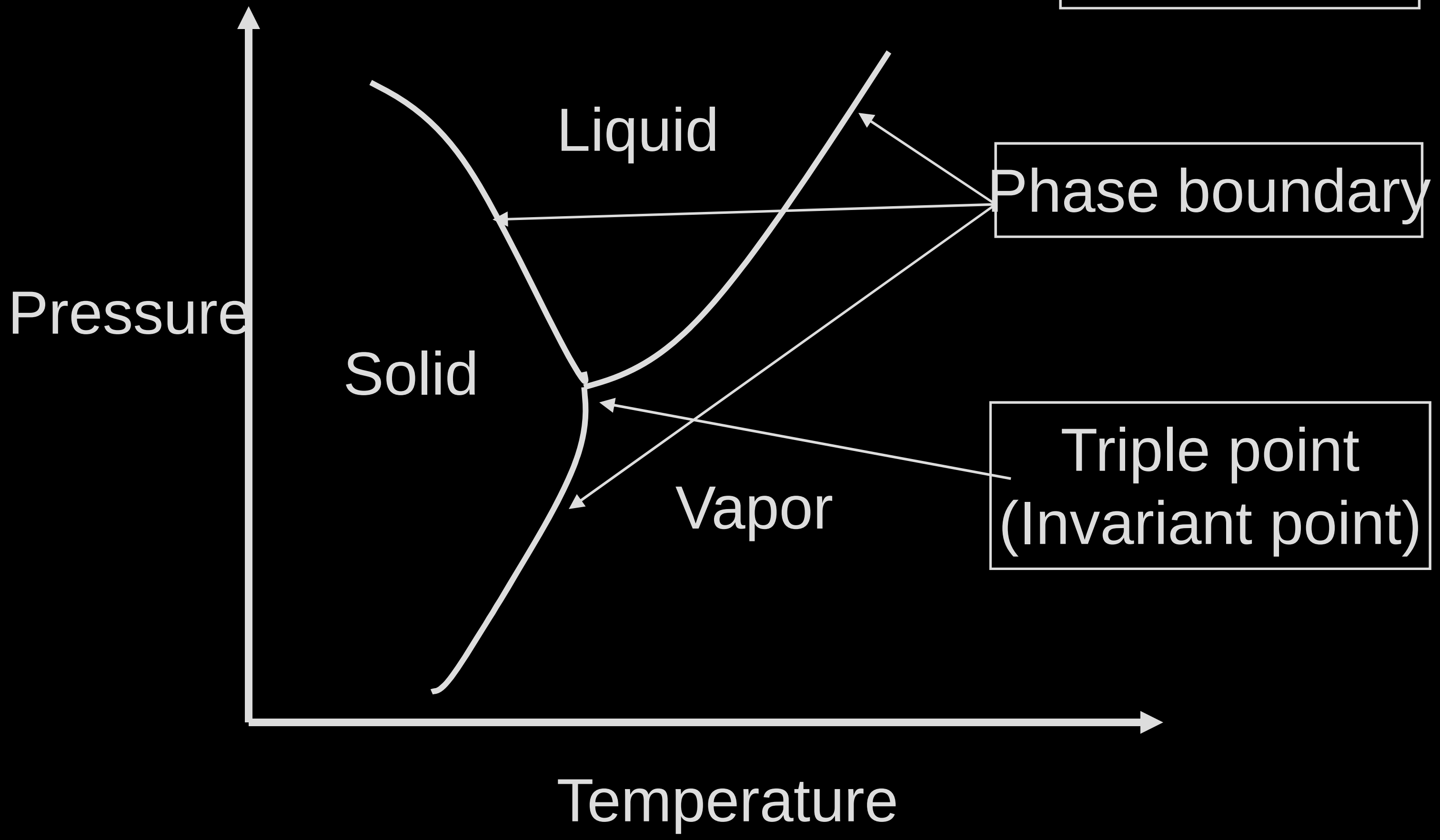
- Phase Diagram
  - Representation of phases present under a set of conditions (P, T, Composition etc.)

Concepts……

- Phase transformation
  - Change from one phase to another
  - E.g. L → S, S → S etc.
  - Occurs because energy change is negative/goes from high to low energy state
- Phase boundary
  - Boundary between phases in a phase diagram

A simple phase diagram

System: H_2O



Liquid

Solid

Vapor

Pressure

Temperature

Phase boundary

Triple point
(Invariant point)

Gibb’s Phase Rule

$P + F = C + 2$

$F = C - P + 2$

P=number of phases
C=number of components
F=number of degrees of freedom
(number of independent variables)

Modified Gibbs Phase Rule (for incompressible system

$P + F = C + 1$

$F = C - P + 1$

Pressure is a constant variable

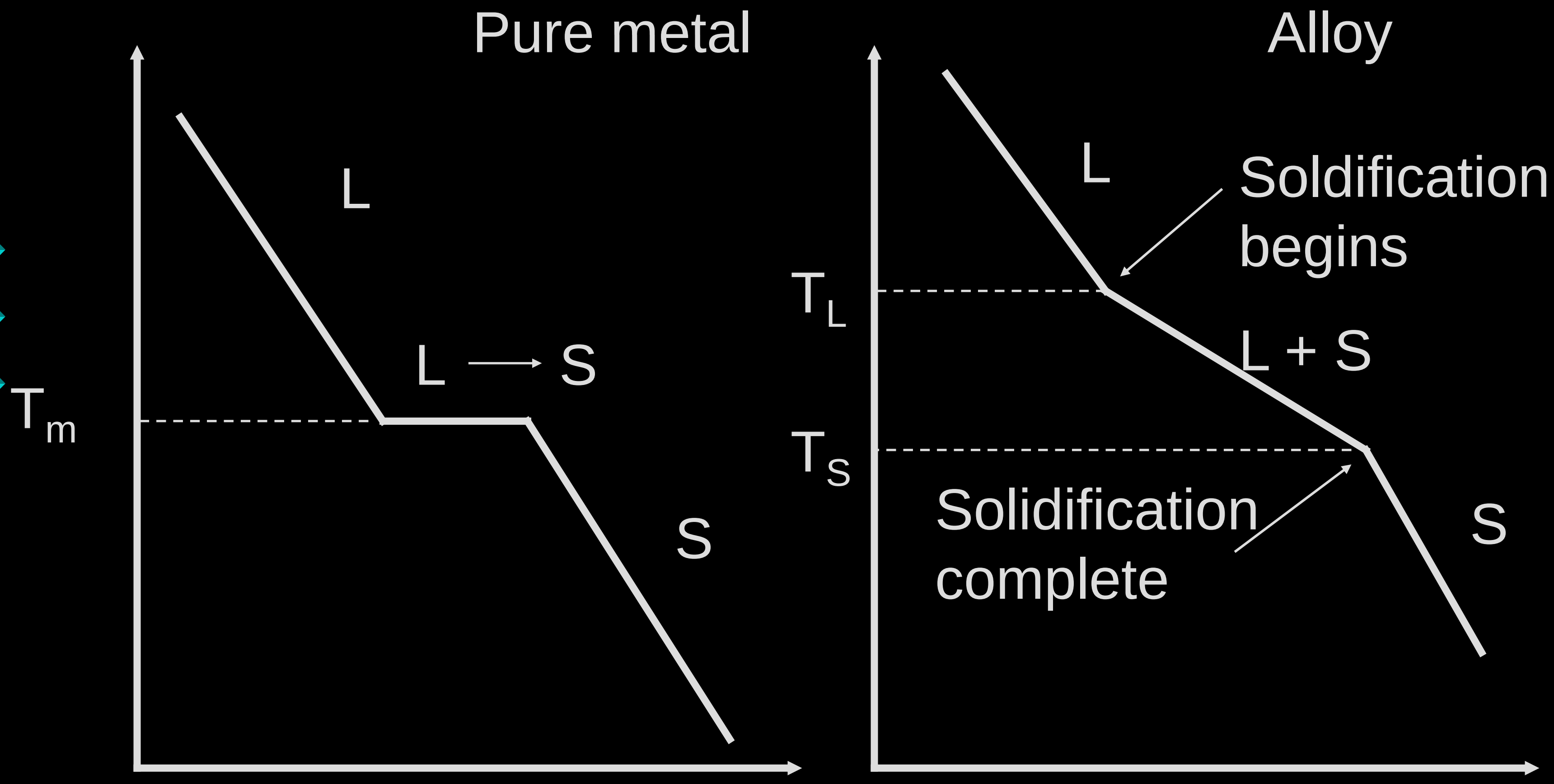
Application of the phase rule

At triple point, P=3, C=1, F=0
i.e. this is an invariant point

At phase boundary, P=2, C=1, F=1

In each phase, P=1, C=1, F=2

Solidification(cooling) curves



Pure metal

L

L → S

S

T_m

Alloy

L

Soldification begins

T_L

L + S

T_S

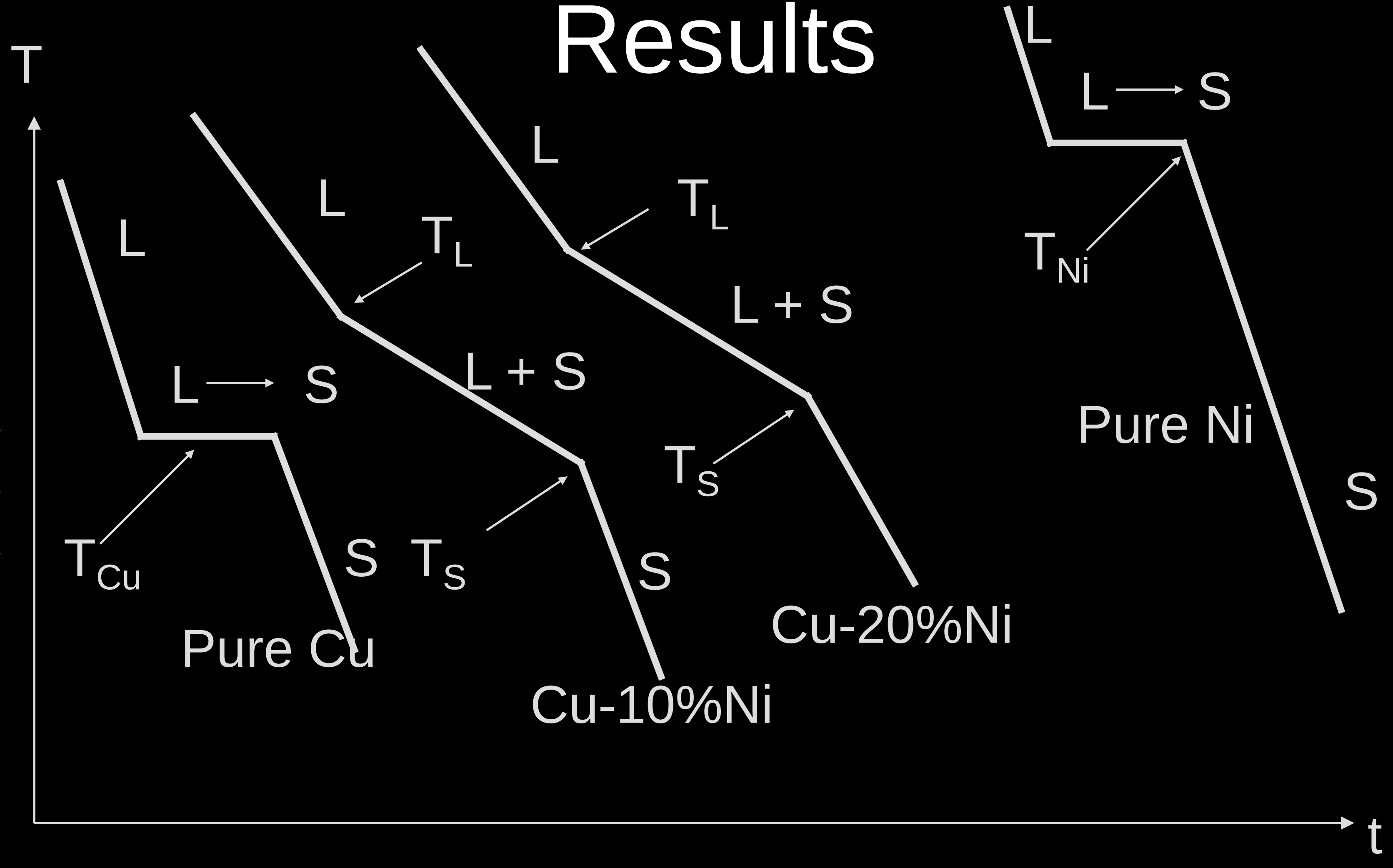
Solidification complete

S

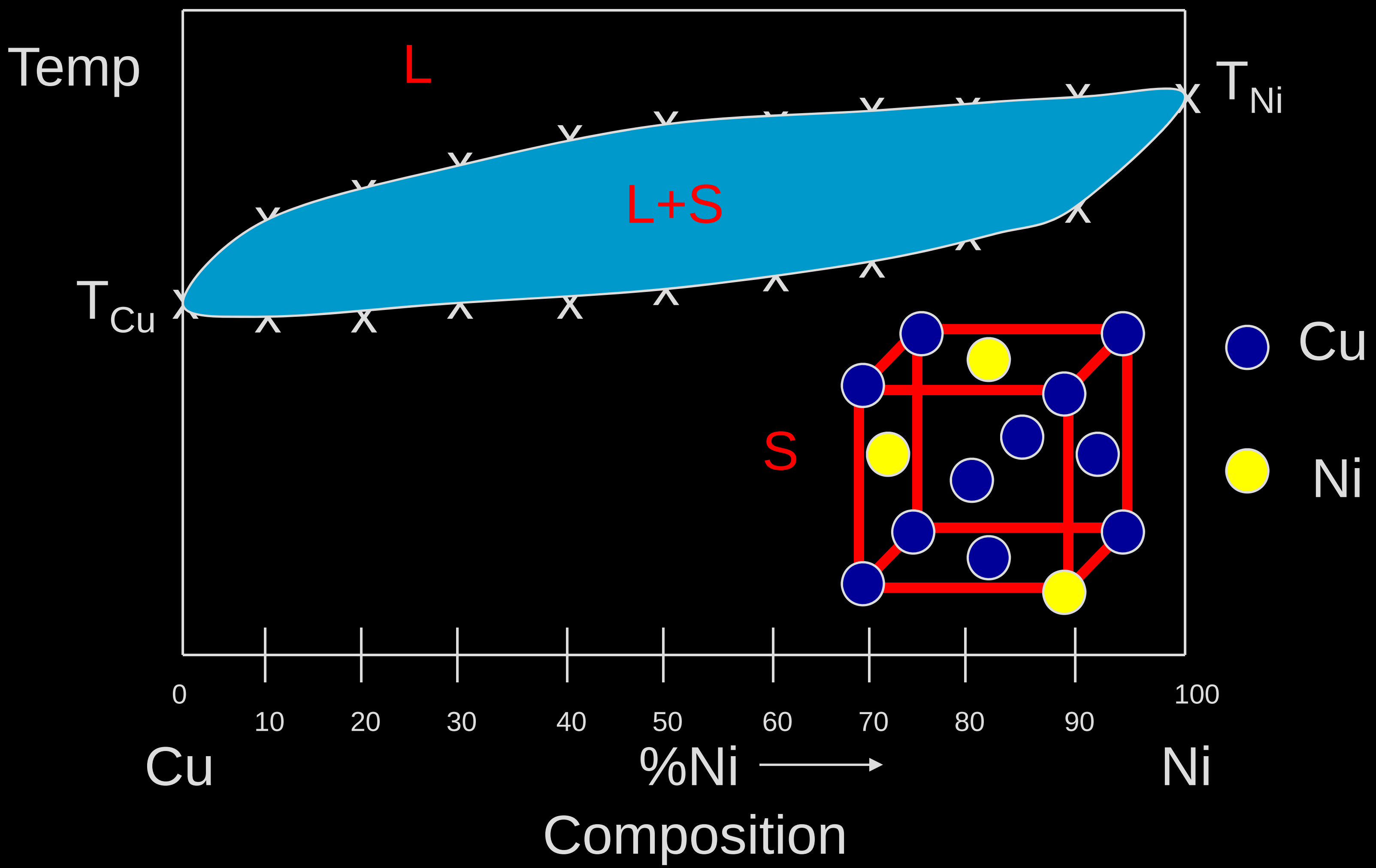
Construction of a simple phase diagram

- Conduct an experiment
- Take 10 metal samples(pure Cu, Cu-10%Ni, Cu-20%Ni, Cu-30%Ni………, pure Ni)
- Melt each sample and then let it solidify
- Record the cooling curves
- Note temperatures at which phase transformations occur

Results

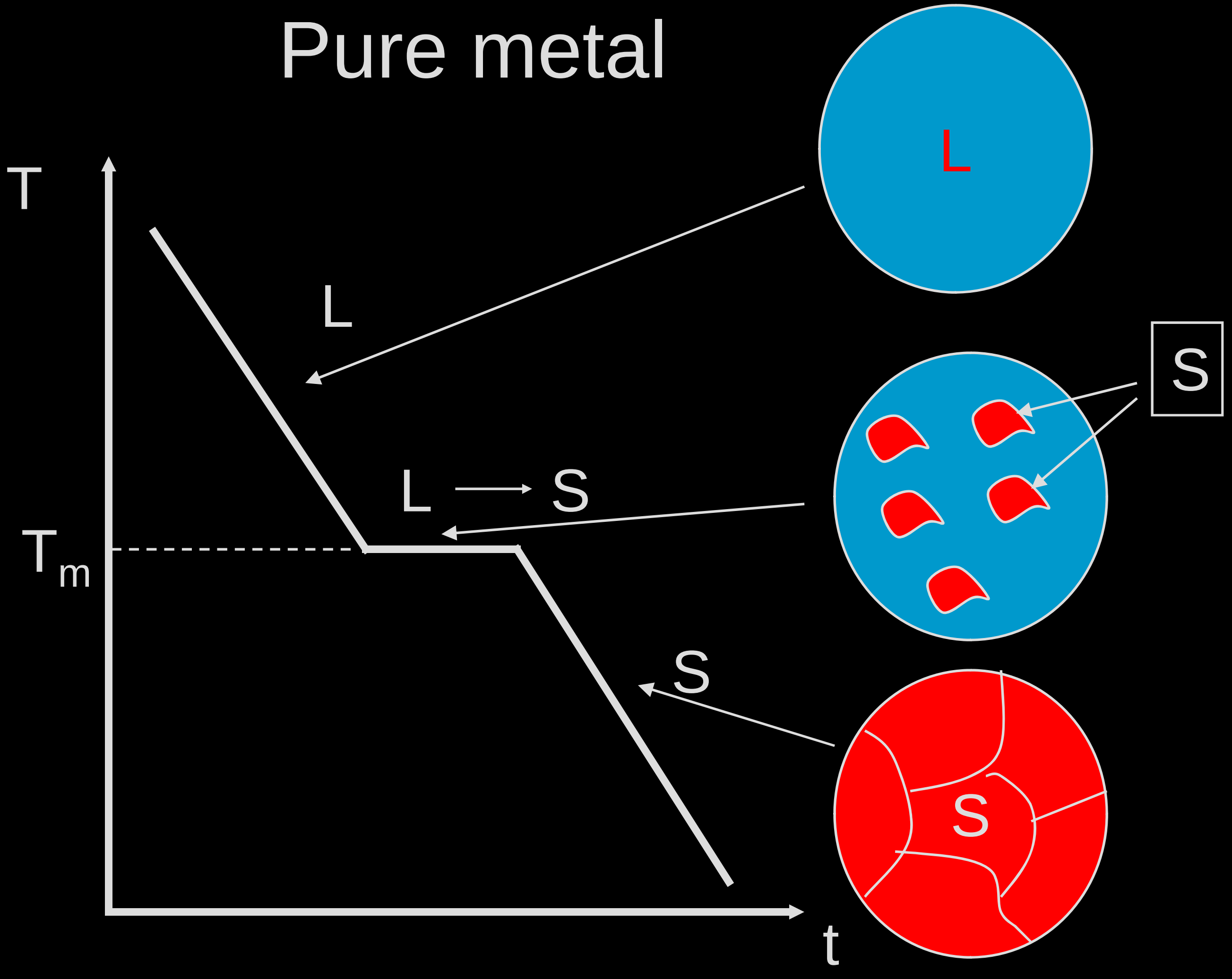

T
t
L
L → S
T_{Cu}
S
Pure Cu
L
T_L
L + S
T_S
S
Cu-10%Ni
L
T_L
L + S
T_S
Cu-20%Ni
L
L → S
T_{Ni}
Pure Ni
S

Binary isomorphous phase diagram

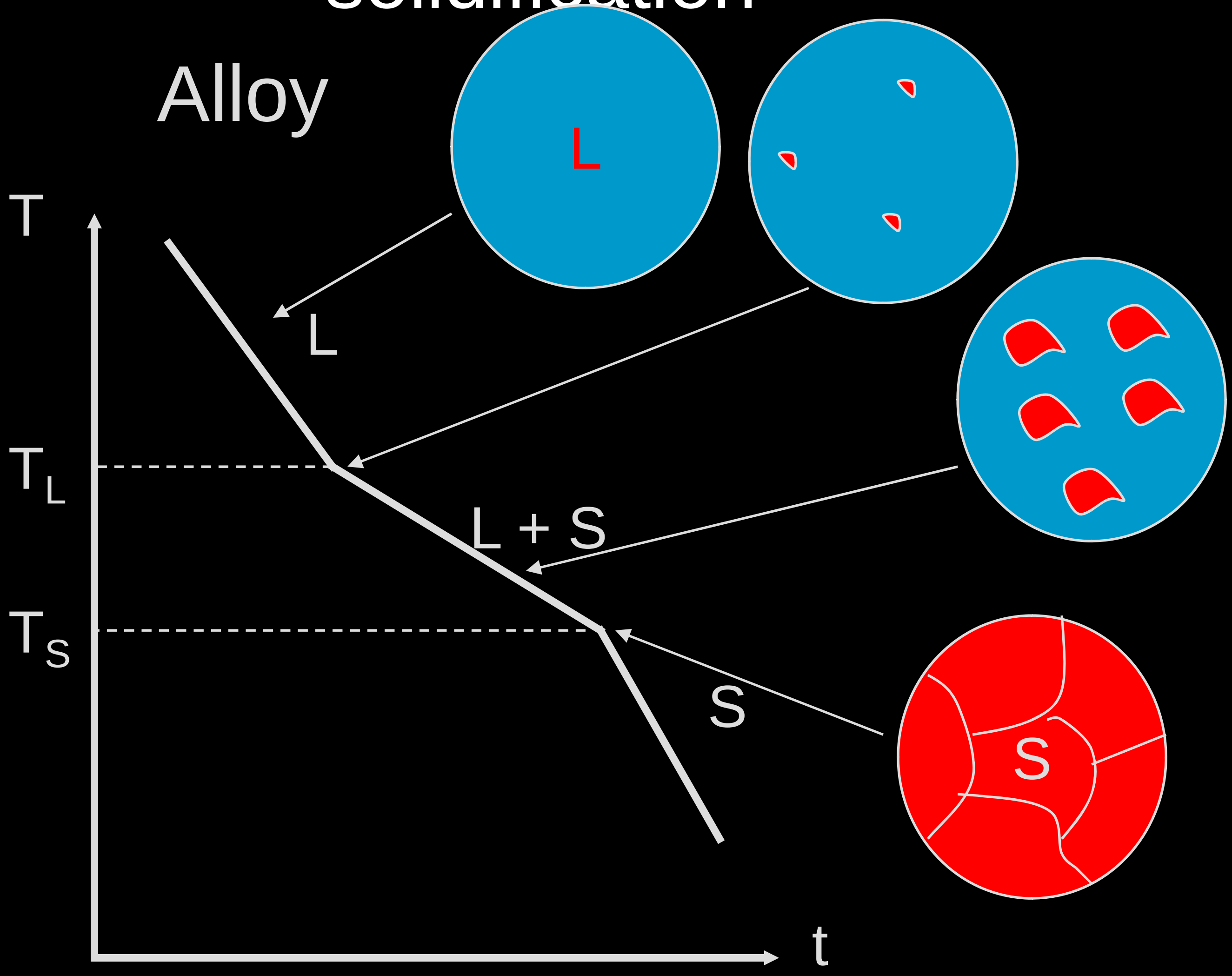


Microstructural changes during solidification

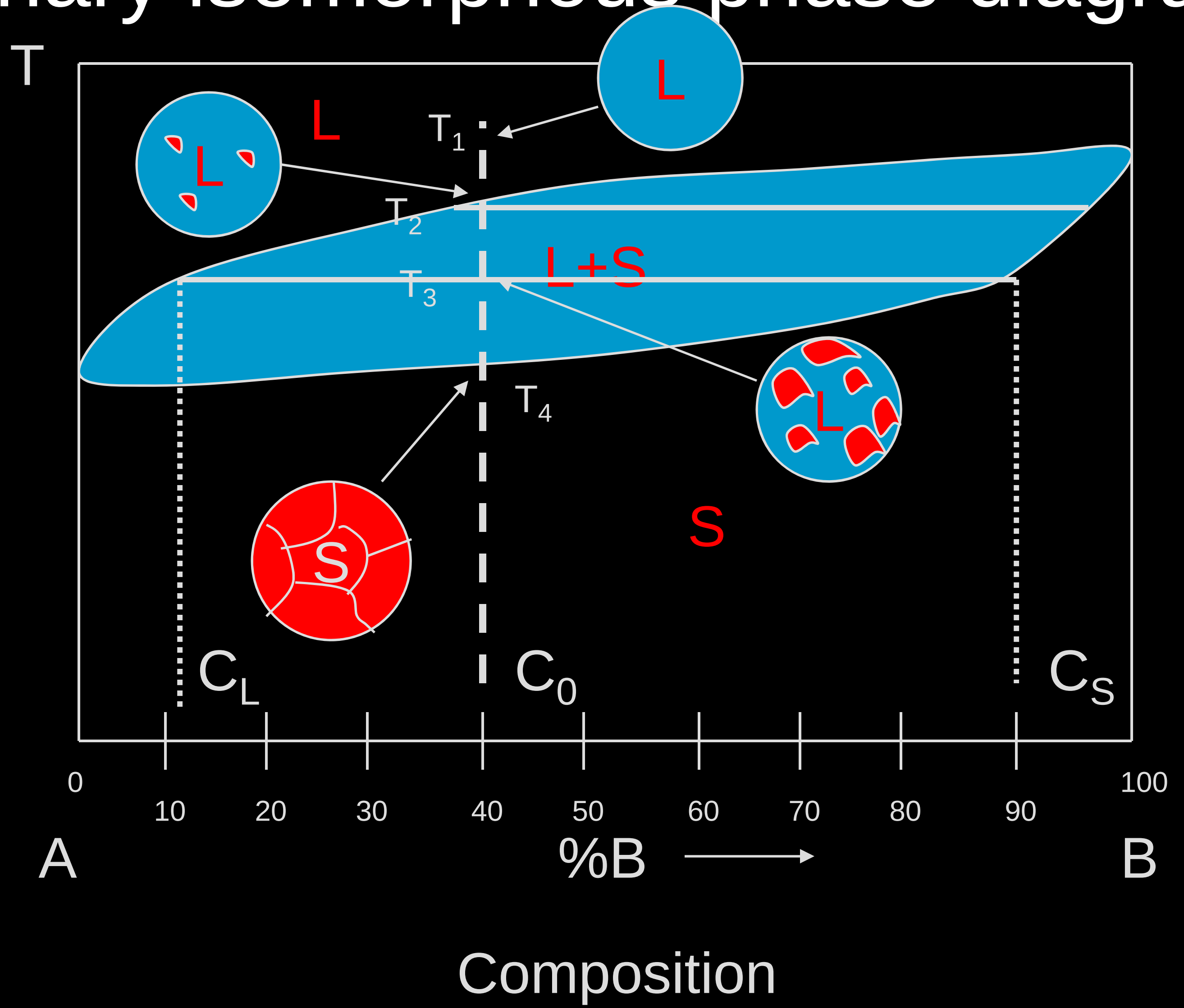
Pure metal



Microstructural changes during solidification



Binary isomorphous phase diagram



Notes

- This is an equilibrium phase diagram (slow cooling)
- The phase boundary which separates the L from the L+S region is called LIQUIDUS
- The phase boundary which separates the S from the L+S region is called SOLIDUS
- The horizontal (isothermal) line drawn at a specific temperature is called the TIE LINE
- The tie line can be meaningfully drawn only in a two-phase region
- The average composition of the alloy is C_O

Notes…..

- The intersection of the tie line with the liquidus gives the composition of the liquid, C_L
- The intersection of the tie line with the solidus gives the composition of the solid, C_S
- By simple mass balance,

$$C_O = f_S C_S + f_L C_L$$

and $f_S + f_L = 1$

$$C_O = f_S C_S + (1 - f_S) C_L$$

$$f_S = \frac{C_O - C_L}{C_S - C_L}$$

Lever Rule

$$f_L = \frac{C_S - C_O}{C_S - C_L}$$

Some calculations

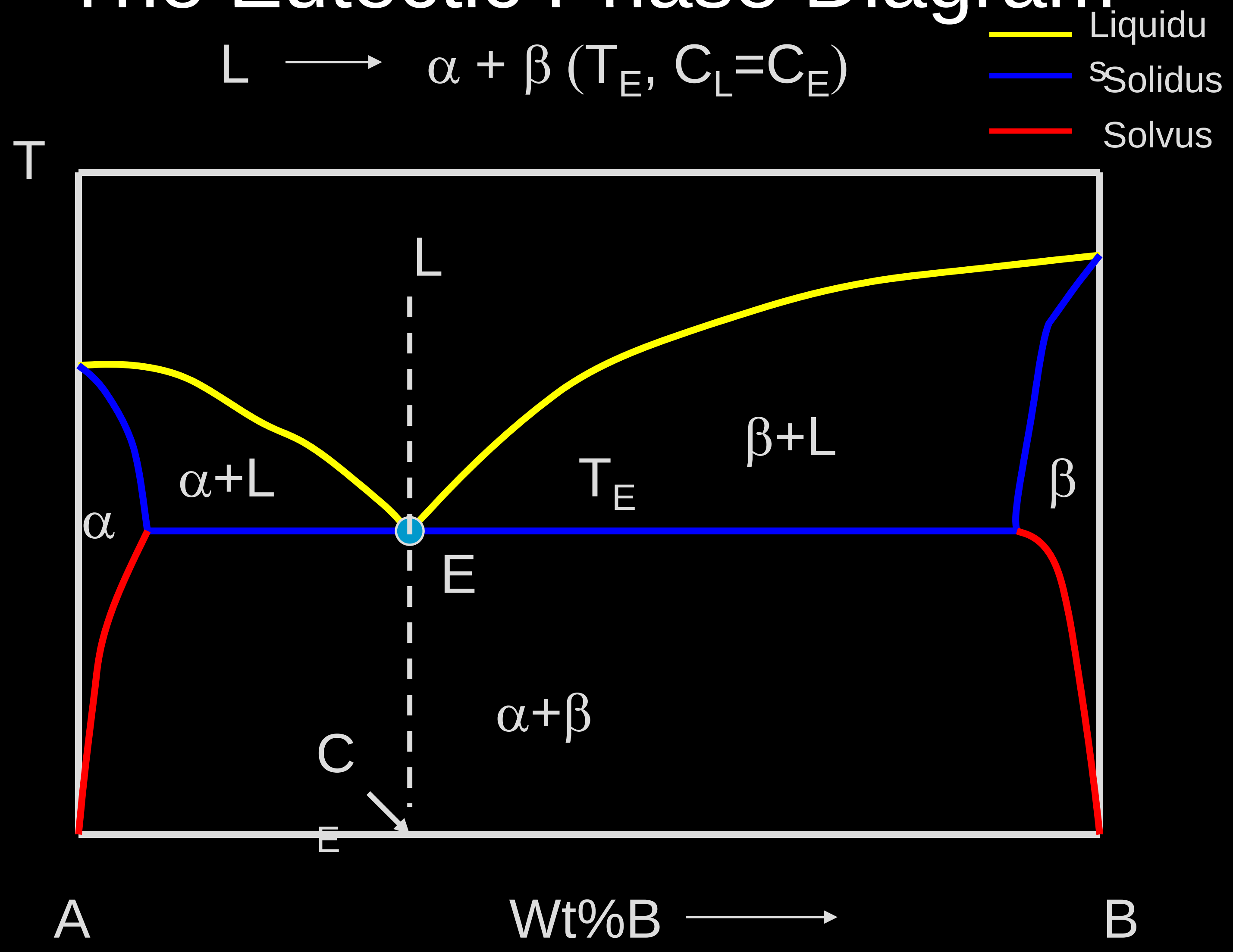
- In our diagram at T_3, C_O= A-40%B, C_S=A-90%B and C_L=A-11%B

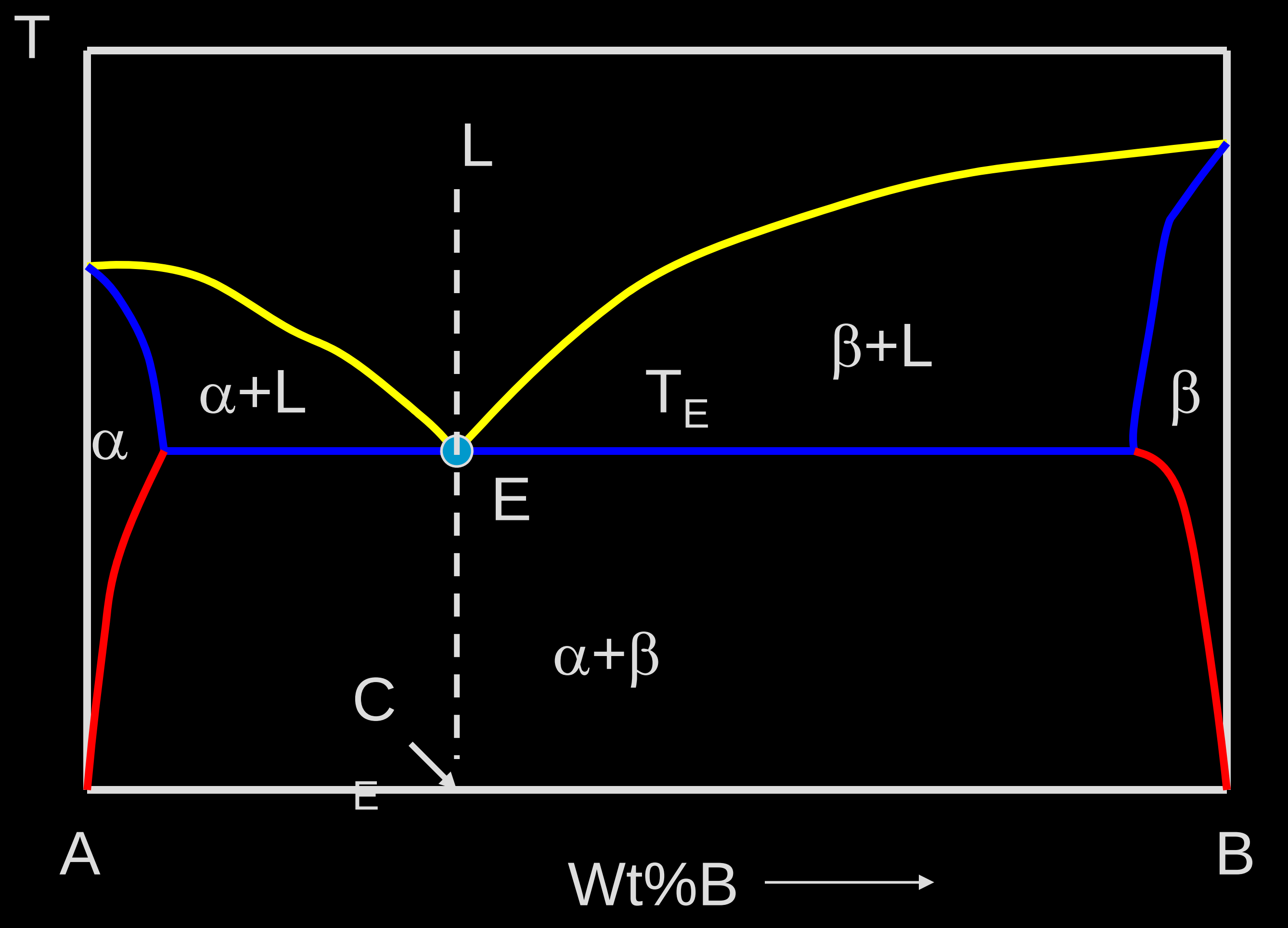
- Therefore, f_S=29/79 or 37% and
  f_L=50/79 or 63%
- If we take an initial amount of alloy =100 g,

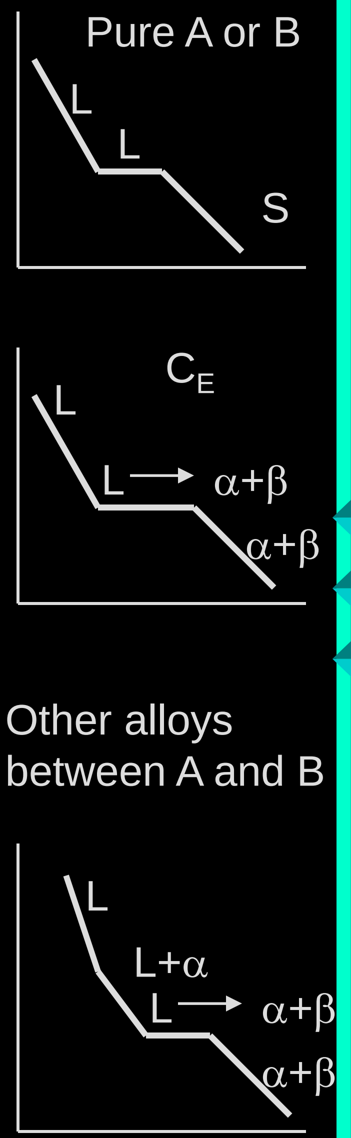
amt. of solid=37 g (3.7 g of A and 33.4 g of B) and amt. of liquid=63 g (56.07 g of A and 6.93 g of B)

The Eutectic Phase Diagram

$L \longrightarrow \alpha + \beta \; (T_E, C_L = C_E)$

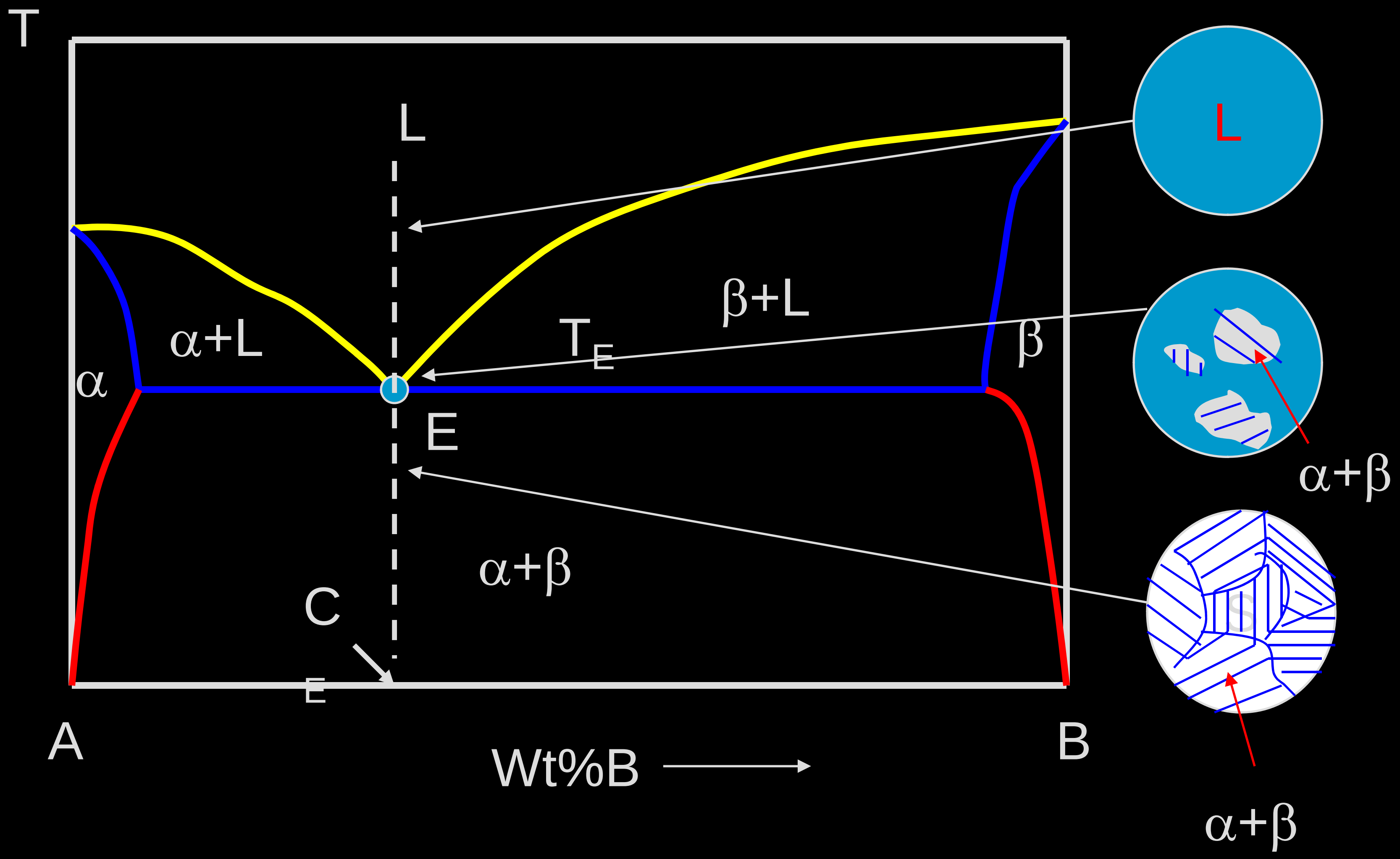





Pure A or B

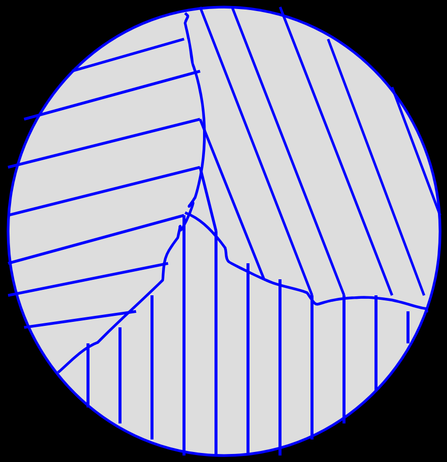
Other alloys between A and B

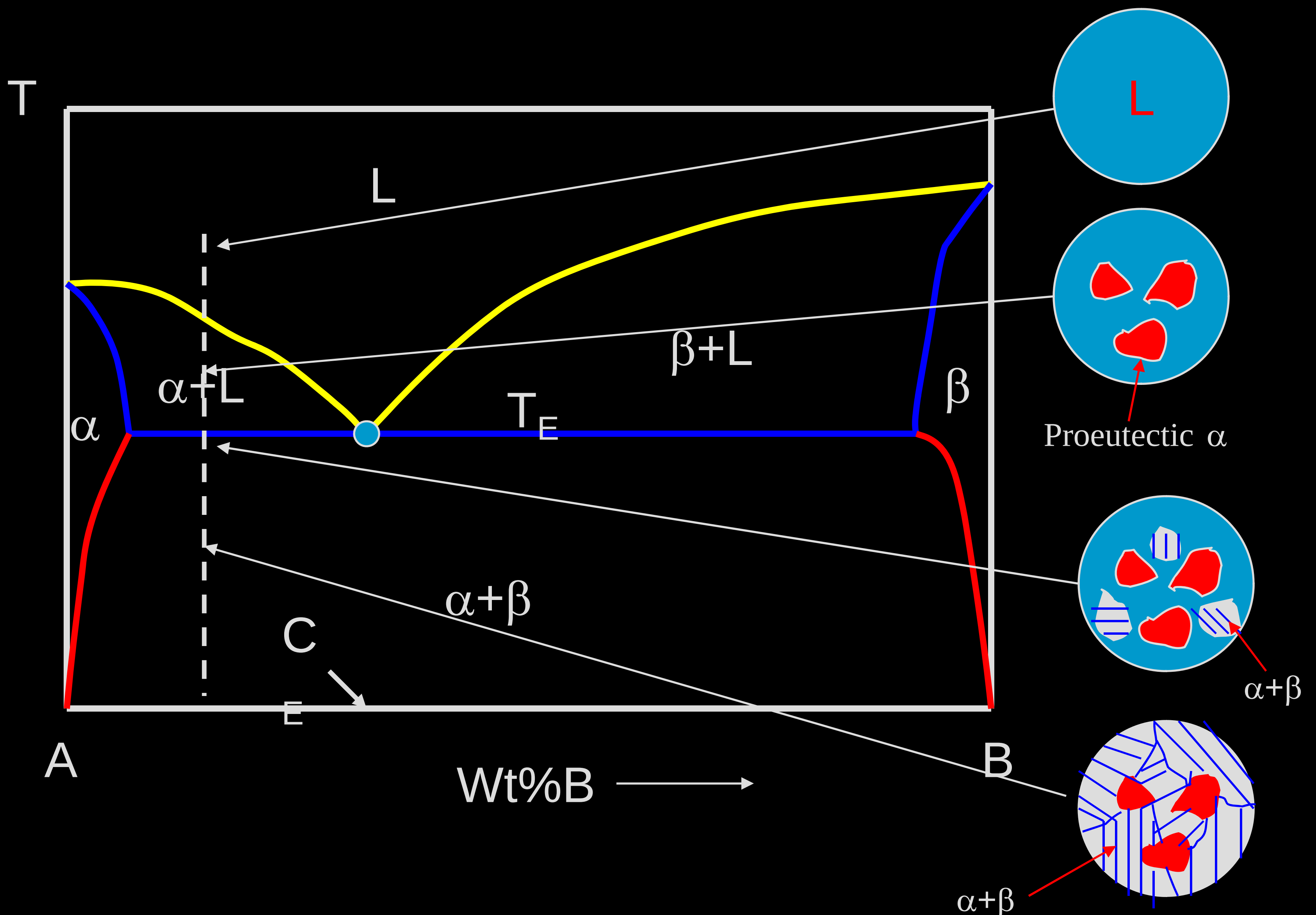
Solidification for alloy of eutectic composition

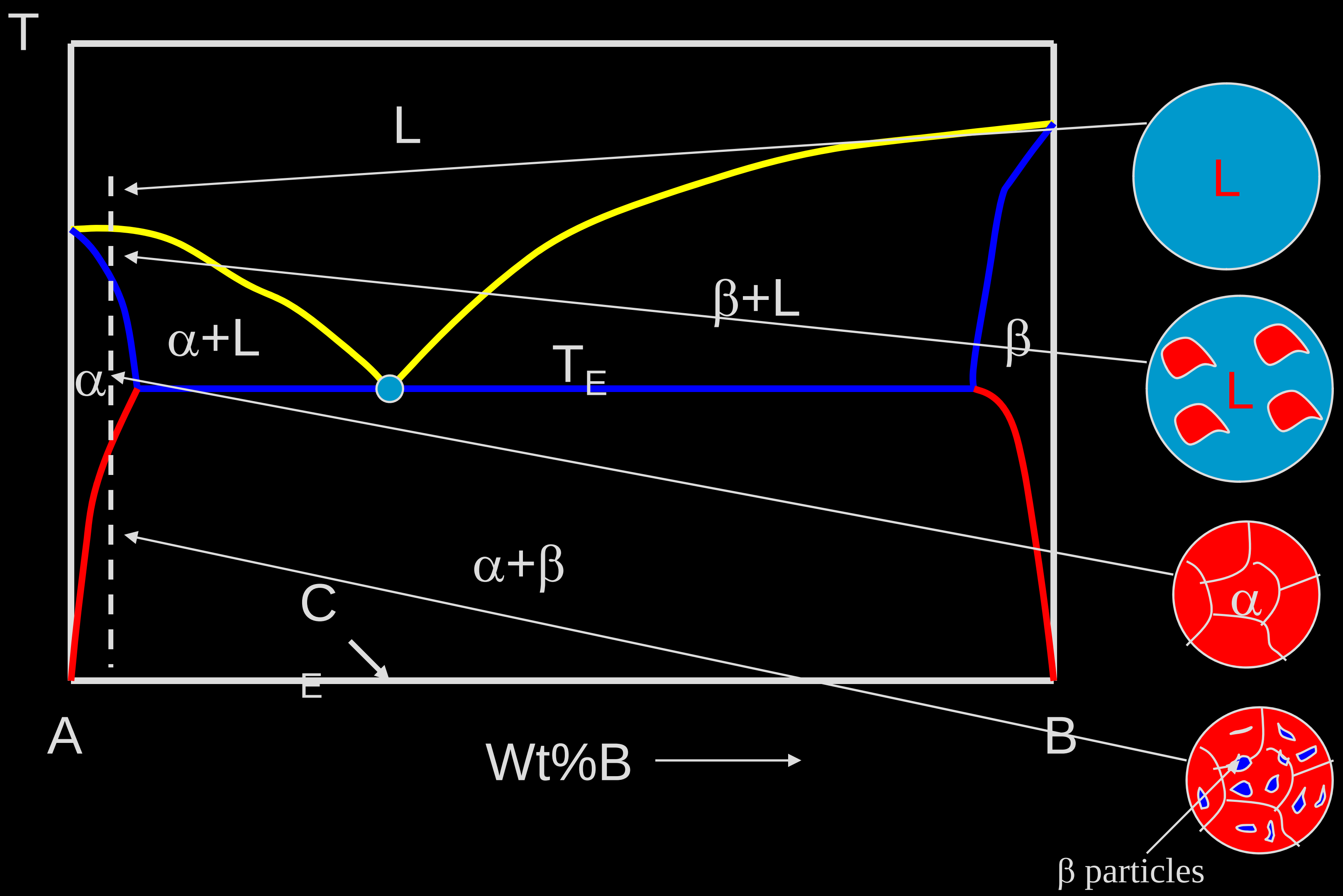


Eutectic microstructure

Lamellar structure

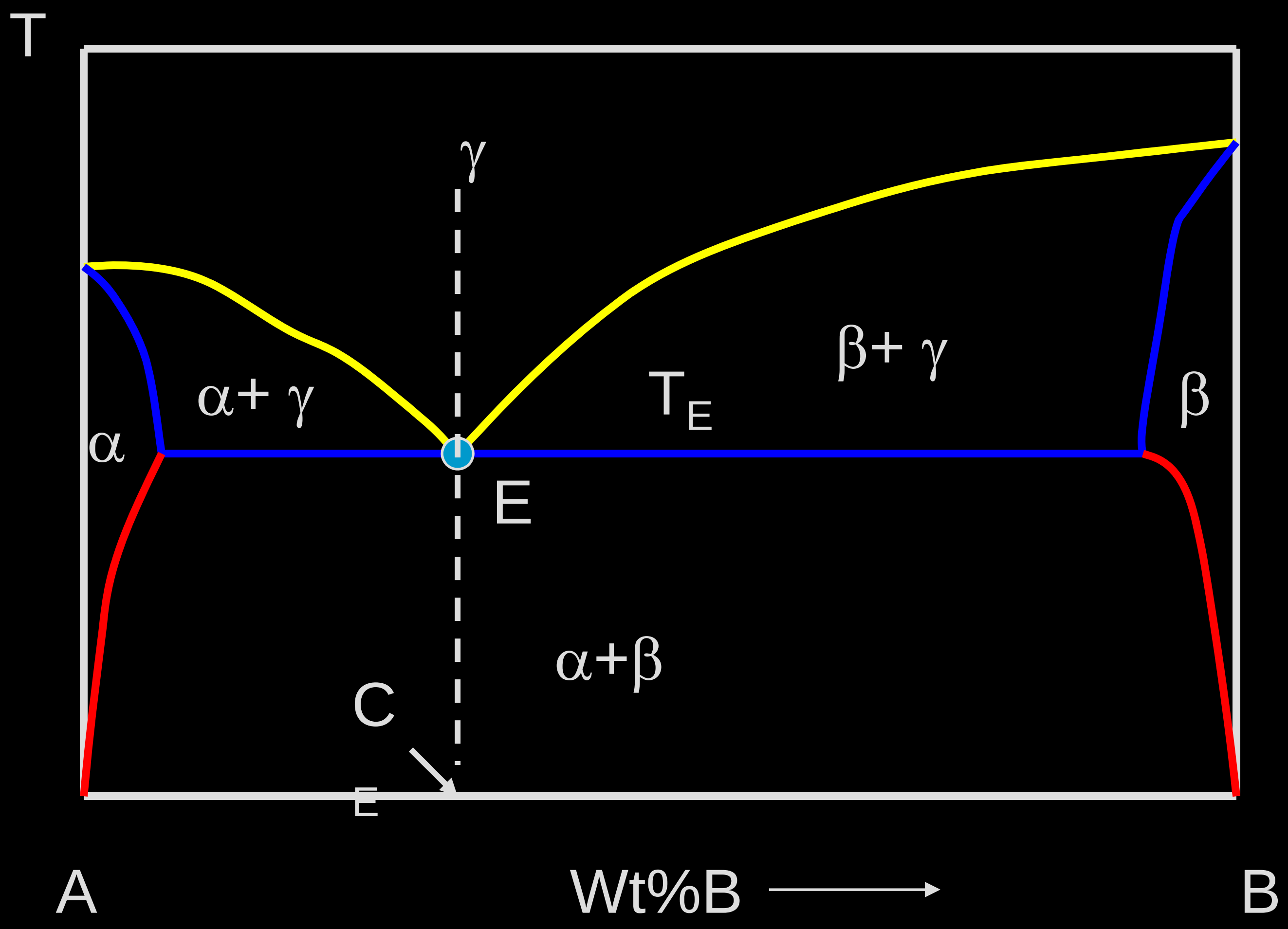



T
L
α+L
α
β+L
T_E
β
α+β
C
E
A
B
Wt%B
L
Proeutectic α
α+β
α+β

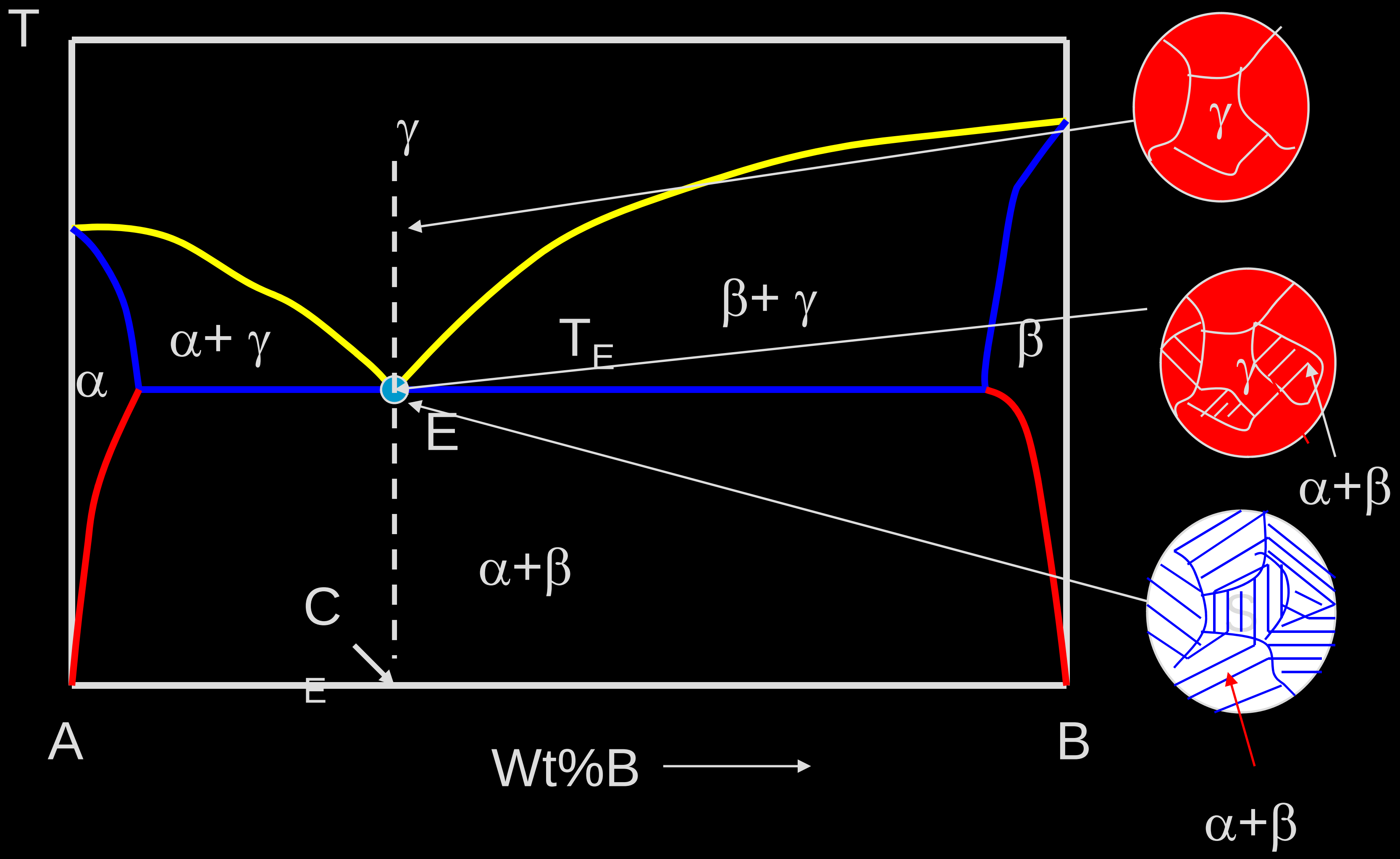

T
L
α+L
β+L
β
α
T_E
α+β
C
E
A
B
Wt%B →
L
L
α
β particles

The Eutectoid Phase Diagram

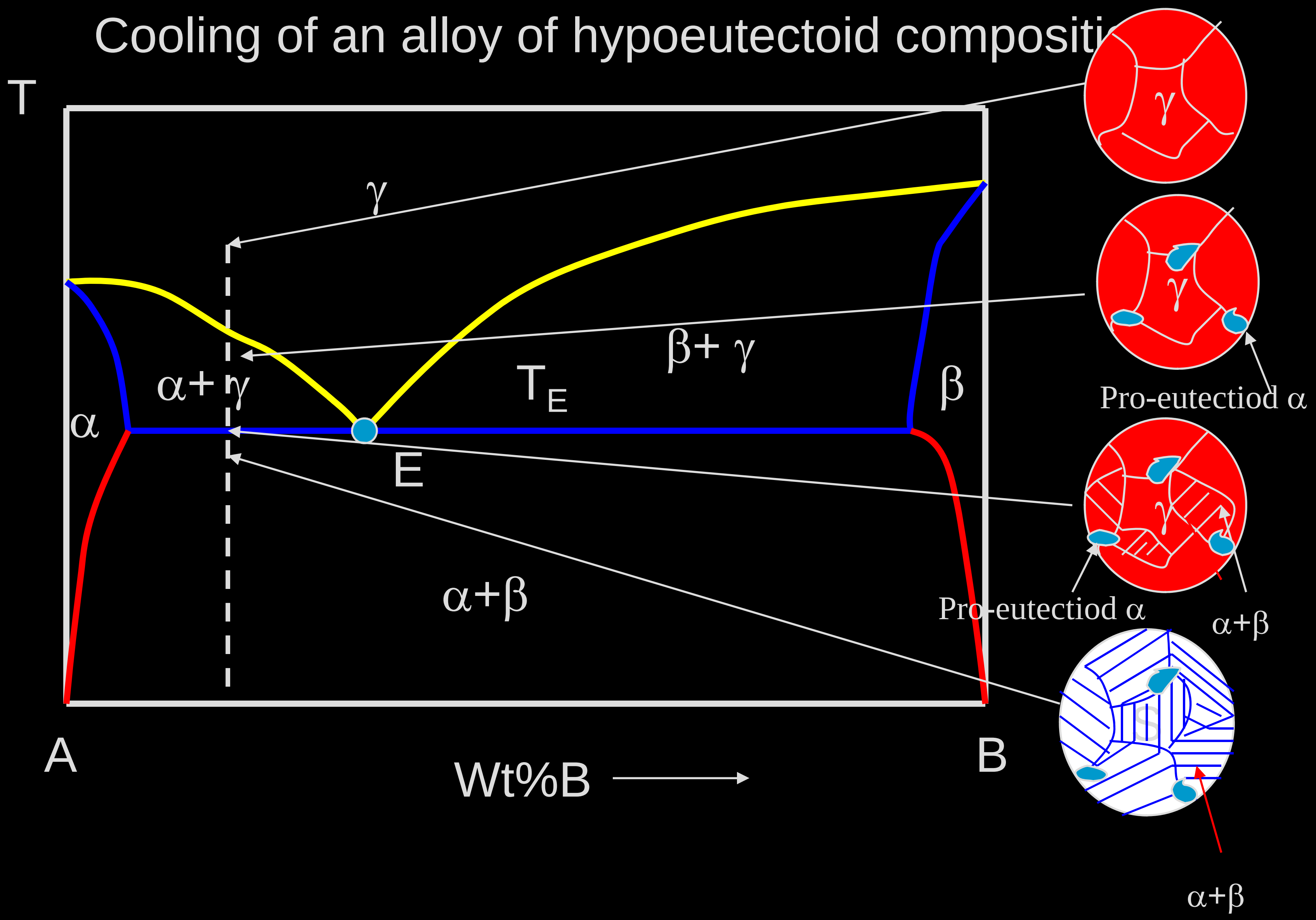
$$\gamma \longrightarrow \alpha + \beta\ (T_E,\ C_\gamma = C_E)$$



Cooling of an alloy of eutectoid composition



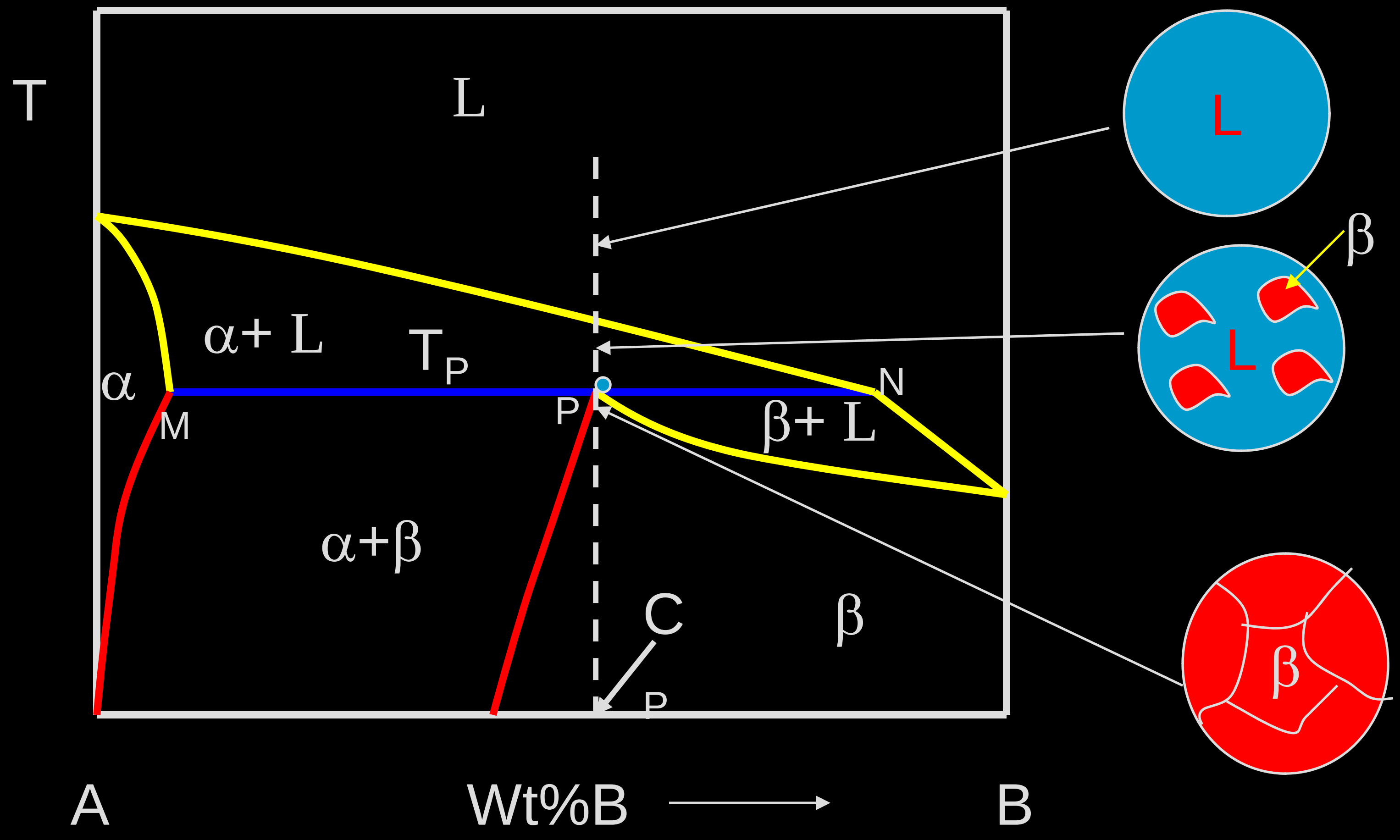
Cooling of an alloy of hypoeutectoid compositi



The Peritectic Phase Diagram

$$\alpha + L \longrightarrow \beta \text{ (at } T_P\text{)}$$

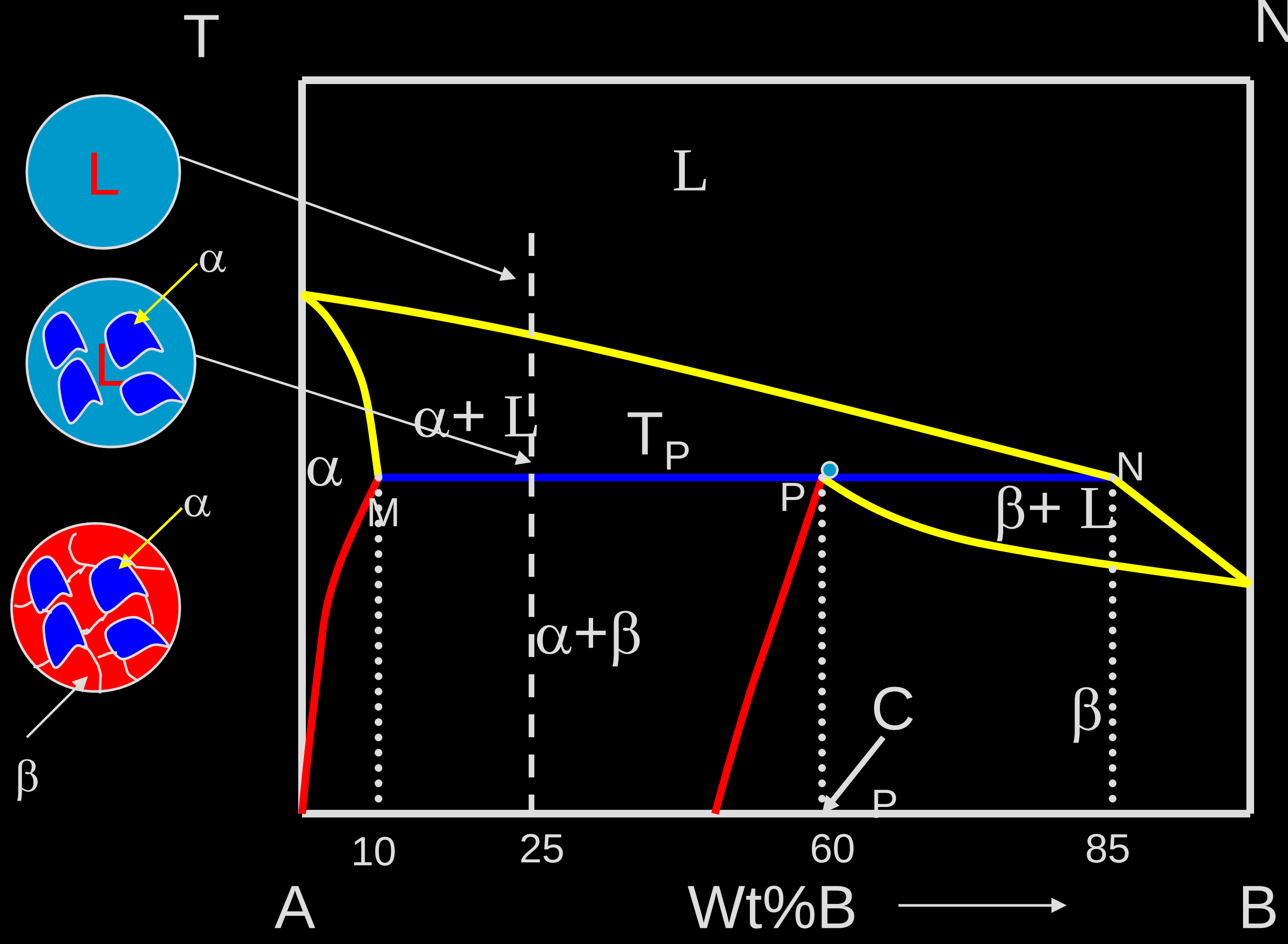
Note: α and L will react only in a certain proportion= NP:PM



$$\alpha + L \longrightarrow \beta \text{ (at } T_P\text{)}$$

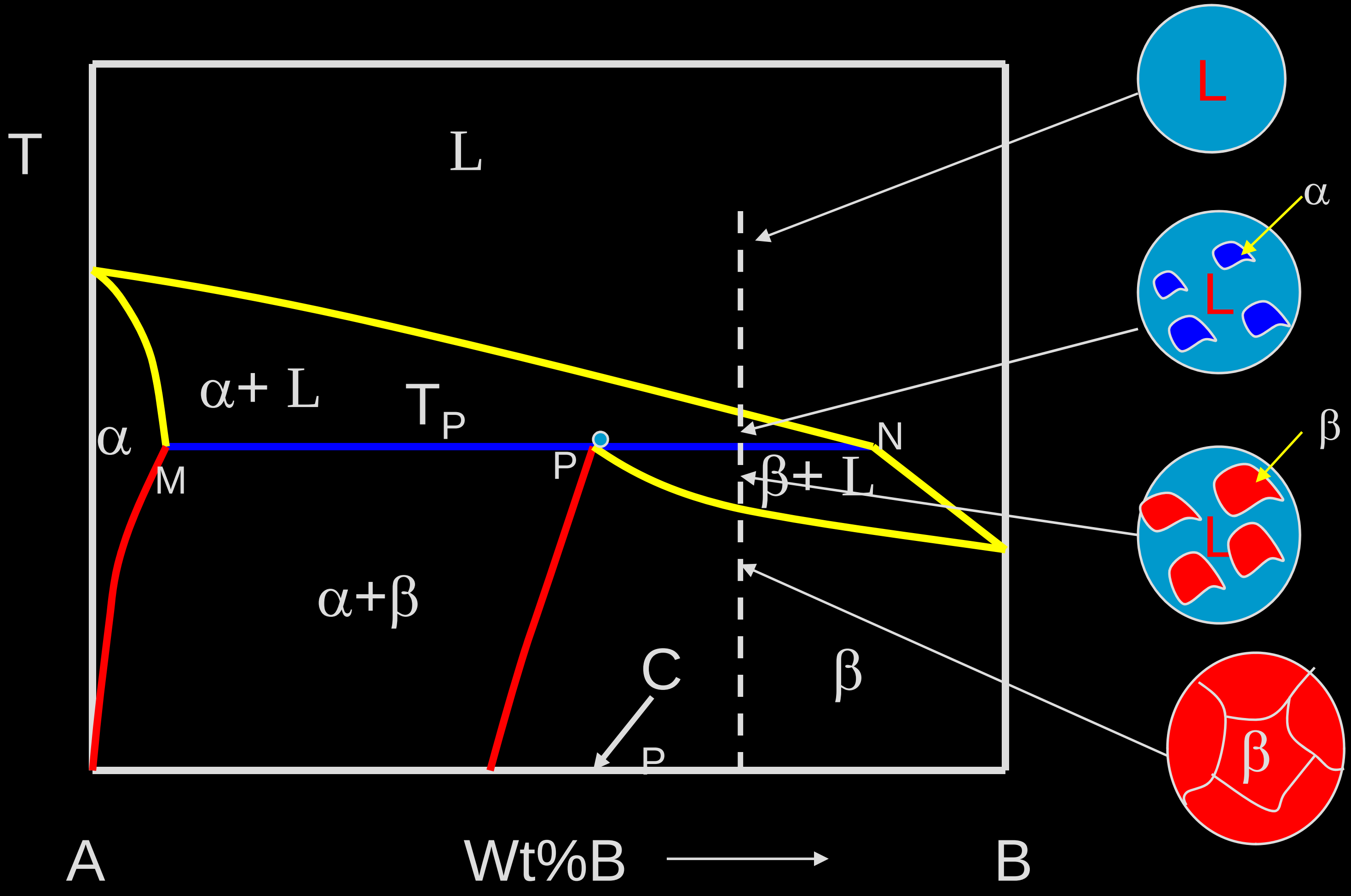
Note: α and L will react only in a certain proportion= NP:PM

NP:PM=1:2



$$\alpha + L \longrightarrow \beta \text{ (at } T_P\text{)}$$

Note: α and L will react only in a certain proportion= NP:PM



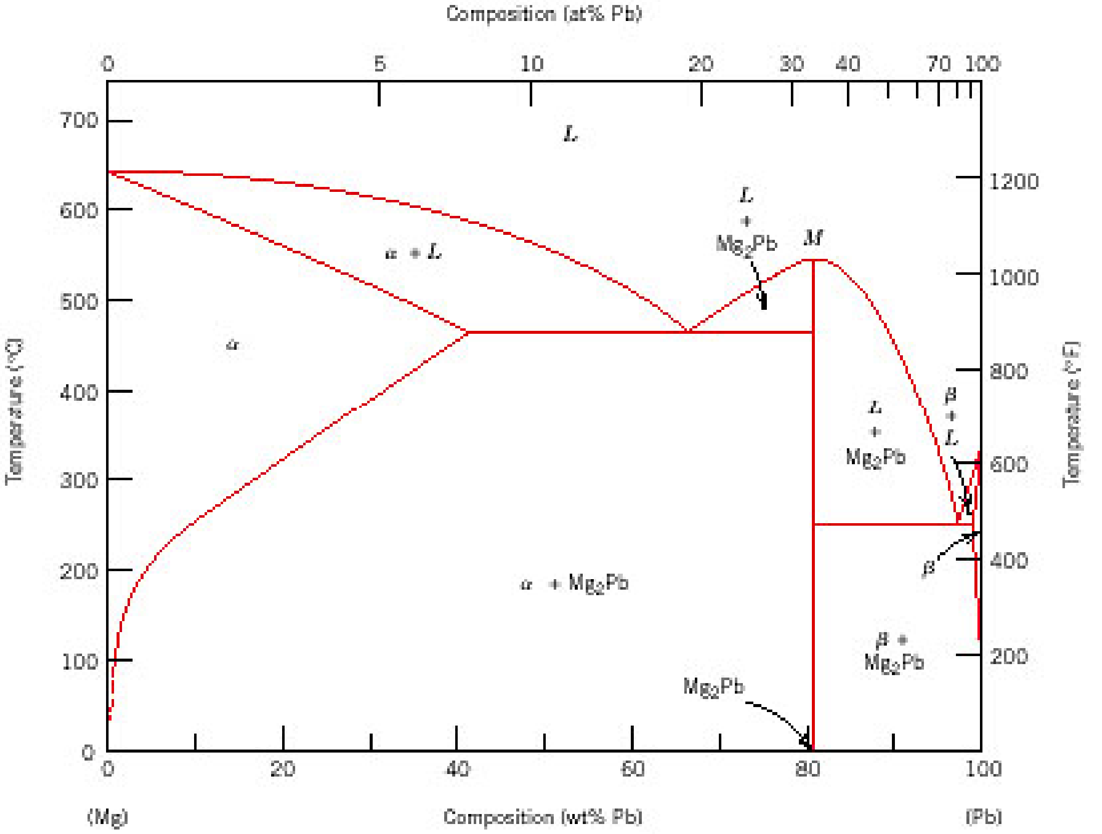


FIGURE 9.18 The magnesium–lead phase diagram. (Adapted from *Phase Diagrams of Binary Magnesium Alloys,* A. A. Nayeb-Hashemi and J. B. Clark, Editors, 1988. Reprinted by permission of ASM International, Materials Park, OH.)

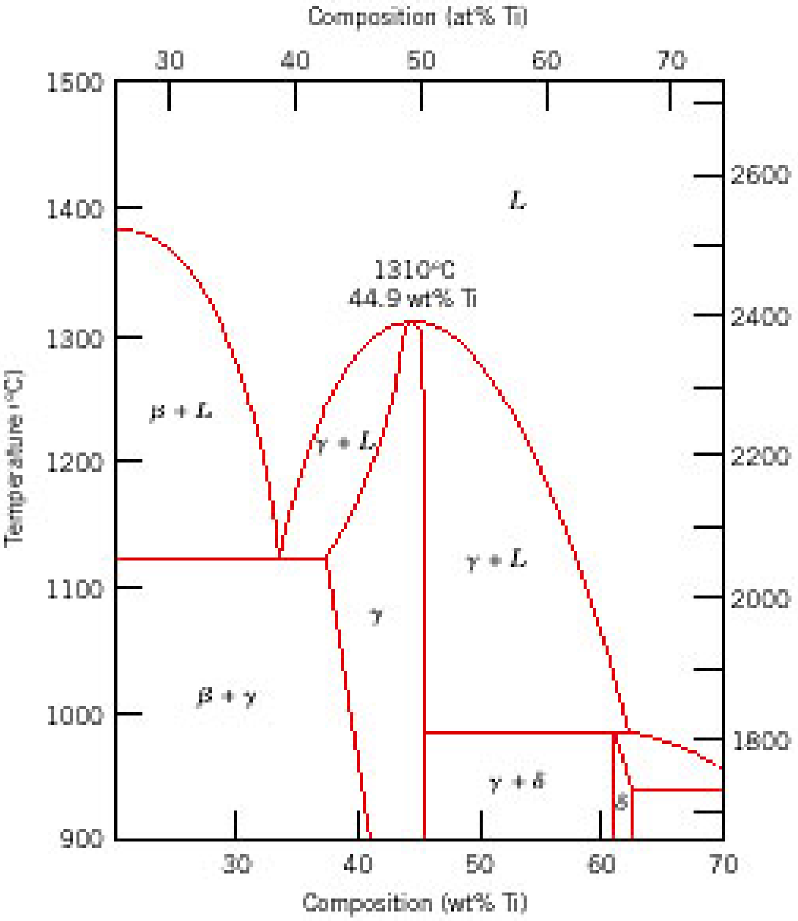


Figure 9.20 A portion of the nickel–titanium phase diagram on which is shown a congruent melting point for the γ phase solid solution at 1310°C and 44.9 wt% Ti. (Adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash, Editor, 1991. Reprinted by permission of ASM International, Materials Park, OH.)

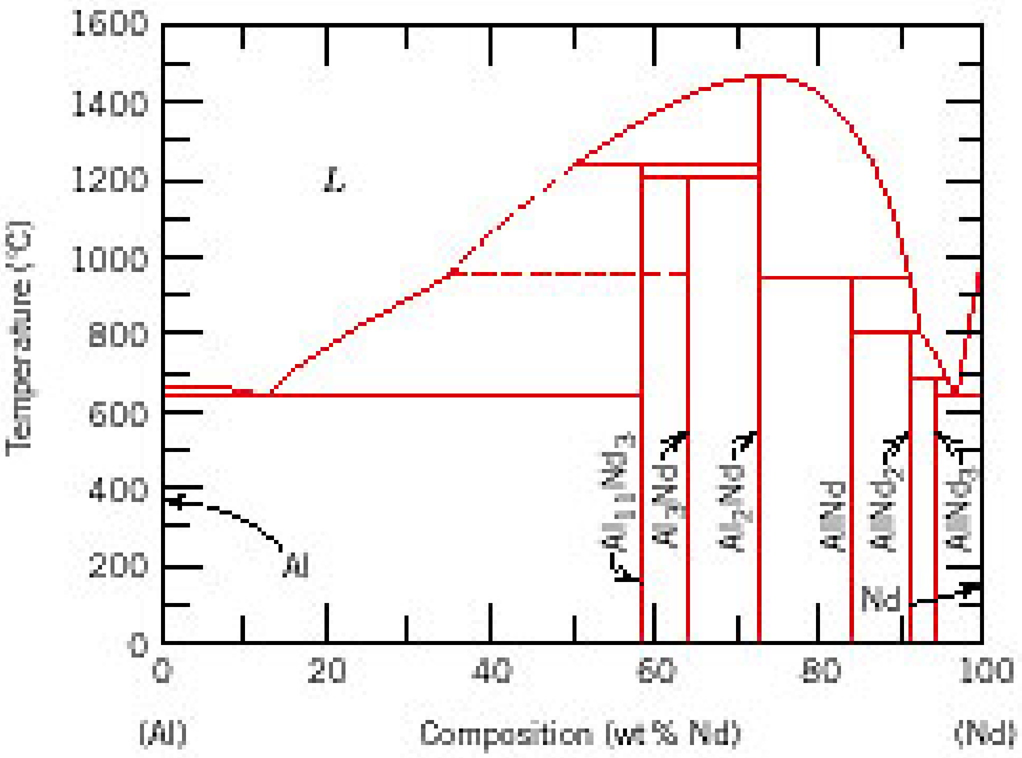


FIGURE 9.35 The aluminum–neodymium phase diagram. (Adapted from *ASM Handbook*, Vol. 3, *Alloy Phase Diagrams*, H. Baker, Editor, 1992. Reprinted by permission of ASM International, Materials Park, OH.)

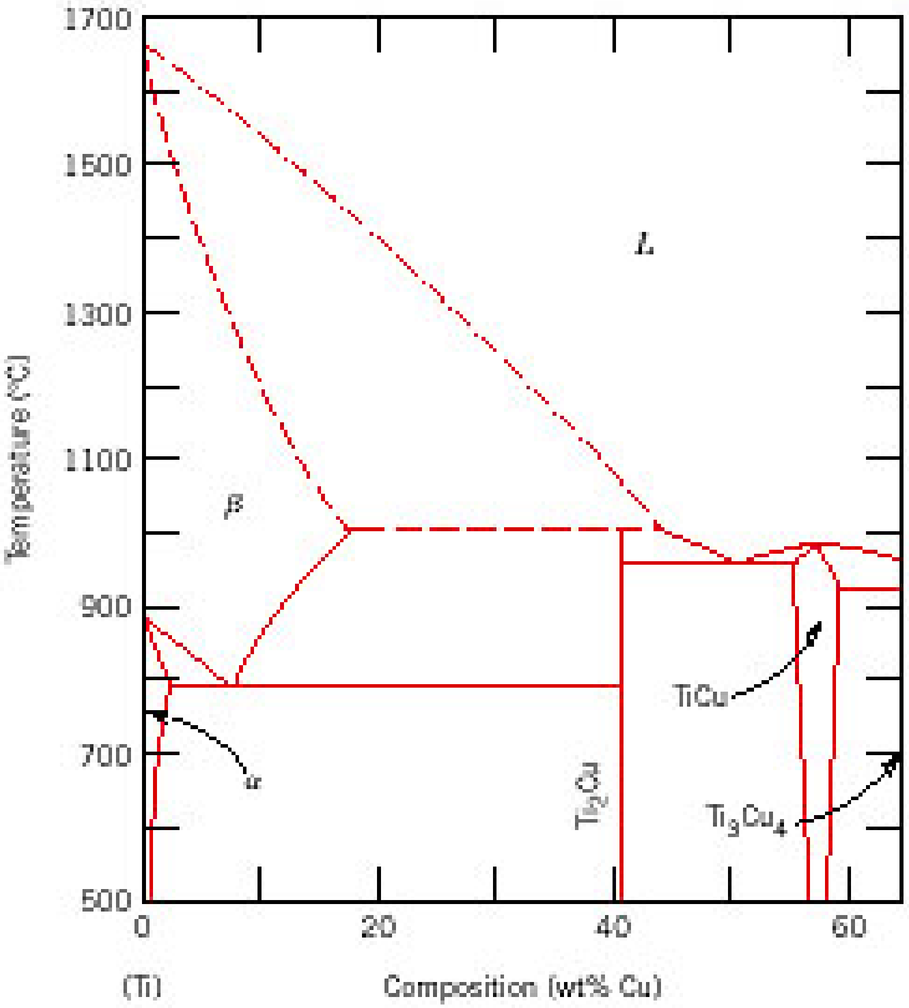


FIGURE 9.36 The titanium–copper phase diagram. (Adapted from *Phase Diagrams of Binary Titanium Alloys*, J. L. Murray, Editor, 1987. Reprinted by permission of ASM International, Materials Park, OH.)

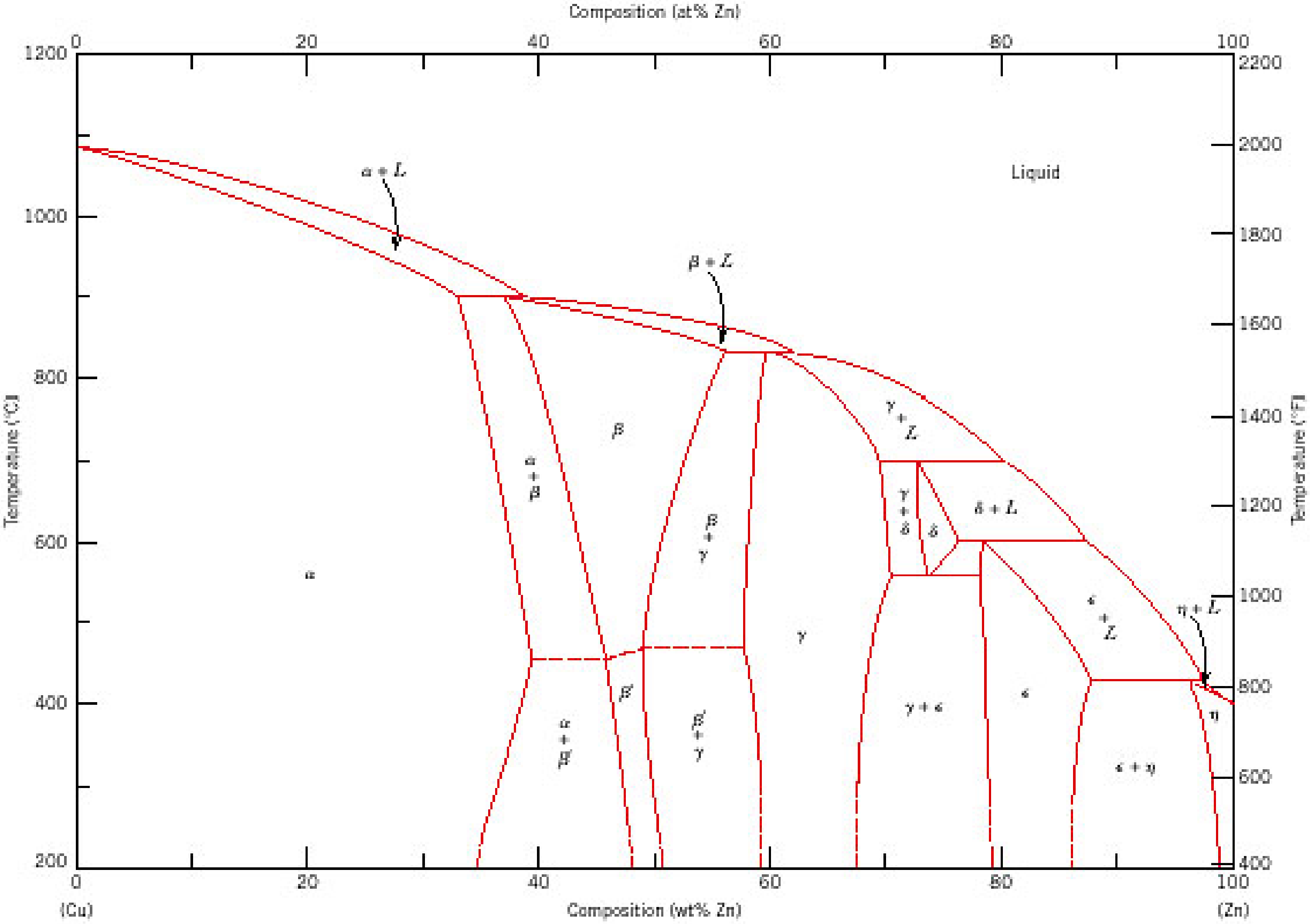


FIGURE 9.17 The copper–zinc phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 2, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)

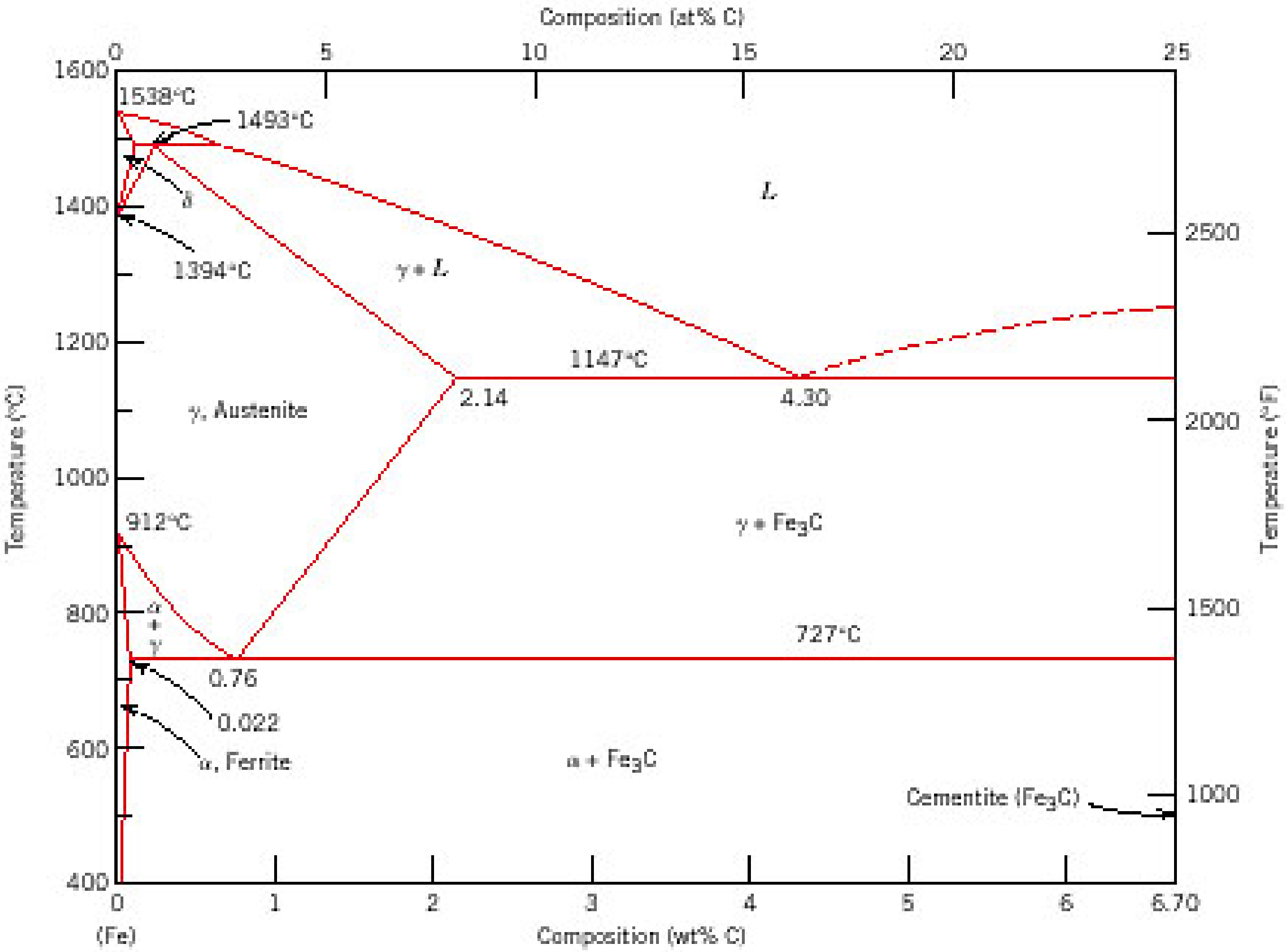


FIGURE 9.22 The iron–iron carbide phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)