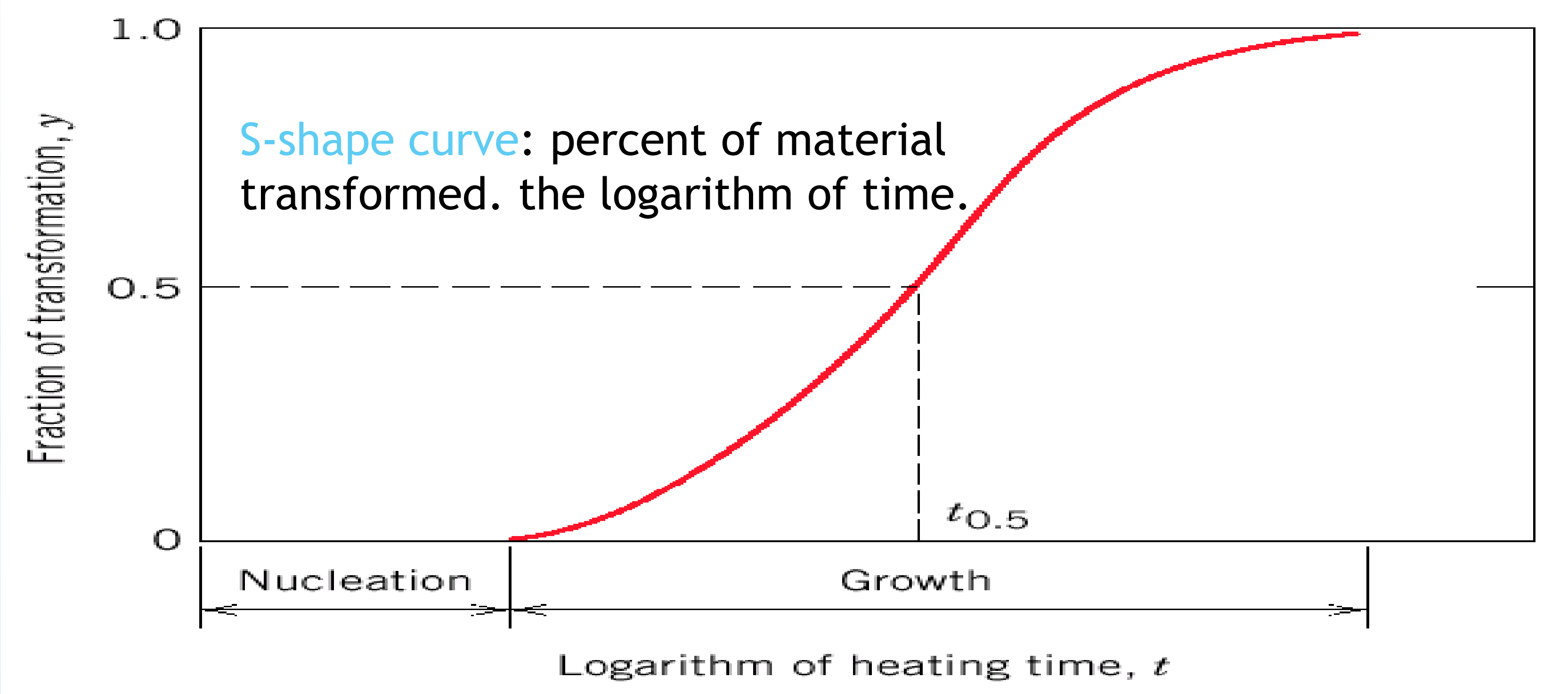
# *Phase transformation heat treatment

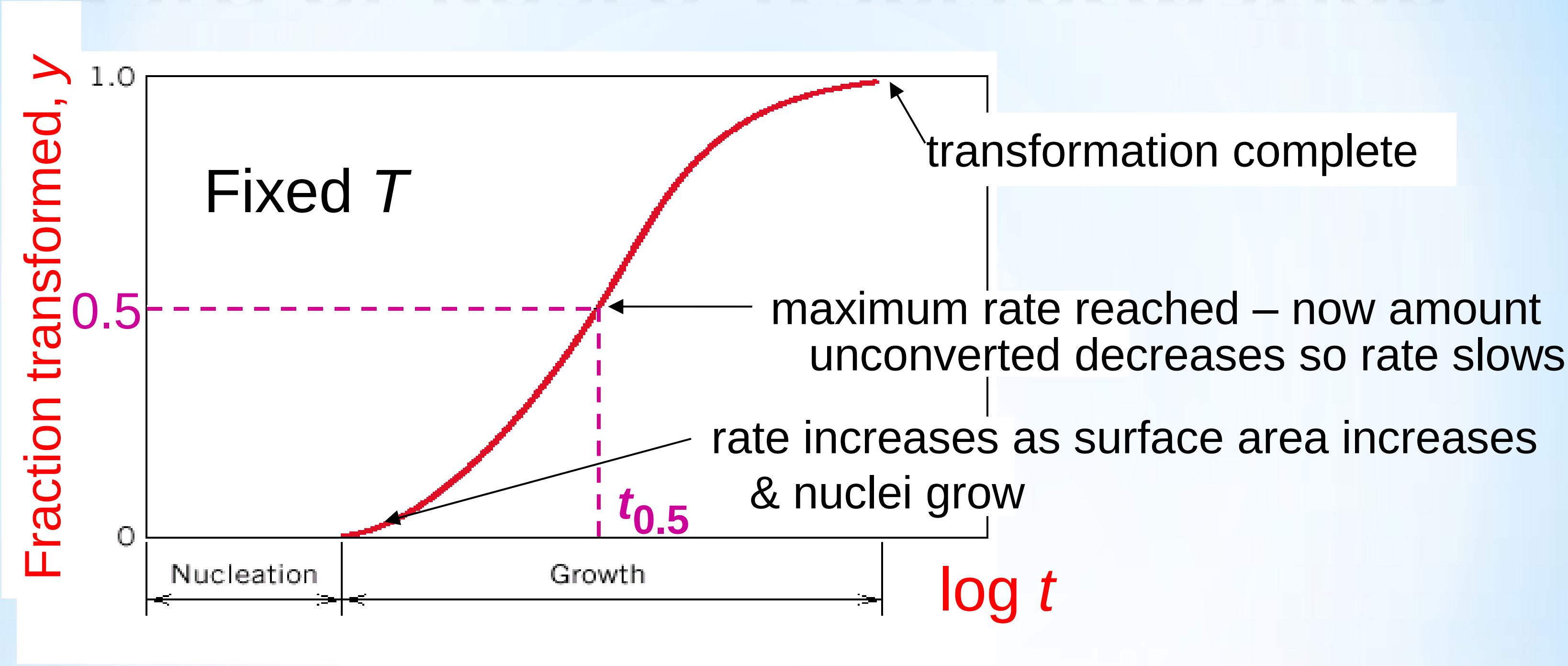
# Rate of transformation

Most phase transformations involve a change in composition ⇒ **redistribution via diffusion phase transformation involves:**

- **Nucleation - formation of small particles (nuclei) of the new phase. Often formed at grain boundaries.**
- **Growth of new phase at the expense of the original phase.**



# *Rate of Phase Transformation




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

The rate of transformation and the time required for the transformation (say 50%) is inversely proportional to one another.

- Rate of transformation **: r = 1/ t0.5**
- t 0.5 is time required for half way to completion.

# Rate of phase transformations

**Rate = Reciprocal of time halfway to completion:**

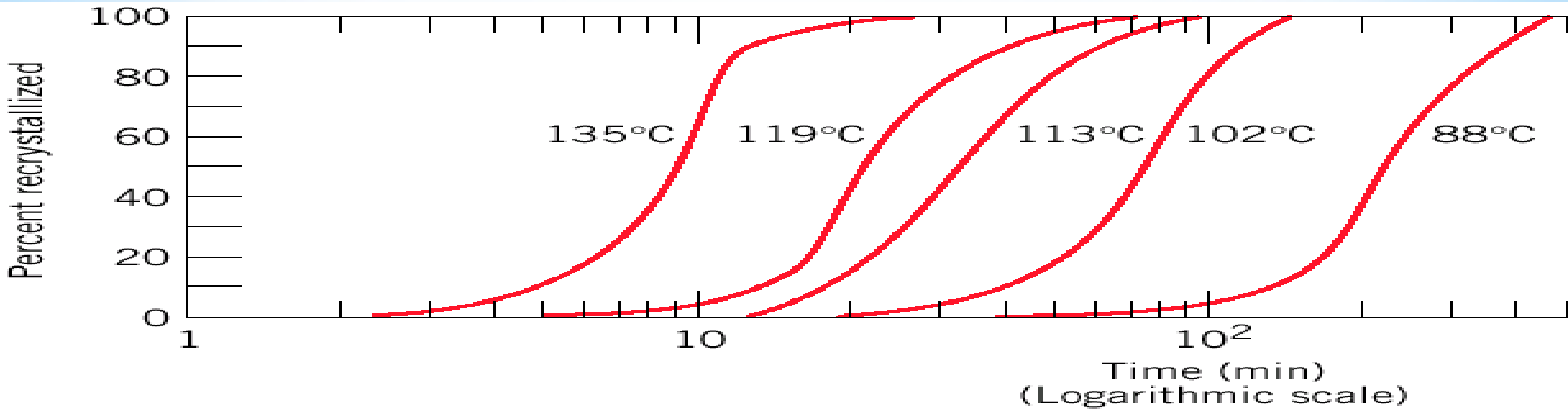
$$r = 1 / t_{0.5}$$

**Arrhenius equation: thermally activated processes:**

$$r = A \exp(-Q_A/kT) = A \exp(-Q_m/RT)$$

Per atom

Per mole




**Percent recrystallization of pure copper at different T**

# Phase transformation

- Phase transformation – Formation of a new phase having a distinct physical/chemical character and/or a different structure than the parent phase.
- It involves two phenomena – Nucleation and Growth
- Nucleation – formation of a nucleus or tiny particles of the new phase.
- A nucleus is formed when the Gibbs free energy, *G*, of the system decreases i.e. G becomes negative.
- Two types of nucleation – Heterogeneous and Homogeneous
- Growth – Increase in size of the nucleus at the expense of the parent phase.

# Metastable versus Equilibrium states

Phase transformation is a time-dependent process, long time is required to reach equilibrium stage.

- Speed or rate of cooling is designed to produce specific microstructure which the phase may

not the equilibrium one → metastable phase.

- Supercooling or superheating happens very often in practical purpose.

# Microstructure and Property Changes in Fe-C Alloys Isothermal Transformation Diagrams

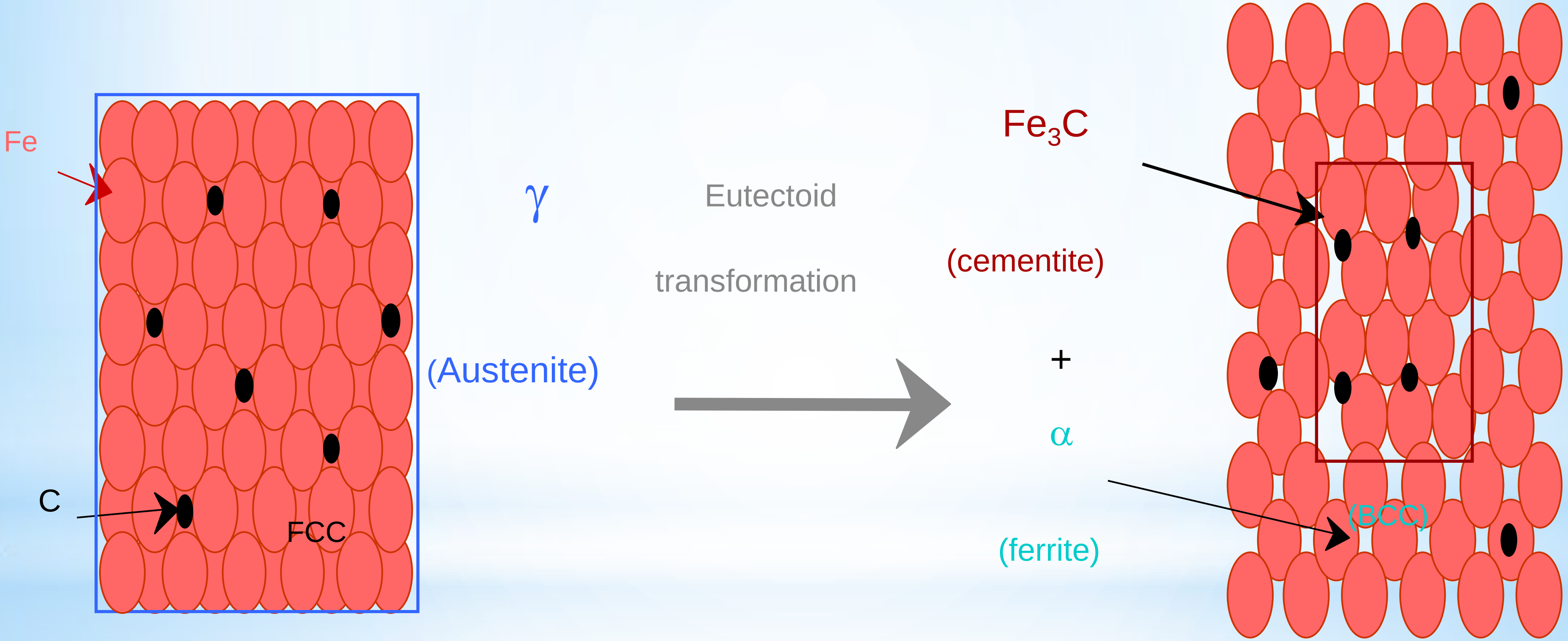
- Eutectoid reaction, at 727°C
- γ → pearlite (α+ Fe3C)
- The lower the temperature, the fast the phase transforms.

## From the Isothermal Transformation Diagrams

See Fig. above which is called isothermal transformation diagram.
(Time-temperature-transformation, T-T-T plot)

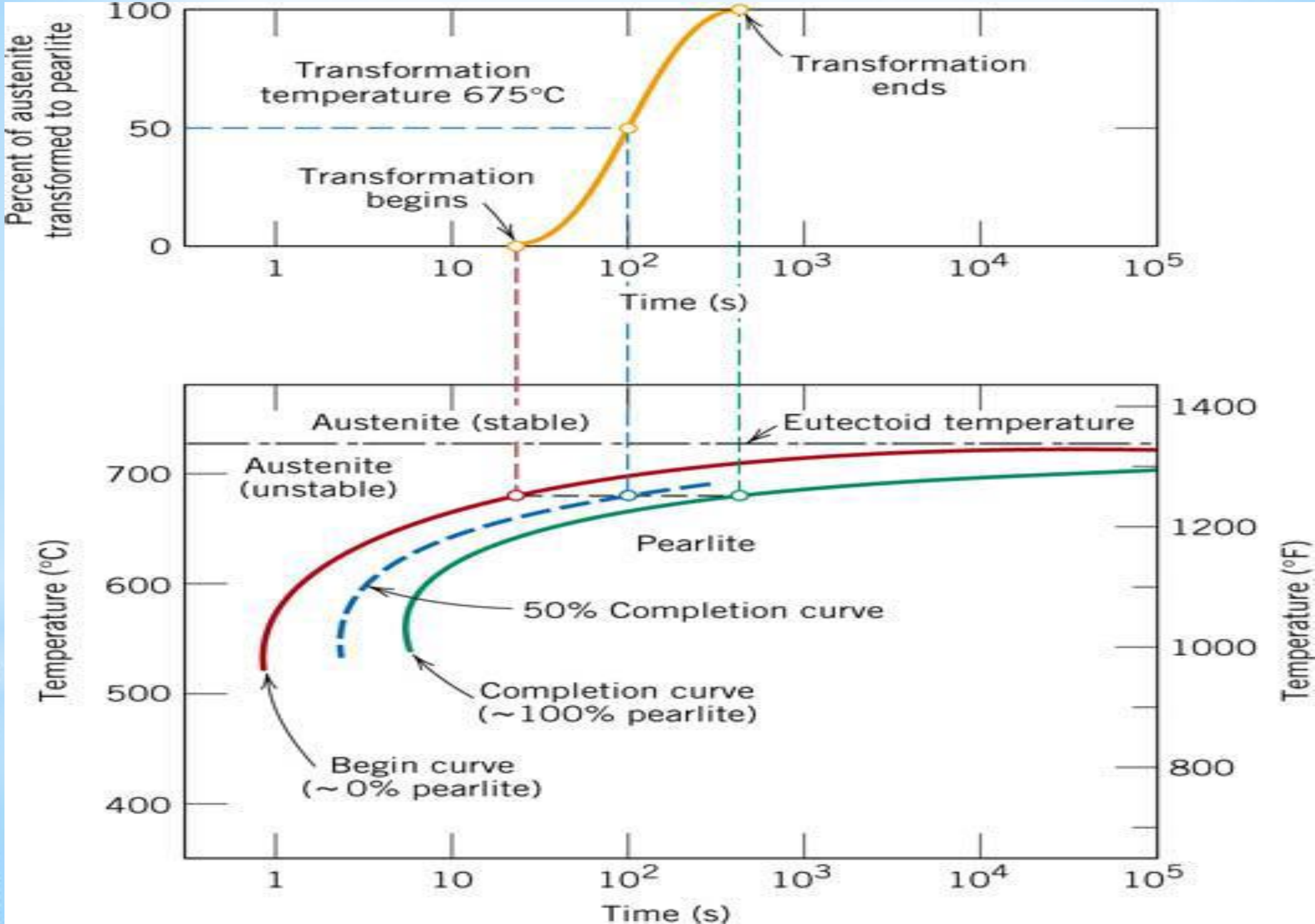
- **T~< 727°C (slightly lower):**
- Phase transformation needs longer time
- Microstructure becomes coarse pearlite.
- **T << 727°C (much lower):**
- Phase transformation is quick.
- Microstructure is fine pearlite.

# Transforming one phase into another takes time.

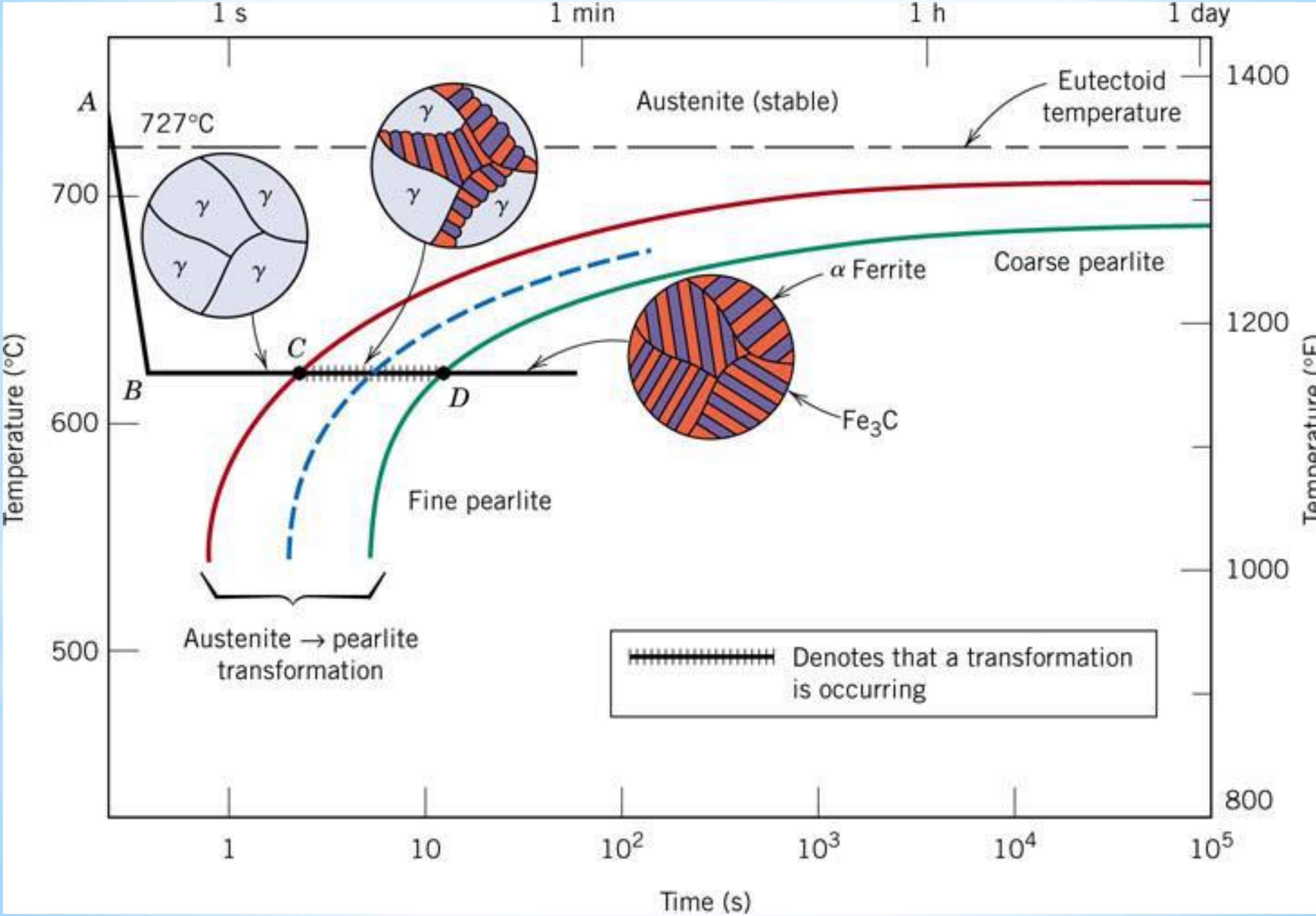


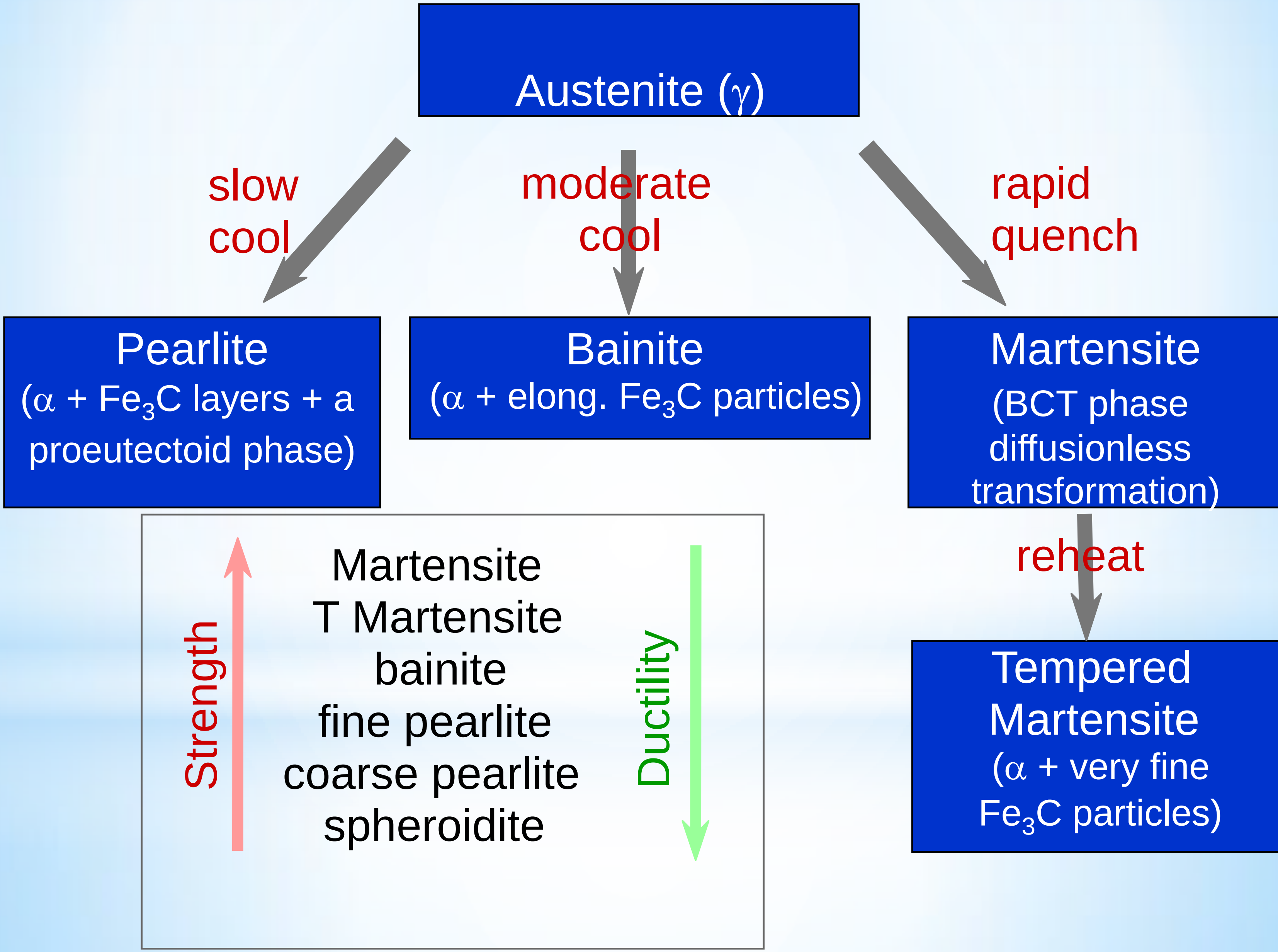

How does the rate of transformation depend on time and temperature?

# Isothermal Transformation Diagrams

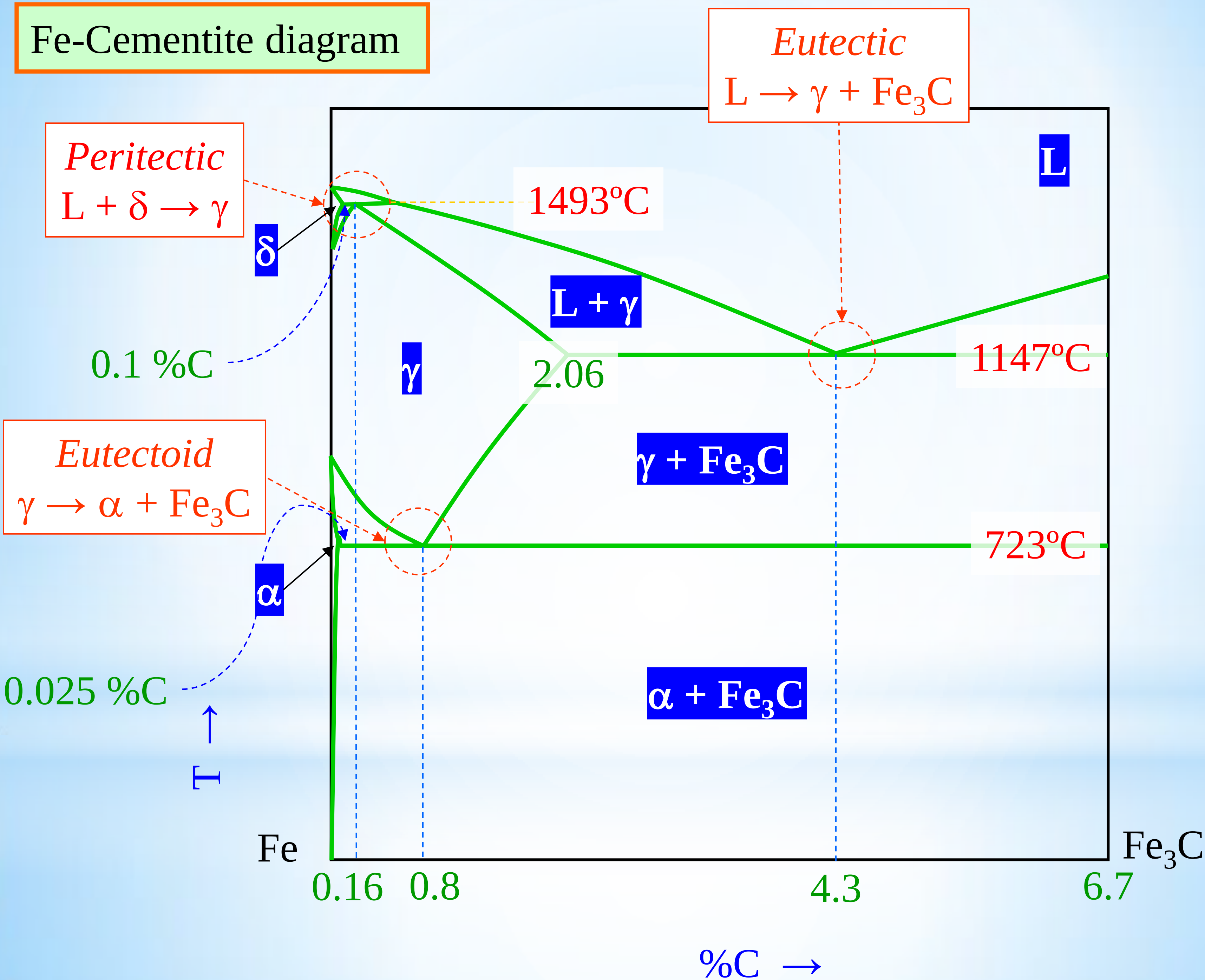


# Cooling curve ABCD in T-T-T plot for eutectoid reaction




Austenite (γ)
slow
cool
moderate
cool
rapid
quench
Pearlite
(α + Fe3C layers + a
proeutectoid phase)
Bainite
(α + elong. Fe3C particles)
Martensite
(BCT phase
diffusionless
transformation)
reheat
Tempered
Martensite
(α + very fine
Fe3C particles)
Strength
Martensite
T Martensite
bainite
fine pearlite
coarse pearlite
spheroidite
Ductility

# Fe-Cementite diagram



# Phase transformation in Fe-C system

- Peritectic reaction at 1495 °C

$L$ (0.53% C) + $\delta$ (0.09% C) $\rightarrow \gamma$ (0.17% C)

- Eutectic reaction at 1146°C

$L$ (4.3% C) $\rightarrow \gamma$ (2.1 % C) + $Fe_3C$ (6.67% C). The eutectic mixture of austenite ($\gamma$) and cementite ($Fe_3C$) is called *Ledeburite*. Compositions right and left of 4.3% are called hyper and hypoeutectic steels (Cast iron) respectively.

- Eutectoid reaction at 727°C

$\gamma$ (0.8 % C) $\rightarrow \alpha$ (0.025% C) + $Fe_3C$ (6.67% C). The eutectoid mixture of ferrite ($\alpha$) and cementite ($Fe_3C$) is called *Pearlite*.

- Compositions right and left of 0.8% are called hyper and hypoeutectoid steels respectively.

Different cooling treatments

Eutectoid steel (0.8%C)