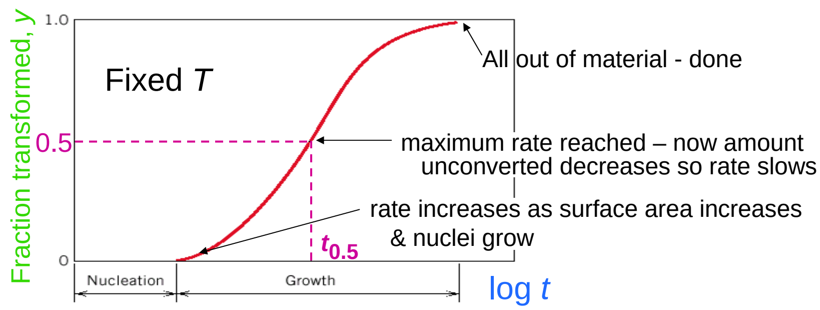
Chapter 10 Phase transformation in metals

- Basic concepts
- The kinetics of solid-state reactions
- Isothermal transformation diagrams

Basic concepts

- Phase transformation takes time to occur
- Types of phase transformation
  - Simple diffusion-dependent transformation -- no change in either the number or composition of the phases present
  - Diffusion-dependent transformation -- change in composition and the number of phases present
  - Diffusionless, martensitic transformation

The kinetics of solid-state reactions



Avrami rate equation => $y = 1 - \exp(-kt^n)$

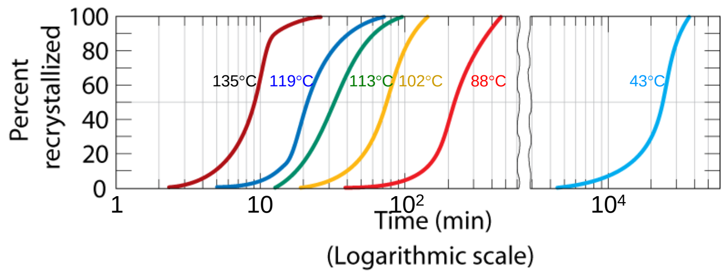
fraction transformed

t: time

- k & n fit for specific sample

By convention $r = 1 / t_{0.5}$

The kinetics of solid-state reactions (*continue*)



- In general, rate increases as $T\uparrow$

$$r = 1/t_{0.5} = A\,e^{-Q/RT}$$

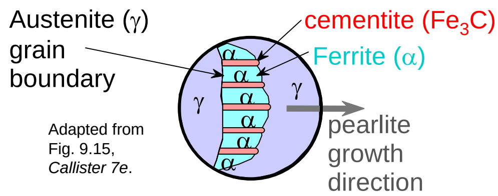
- R = gas constant
- T = temperature (K)
- A = preexponential factor
- Q = activation energy

Arrhenius expression

- r often small: equilibrium not possible!

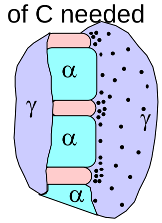
Eutectoid transformation rate

- Growth of pearlite from austenite:

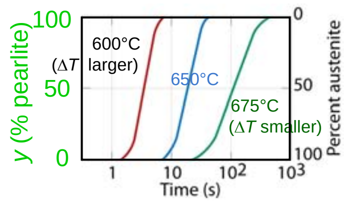


Adapted from Fig. 9.15, *Callister 7e*.

Diffusive flow of C needed



- Recrystallization rate increases with ΔT.



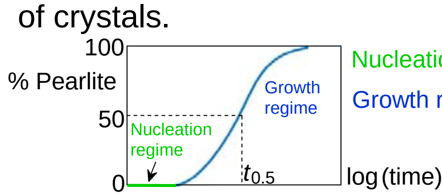
Adapted from Fig. 10.12, *Callister 7e*.

Course pearlite → formed at higher *T* - softer

Fine pearlite → formed at low *T* - harder

Nucleation and growth

- Reaction rate is a result of nucleation <u>and</u> growth of crystals.

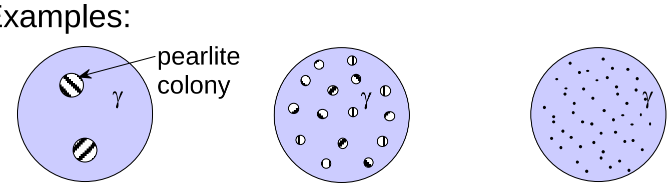


Nucleation rate increases with ΔT

Growth rate increases with *T*

Adapted from Fig. 10.10, *Callister 7e*.

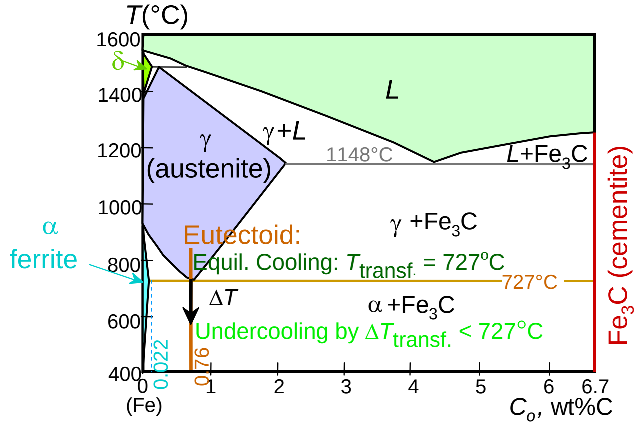
- Examples:



T just below T_E	*T* moderately below T_E	*T* way below T_E
Nucleation rate low	Nucleation rate med .	Nucleation rate high
Growth rate high	Growth rate med.	Growth rate low

Transformations & undercooling

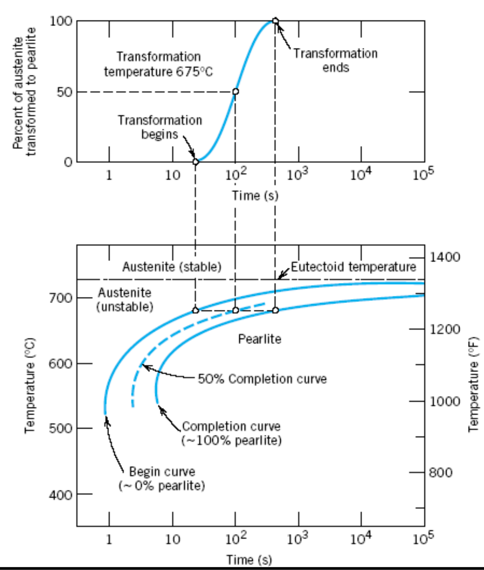
- Eutectoid transf. (Fe-C System): $\gamma \Rightarrow \alpha + Fe_3C$ (0.76 wt% C; 0.022 wt% C; 6.7 wt% C)
- Can make it occur at:
  - ...727ºC (cool it slowly)
  - ...below 727ºC ("undercool" it!)



Isothermal transformation diagrams

- Iron-iron carbide eutectoid reaction
  - C_0=0.77wt%C
  - Transformation at T=675⁰C

Time-temp-transformation (T-T-T) plots



Pearlite morphology

- T_{Transf} is just below Teu
  T larger, ΔT small -- Coarse grains

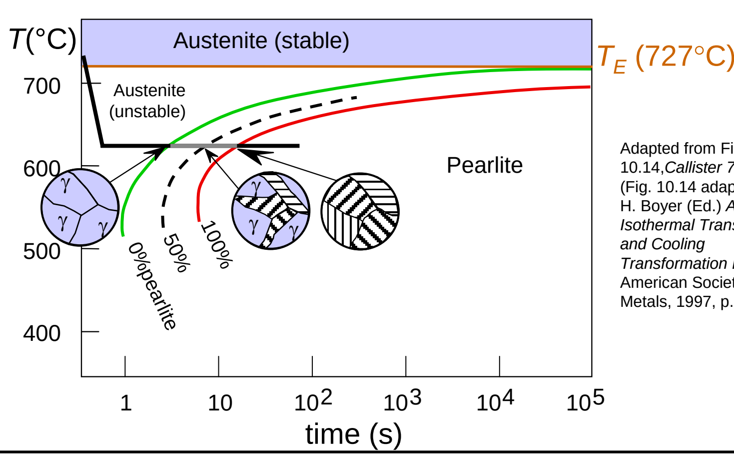
- T_{Transf} is far below Teu
  T small, ΔT large --fine grains

Coarser

Finer

Effect of cooling history in Fe-C system

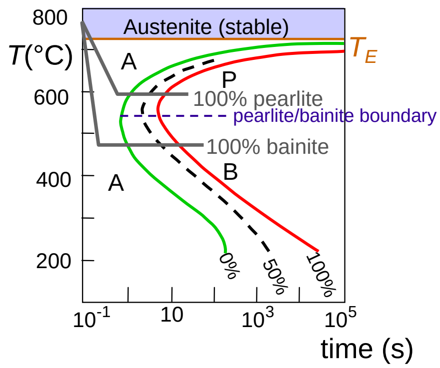
- Eutectoid composition, C_o = 0.76 wt% C
- Begin at T > 727°C
- Rapidly cool to 625°C and hold isothermally.

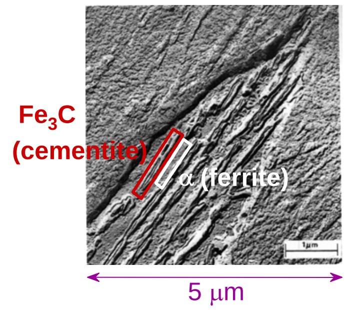


Adapted from Fig. 10.14,*Callister 7e*.
(Fig. 10.14 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1997, p. 28.)

Non-equilibrium transformation products: Fe-C

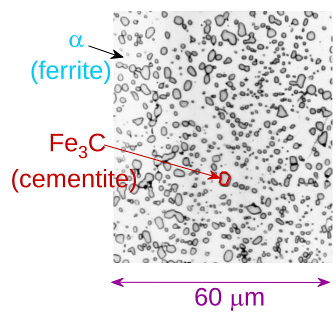
- Bainite:
  - --α lathes (strips) with long rods of Fe_3C
  - --diffusion controlled.
- Isothermal Transf. Diagram





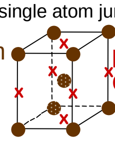
Spheroidite: Fe-C System

- Spheroidite:
  - --α grains with spherical Fe_3C
  - --diffusion dependent.
  - --heat bainite or pearlite for long times
  - --reduces interfacial area (driving force)

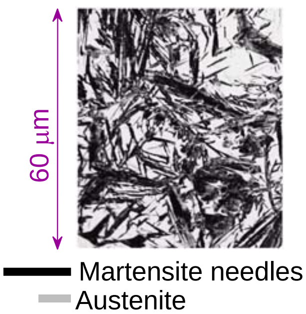


Martensite: Fe-C system

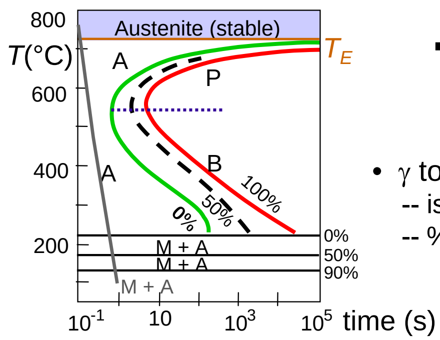
- Martensite:
  --γ(FCC) to Martensite (BCT)
  (involves single atom jumps)



(Adapted from Fig. 10.20, *Callister, 7e*.)

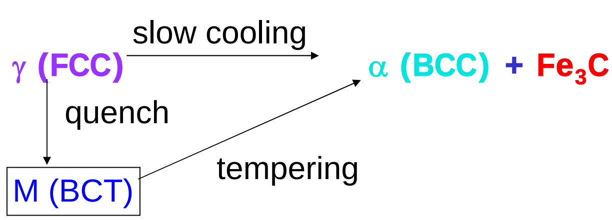


- Isothermal Transf. Diagram



- γ to M transformation..
  -- is rapid!
  -- % transf. depends on T only.

Martensite formation

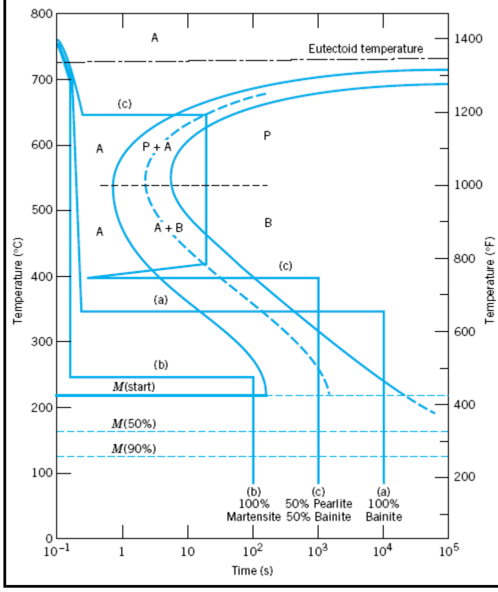


M = martensite is body centered tetragonal (BCT)

Diffusionless transformation BCT if C > 0.15 wt%

BCT → few slip planes → hard, brittle

Example



Rapid cool to:	Hold for:	Rapid cool to:	Hold for:	Rapid cool to:
350°C	10^4s	T_{room}		
250°C	10^2s	T_{room}		
650°C	20s	400°C	10^3s	T_{room}

Dynamic phase transformations

On the isothermal transformation diagram for 0.45 wt% C Fe-C alloy, sketch and label the time-temperature paths to produce the following microstructures:

a) 50% fine pearlite and 50% bainite

b) 100% martensite

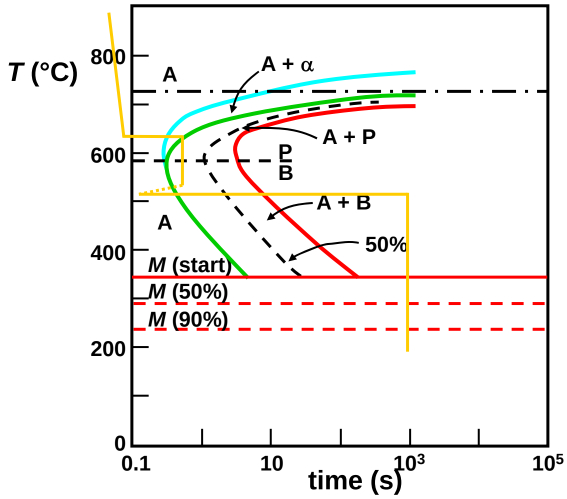
c) 50% martensite and 50% austenite

Example problem for C_o = 0.45 wt%

a) 50% fine pearlite and 50% bainite

first make pearlite then bainite

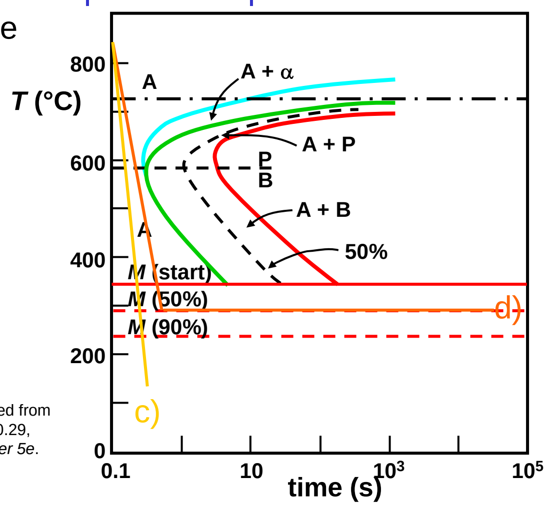
fine pearlite
∴ lower T



Example problem for C_o = 0.45 wt%

b) 100 % martensite – quench = rapid cool

c) 50 % martensite and 50 % austenite



Adapted from Fig. 10.29, *Callister 5e*.