MLL 100

Introduction to Materials Science and Engineering

Lecture-18 (February 22, 2022)

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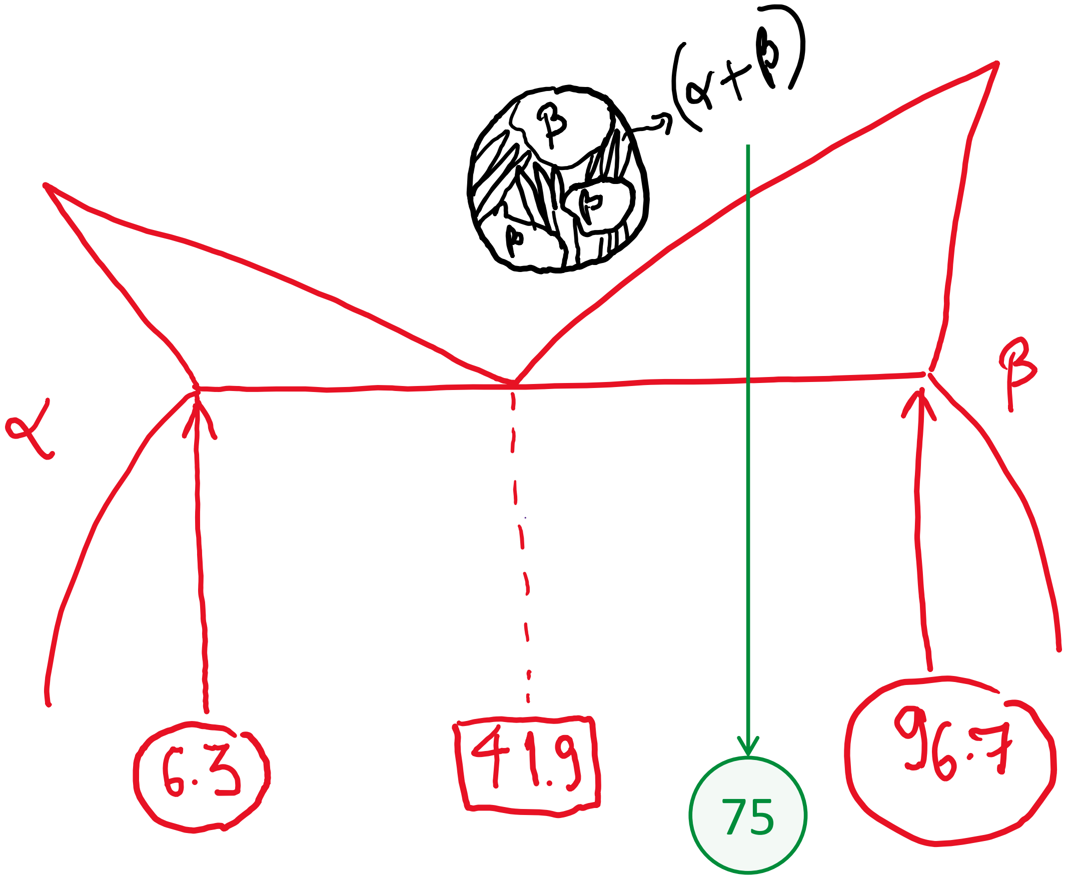
P-Q forms an eutectic phase diagram with an eutectic composition of 41.9 wt.% Q at an eutectic temperature of 200 ºC. The two terminal solid solutions, α and β have respective compositions of 6.3 wt.% Q and 96.7 wt.% Q at 200 ºC. What percentage of the β phase (in %) constitutes the eutectic mixture just at a temperature below 200 ºC for an alloy with a composition of 75.0 wt.% Q? Write your answer up to two decimal places and in %.



$$\rightarrow \beta = \left(\frac{75 - 41.9}{96.7 - 41.9}\right) = 60.4\,\%$$

$$L = 39.6\,\%$$

$$\rightarrow \alpha = \left(\frac{96.7 - 75}{96.7 - 6.3}\right) = 24\,\%$$

24 % of a part of 39.6 % L

$$\therefore \begin{cases} 60.6\,\% \text{ of } \alpha \text{ in E.M} \\ 39.39\,\% \text{ of } \beta \text{ in E.M} \end{cases}$$

What have we learnt in Lecture-17?

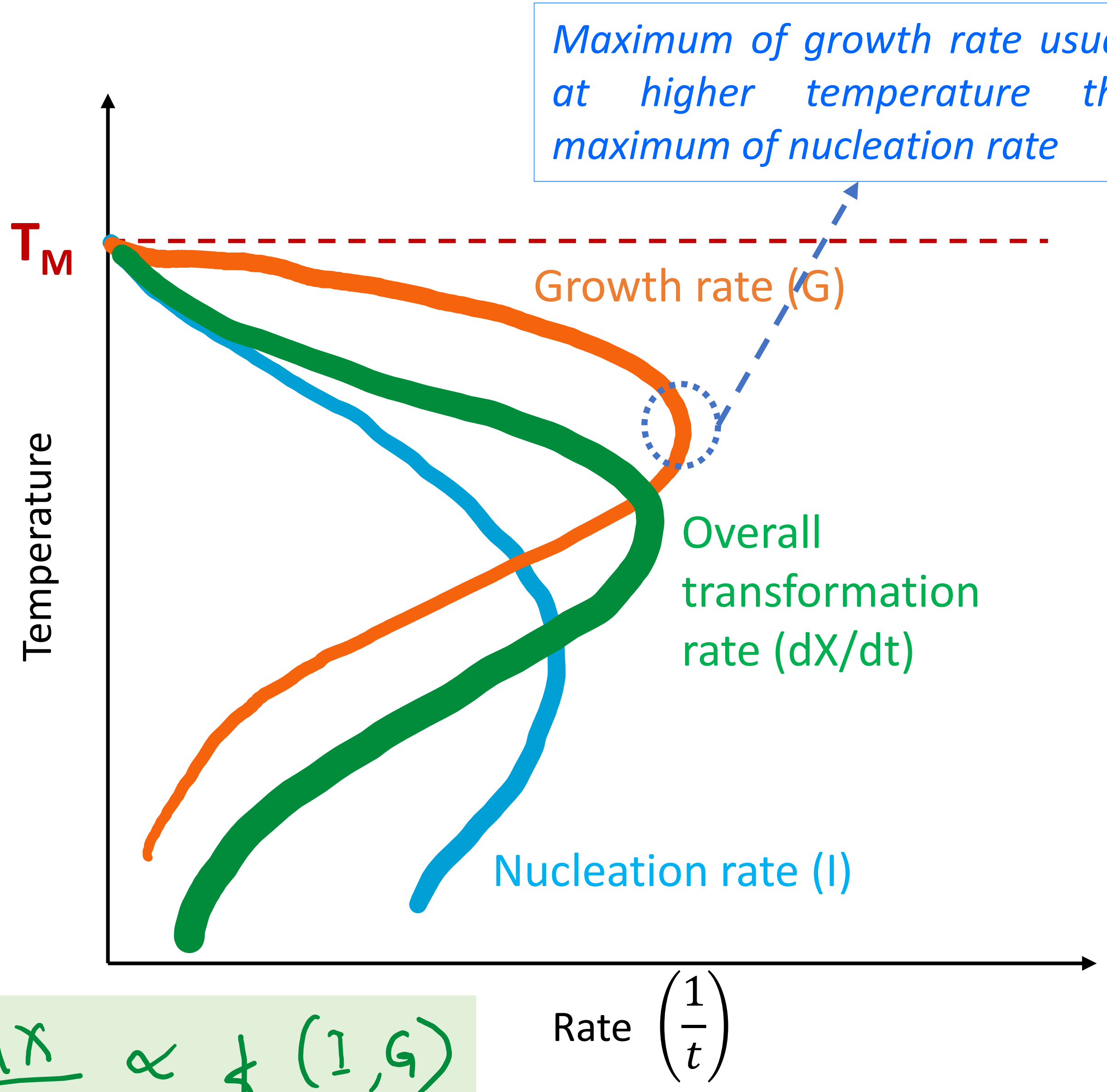
- ❑ Nucleation and growth rate
- ❑ Transformation rate
- ❑ Transformation curve: Start of the curve and nose of the curve

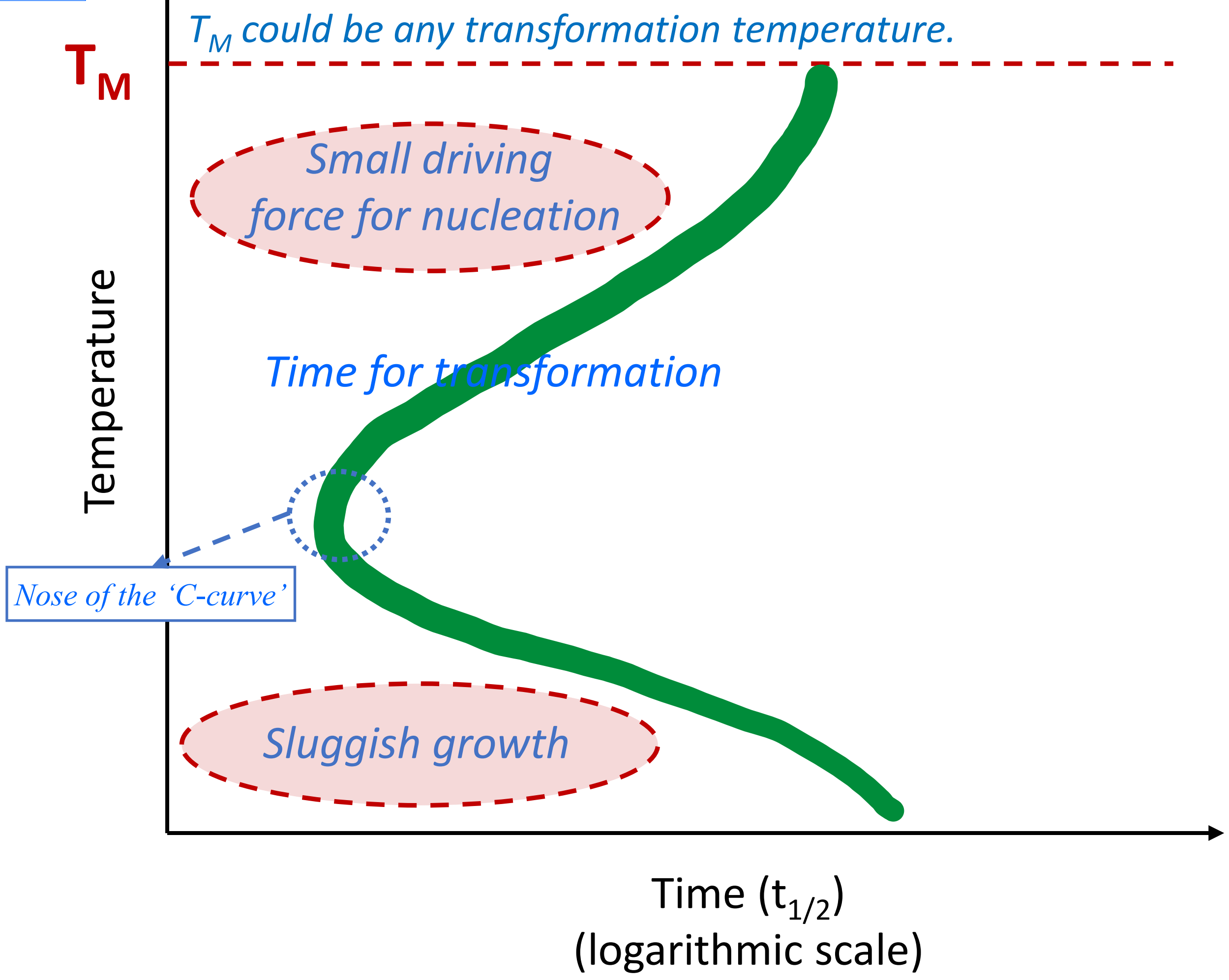
Fri (END)
Girlfri (END)
Boyfri (END)
Bestfri (END)

Everything has an end.

Let us see how a transformation of a material ends!!

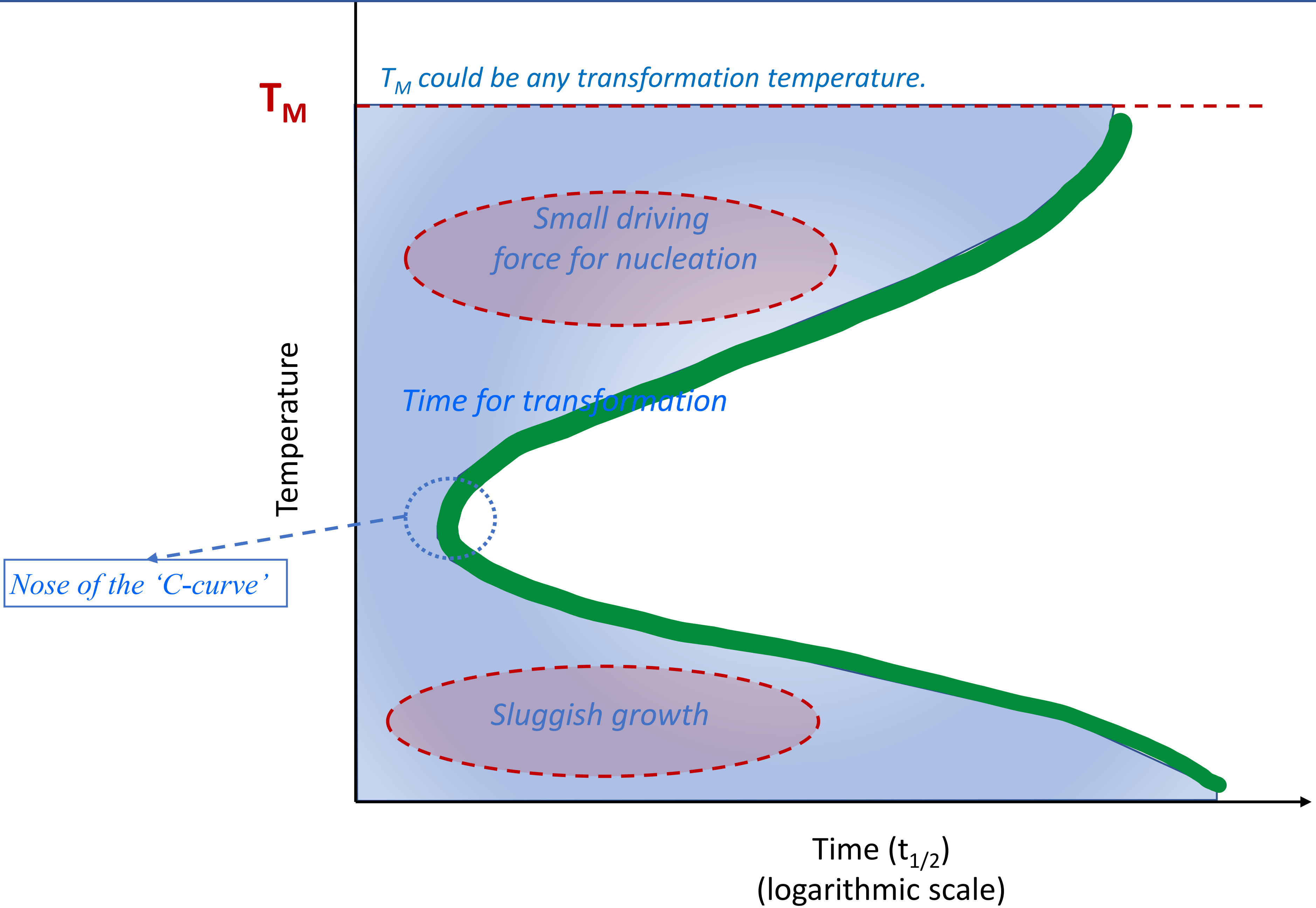
Transformation rate



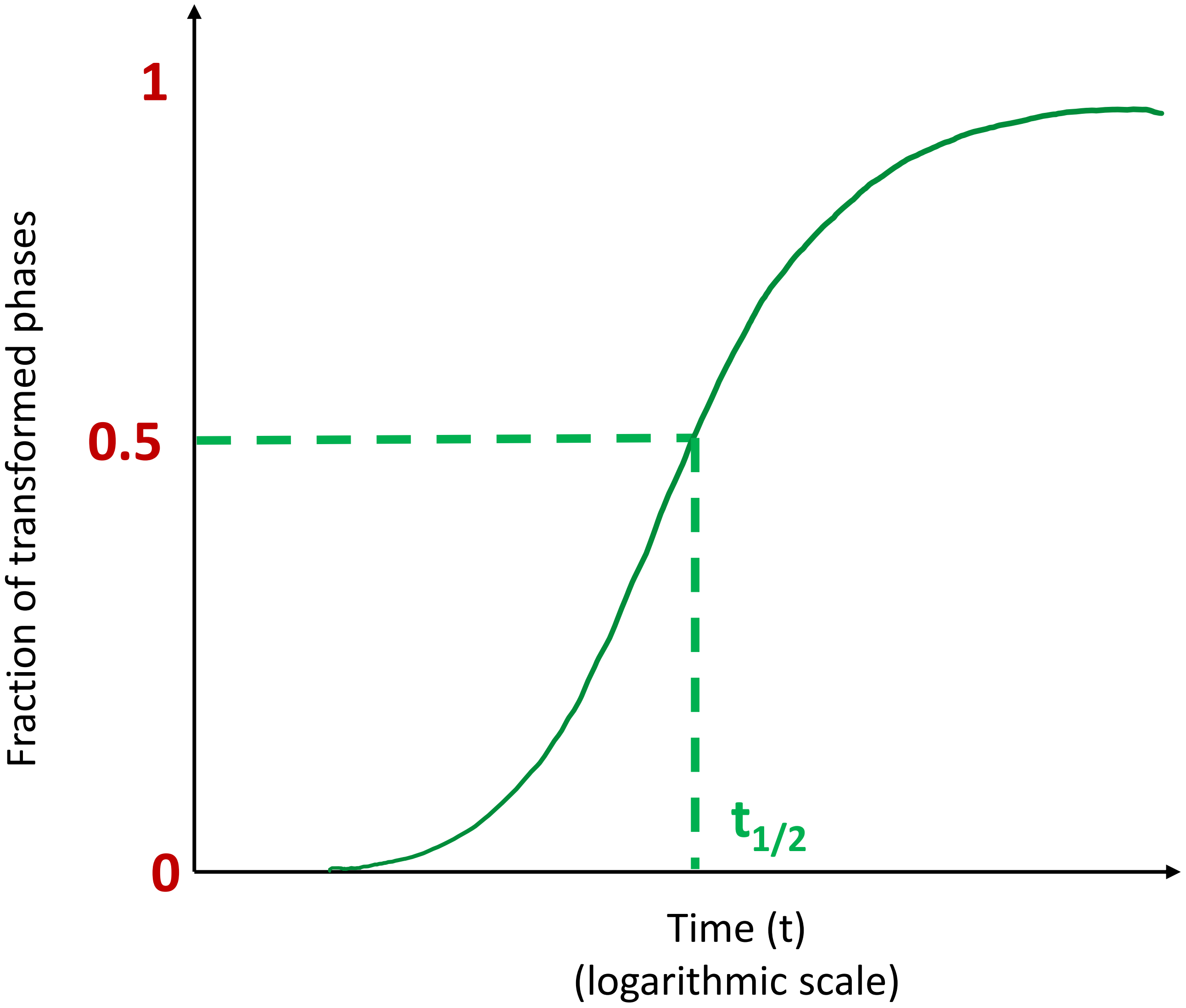


$$\frac{dx}{dt} \propto f(I, G)$$

Transformation rate



Avrami Equation

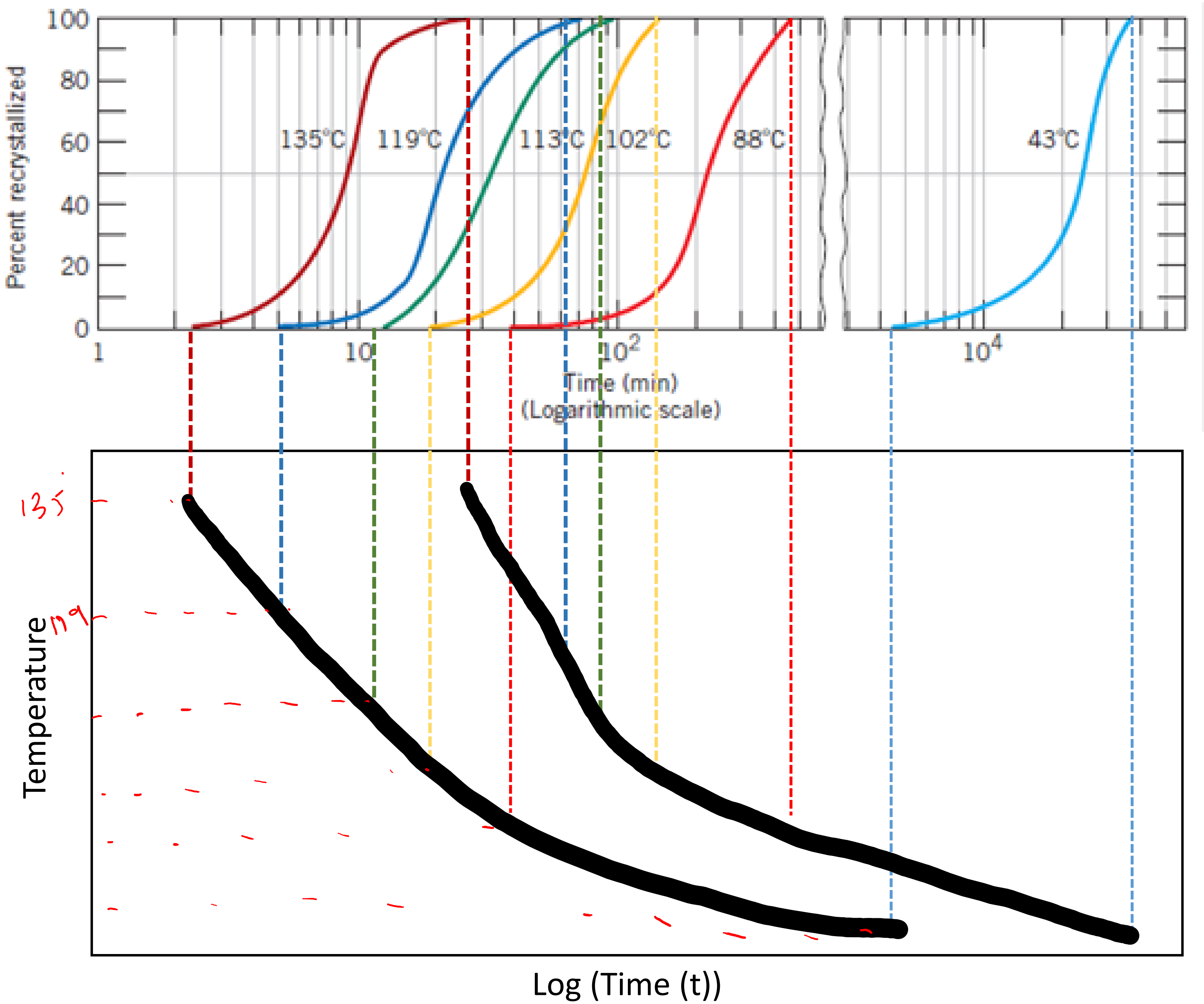


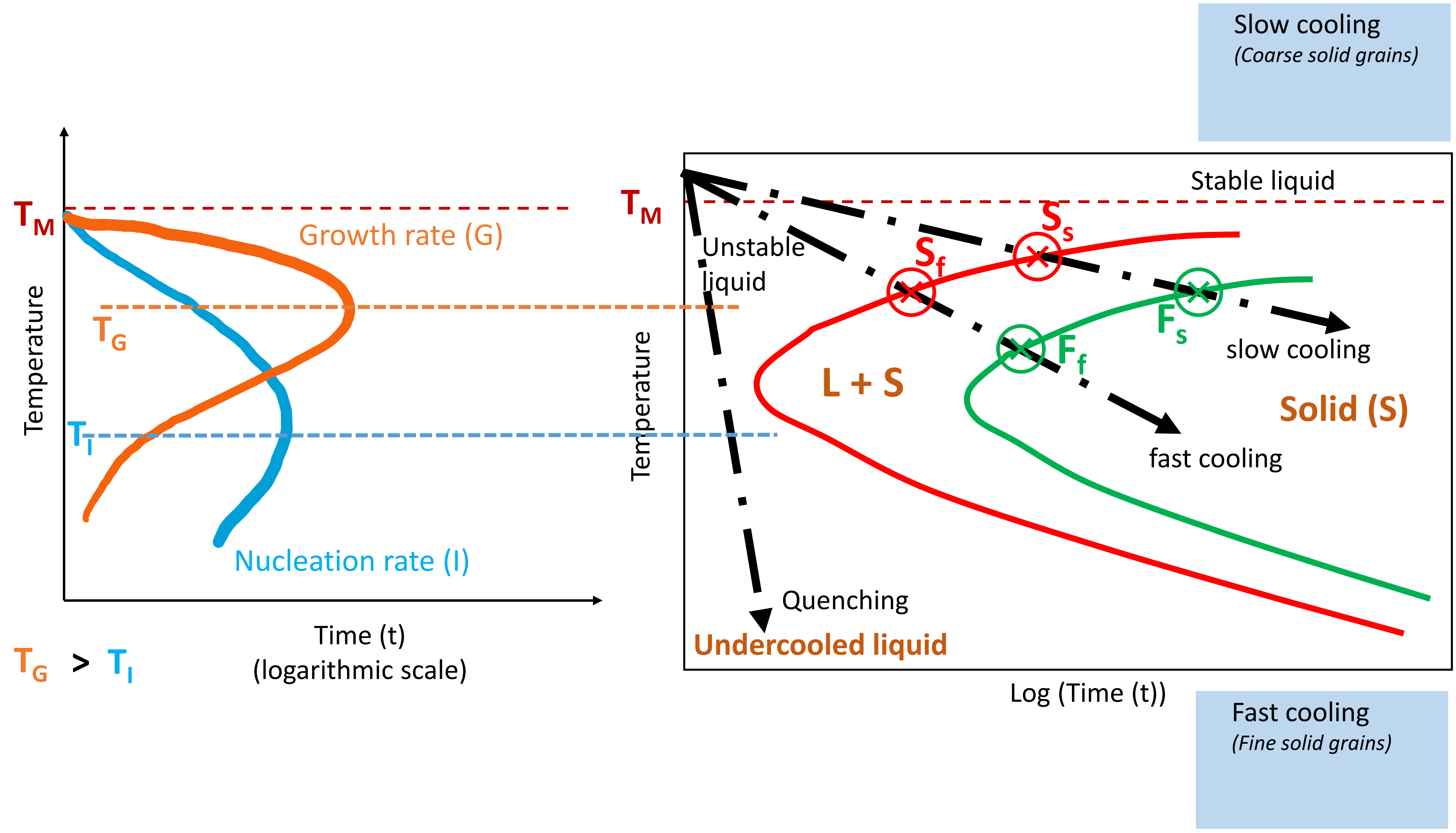
$$f \rightarrow \frac{volume\ fraction\ of\ \alpha\ at\ t}{final\ volume\ of\ \alpha}$$

$$\boxed{L \rightarrow \alpha}$$

$$f \rightarrow volume\ fraction\ of\ \alpha$$

Fraction of transformed phases: $y = 1 - \exp(-kt^n)$


100
80
60
40
20
0
Percent recrystallized
135°C
119°C
113°C
102°C
88°C
43°C
1
10
10^2
10^4
Time (min)
(Logarithmic scale)
135
119
Temperature
Log (Time (t))



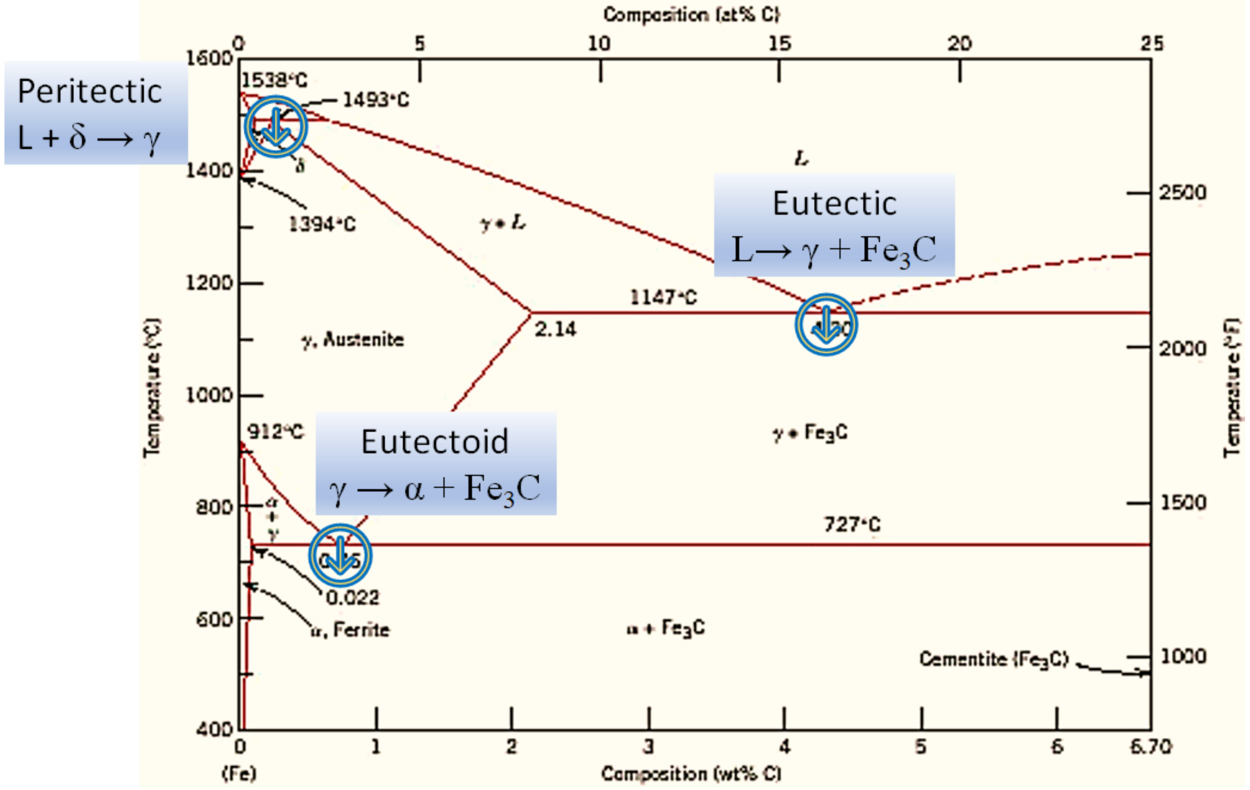
Slow cooling
(Coarse solid grains)
T_M
Growth rate (G)
T_G
Temperature
T_I
Nucleation rate (I)
Time (t)
(logarithmic scale)
$T_G > T_I$
T_M
Stable liquid
Unstable liquid
S_s
S_f
F_s
F_f
L + S
slow cooling
fast cooling
Solid (S)
Temperature
Quenching
Undercooled liquid
Log (Time (t))
Fast cooling
(Fine solid grains)

❑ Steel:

Iron (Fe)-based alloy containing C < 2.14 wt.%)

❑ Broad classification of steel based on the carbon content:

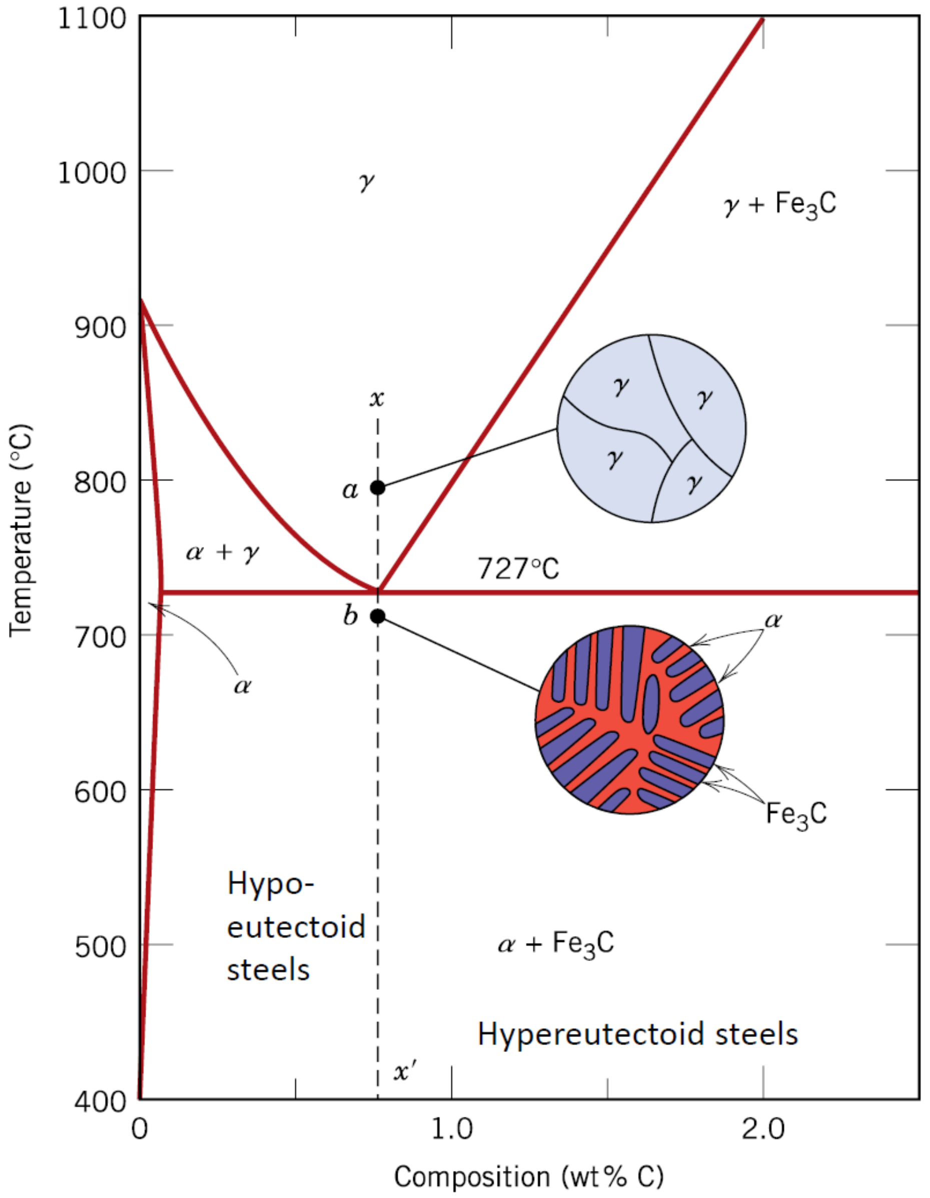
- Eutectoid steel (C ~ 0.8 wt.% C)
- Hypo-eutectoid steel (C < 0.8 wt.% C)
- Hyper-eutectoid steel (C > 0.8 wt.% C)

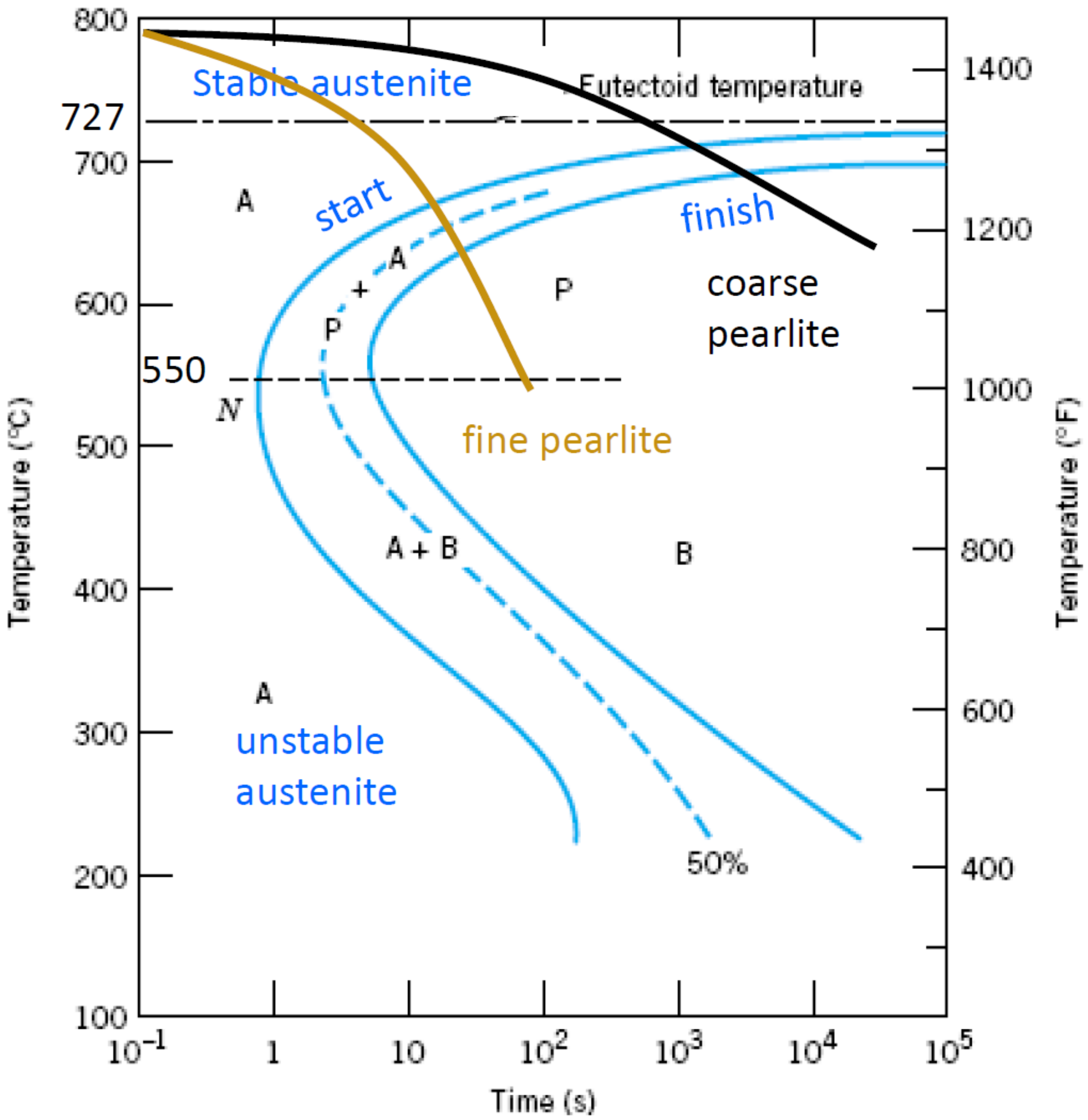


❑ What about the alloy with C > 2.14 wt.% C?

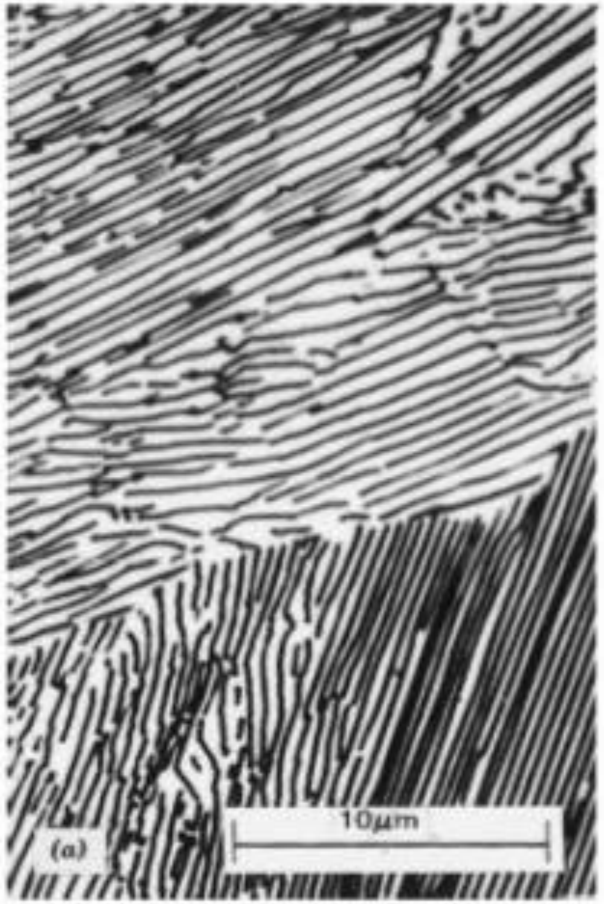
Cast iron

TTT diagram for Eutectoid steel (0.8 wt.% C)





Microstructure of Pearlite



Coarse pearlite
(Slow cooling)

Fine pearlite
(Fast cooling)

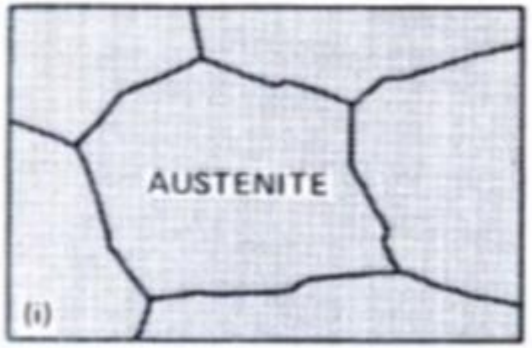
'Pearlite' is not a phase, rather a mixture of phases.

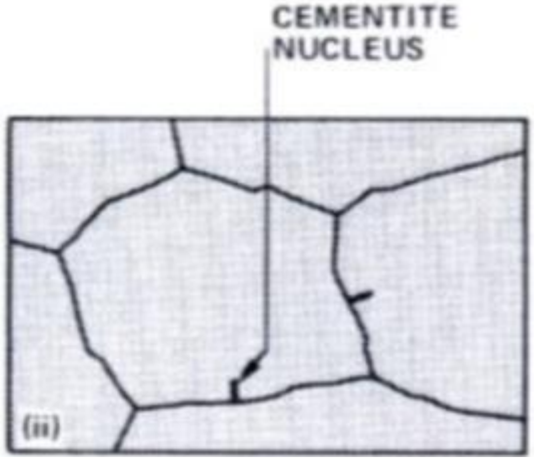
Coarse pearlite → Annealing → Furnace cooling

Fine pearlite → Normalizing → Air cooling

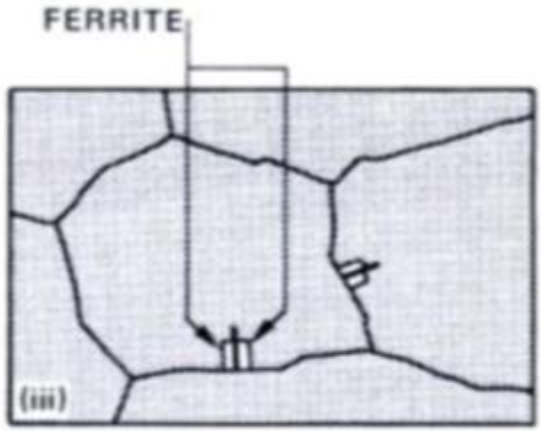
Austenite to pearlite transformation mechanism

$\gamma \rightarrow \alpha + Fe_3C$

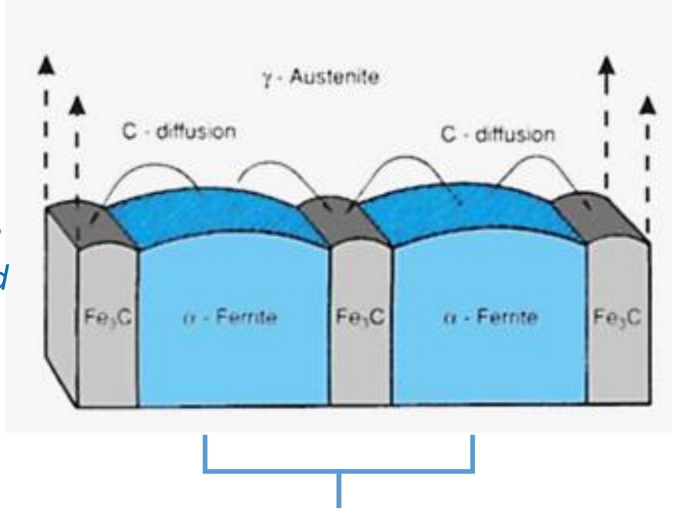




Heterogeneous nucleation at grain boundaries of austenite



Heterogeneous nucleation of ferrite at grain boundaries of austenite and in the vicinity of cementite nucleus

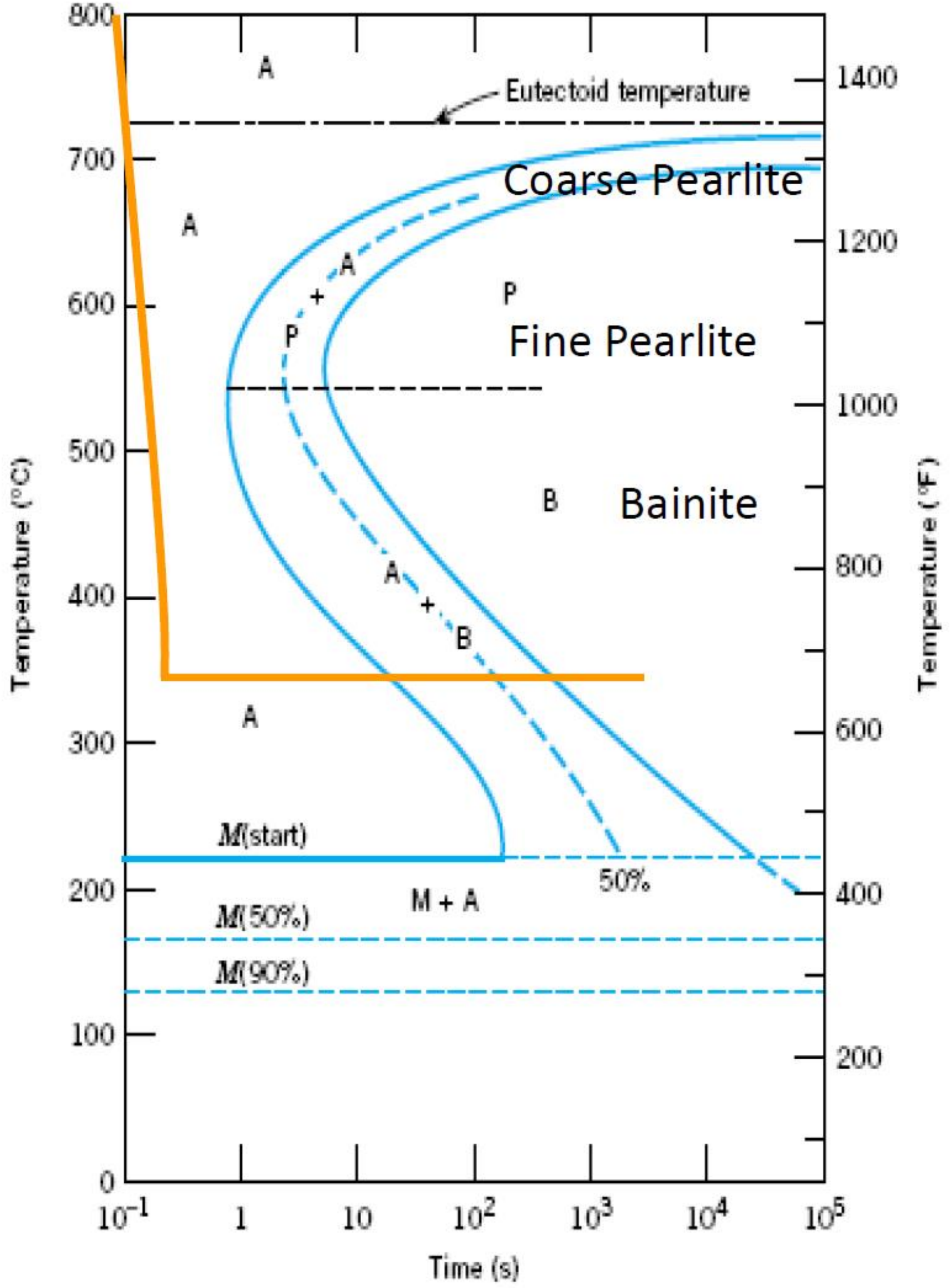


Interlamellar spacing (λ)

Ferrite and cementite phases grow inward of the austenite grain

How does the interlamellar spacing vary with temperature?

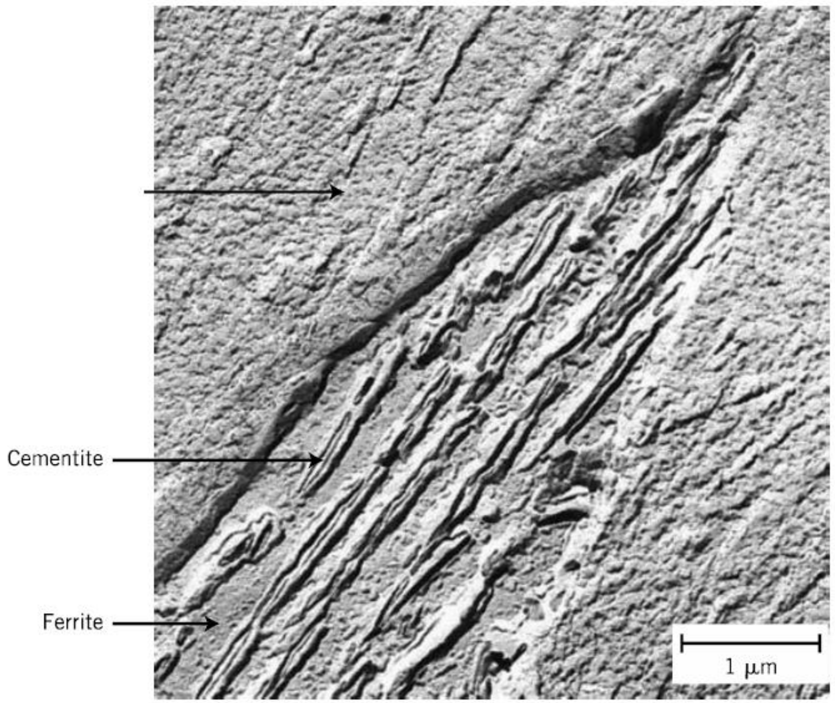
- *Interlamellar spacing is a function of temperature of transformation.*
- *Lower T → nucleation rate higher → finer interlamellar spacing → higher hardness/strength*



Bainite

Short needles of Fe_3C embedded in plates of ferrite

C diffuses only to short distances



Austempering

QUENCHING

$$\gamma \xrightarrow{\textit{rapid cooling}} \alpha'$$

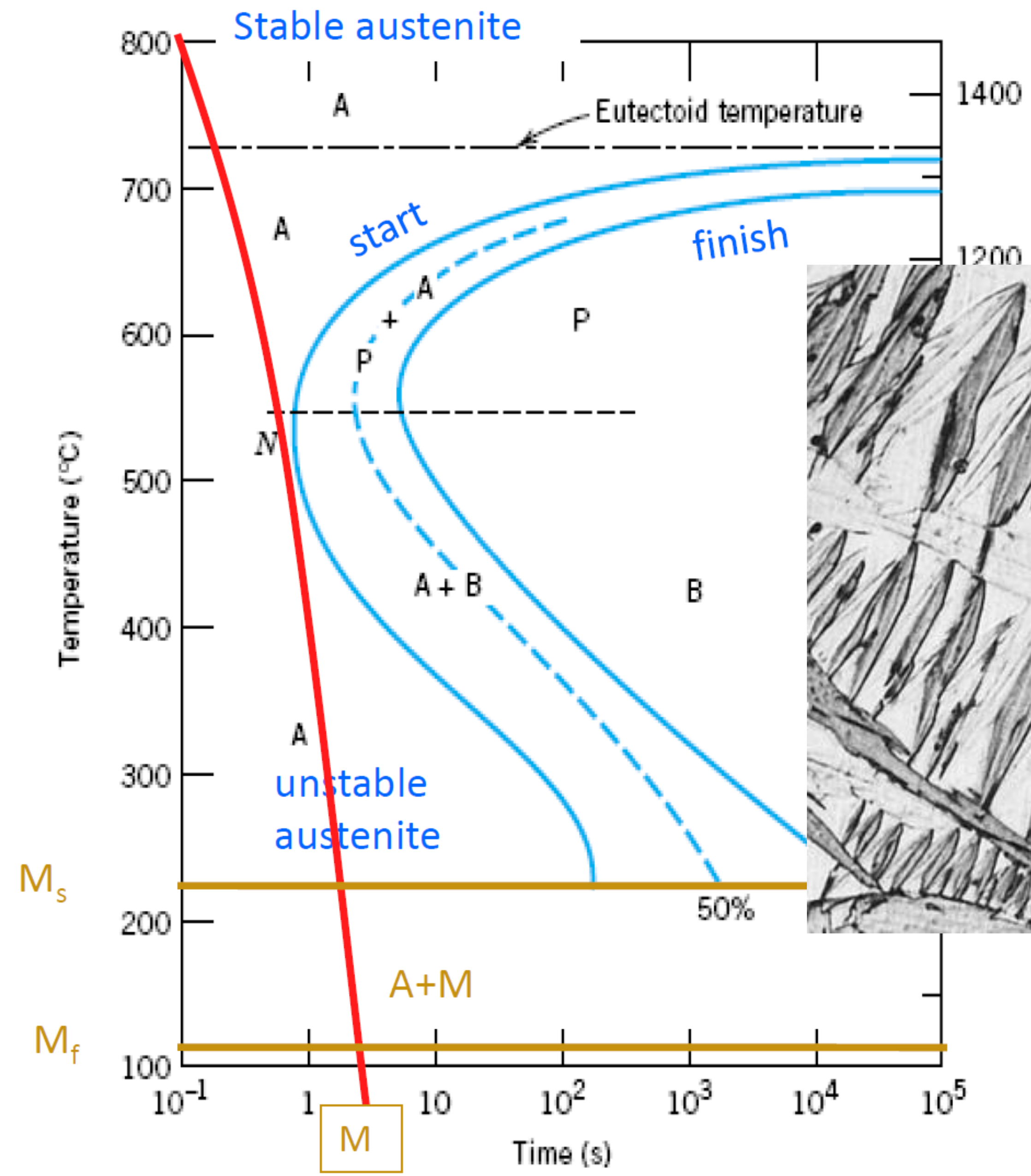
α': martensite (M)

Extremely rapid, no C-curves are present for this phase

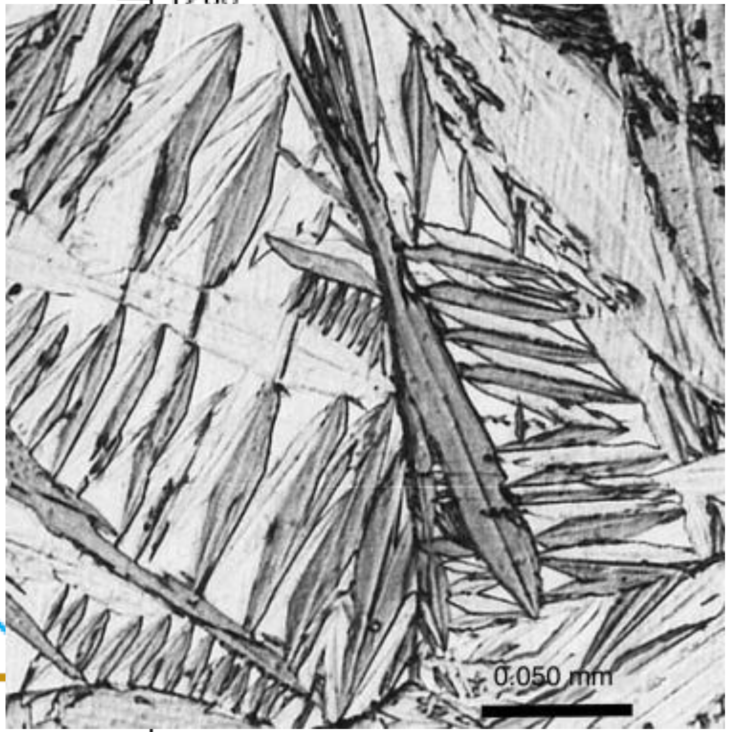
M_s : Martensite start temperature

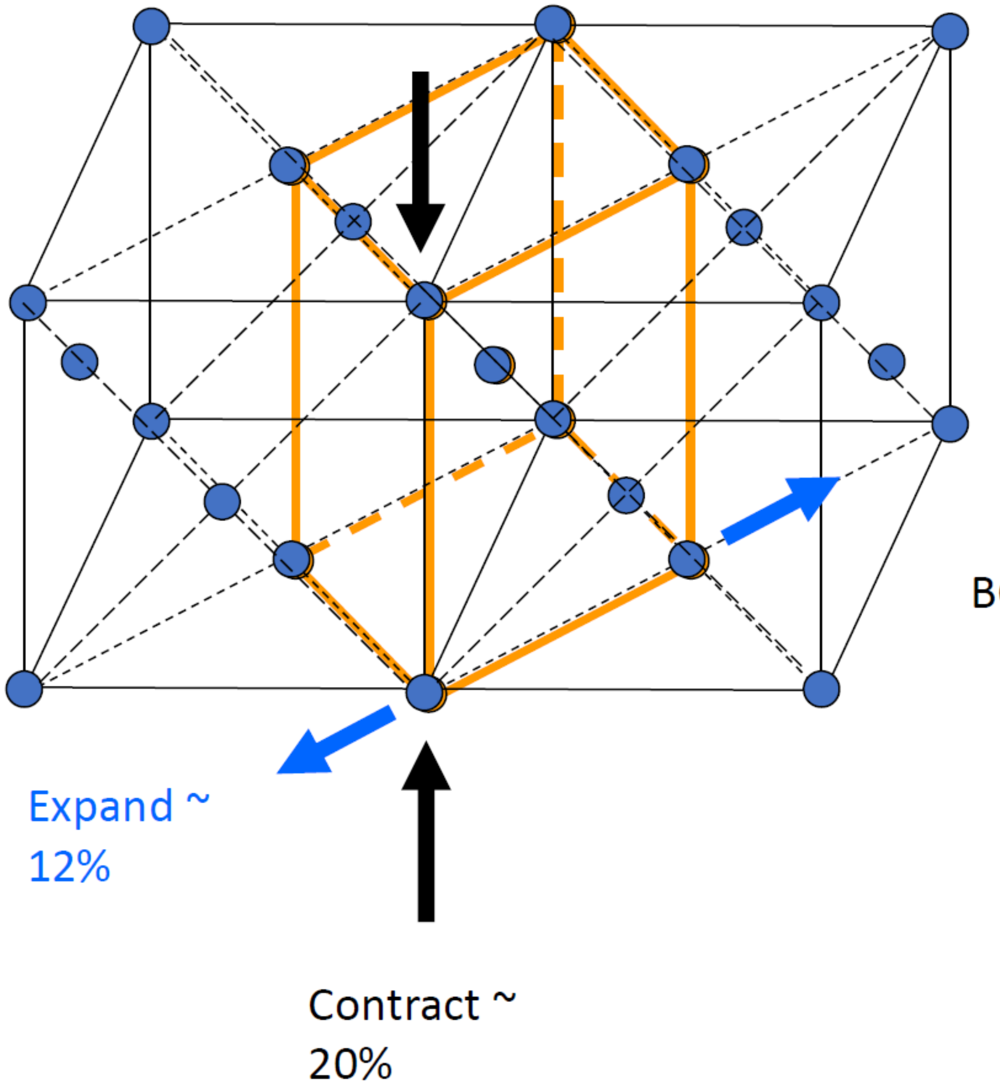
M_f : Martensite finish temperature

TTT diagram for eutectoid steel



Guimarães, JMRT (2019)





BCT unit cell of γ (austenite)

$$\boxed{\frac{c}{a} = \sqrt{2} = 1.414}$$

BCT unit cell of α' (martensite)

$$\frac{c}{a} = 1.00 - 1.08$$

0% C (BCC)

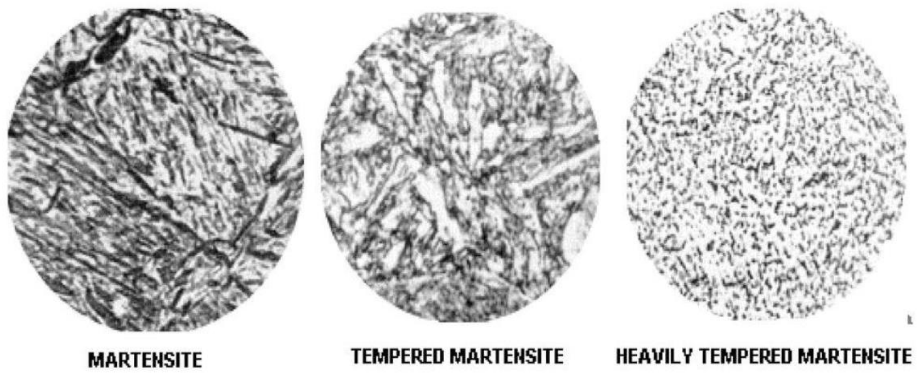
1.2 % C

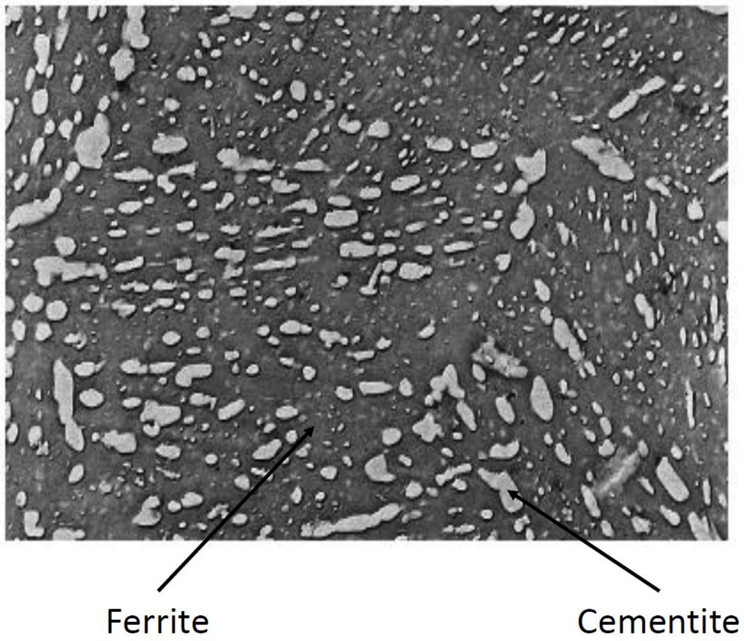
Tempering of Martensite

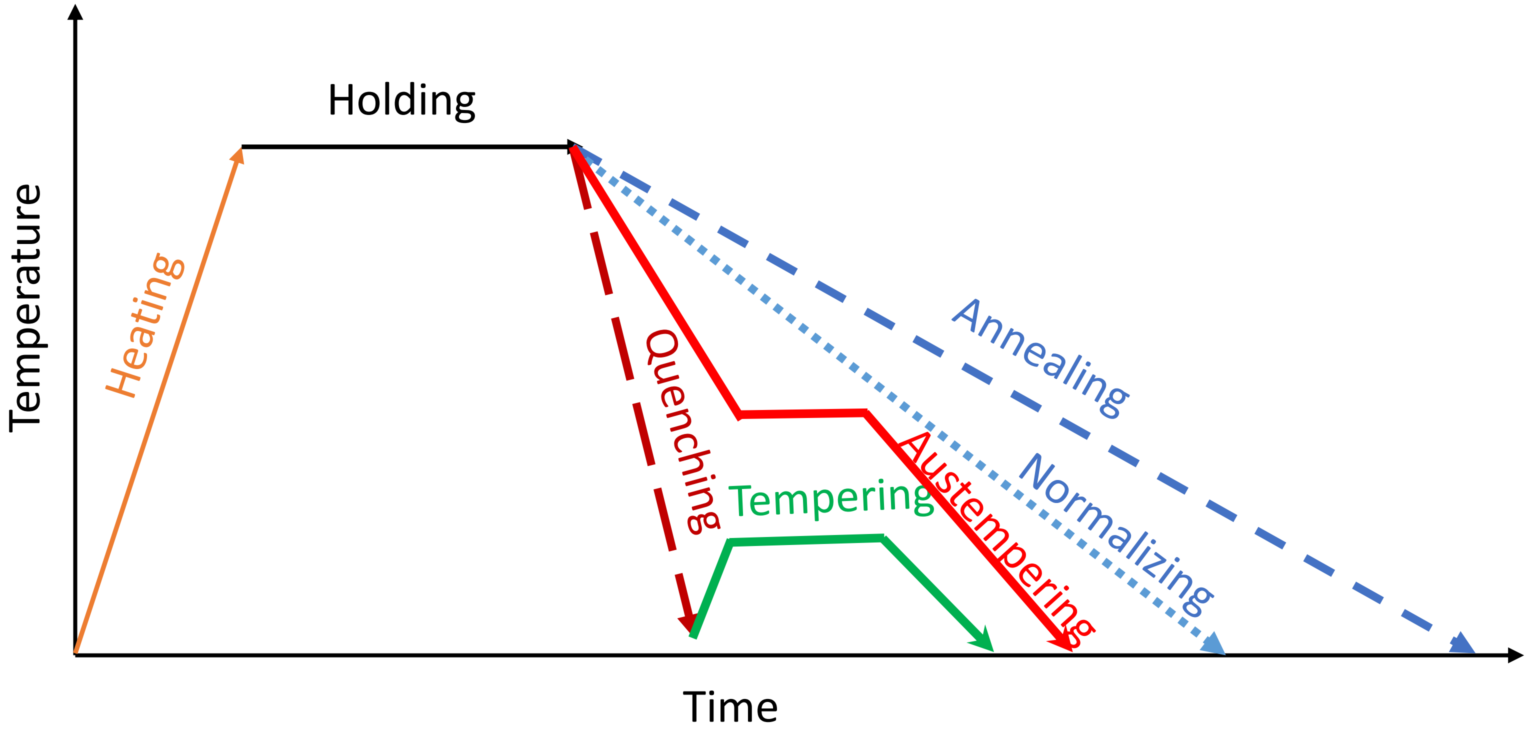
The hard martensite is brittle, so what to do???

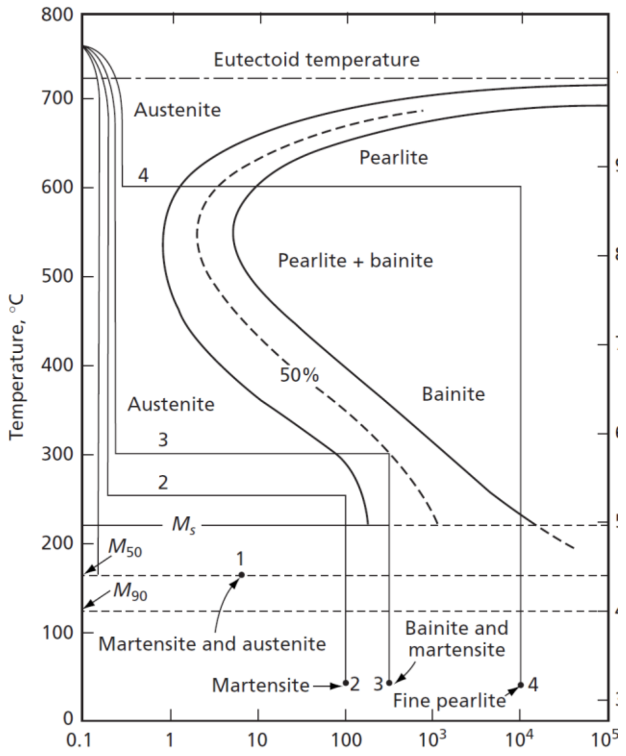
Tempering of martensite

Heating of quenched martensite to some intermediate temperature to allow the trapped C to come out and increase the toughness of steel









Annealing	Furnace cooling →	Coarse pearlite
Normalizing	Air cooling →	Fine pearlite
Quenching	Water cooling →	Martensite
Austempering	Cooling to an intermediate temperature hold and again cooling →	Bainite
Tempering	Quenching, heating to an intermediate temperature and hold and then cooling again →	Tempered martensite