Karlsruhe Institute of Technology

Institute for Applied Materials

Phase Transformations in Materials

Lecture for “Mechanical Engineering” and “Materials Science and Engineering”

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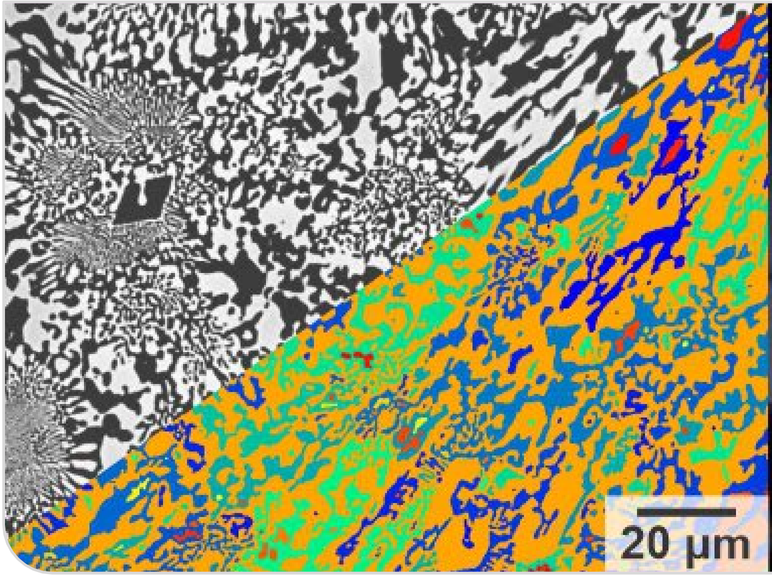
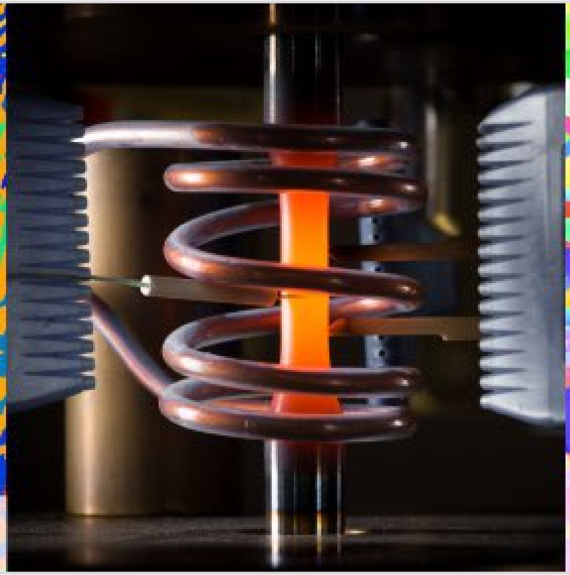
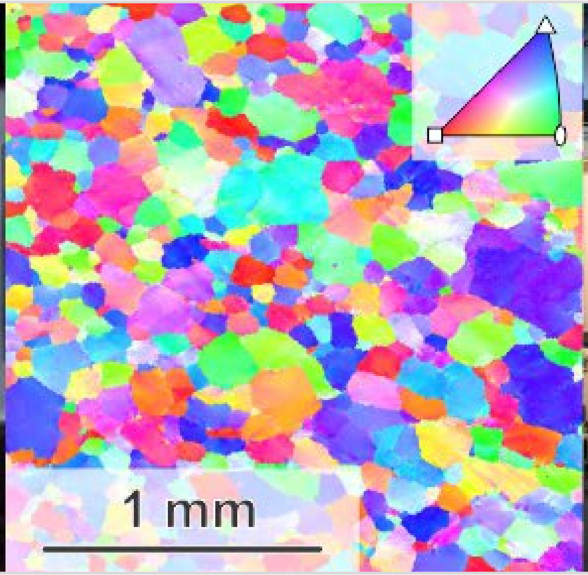
Version 23-10-24







Topics

- Overview about Phase Transformations
  - General Aspects
  - Schemes

Phase Transformations in General

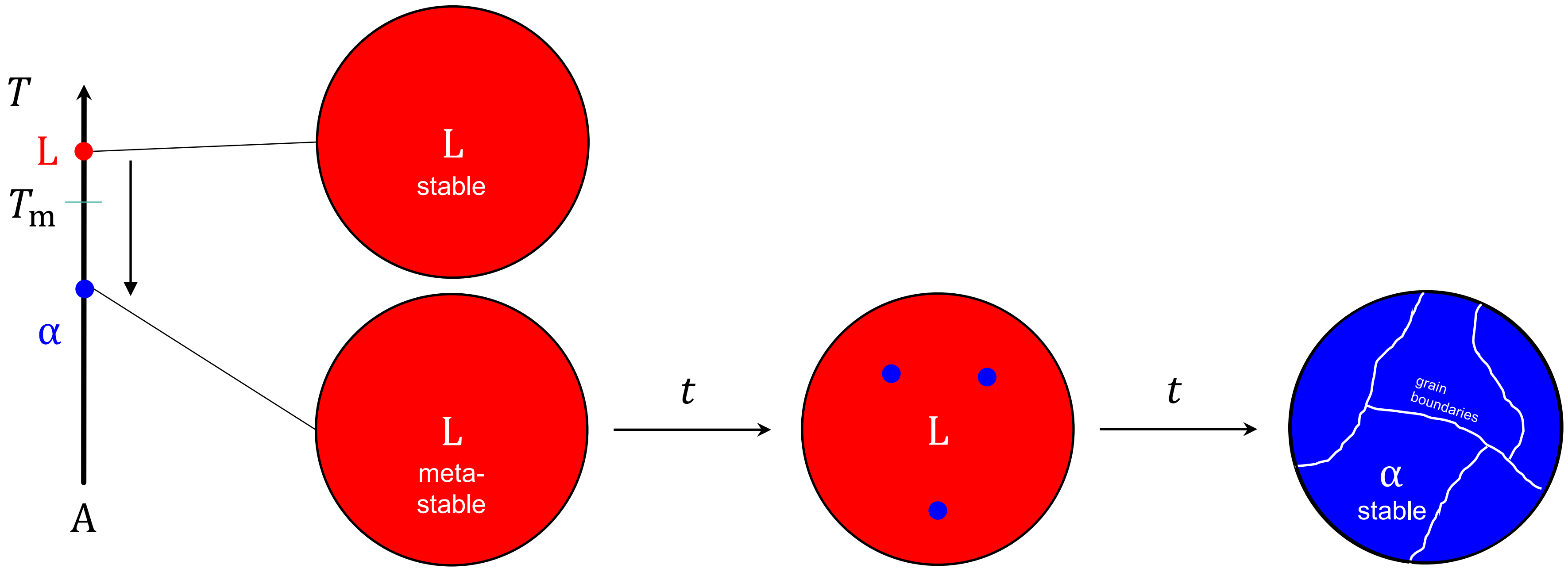
- Based on the definition of a phase in Ch. 1a, a phase transformation occurs when one or more phases in a material change their chemical or physical (incl. structural) properties upon a change of the external conditions.
- For the phase transformations mostly addressed in this lecture, we focus on phase transformations due to changing temperatures. The principles might easily be transferred to the application of stress/strain to a material.
- Before starting with the details on the specific types of transformations, this chapter provides an overview about the different reactions and potential types of categories.

Phase Transformations in General

Type	Displacive	Reconstructive			
Effect of Temperature Change	Athermal	Thermally activated			
Interface Mobility	Glissile	Non-glissile			
Interface Structure	Coherent Semi-coherent	Coherent, semi-coherent, incoherent for solid state transformations Solid-liquid for solidification			
Change of the Composition	No change	No change	Change		
Atomic Motion	Diffusionless by deformation (cooperative)	Diffusionless by motion across the interface (non-cooperative)	Diffusion		
Rate-Controlling Factor	Interface mobility	Interface mobility	Interface mobility	Diffusion	Mixed diffusion and interface mobility
Examples	Martensite Formation	Massive Transformation Ordering Polymorphic Transformation Allotropic Transformation	Precipitation Dissolution Bainitic Transformation	Precipitation Dissolution	Precipitation Dissolution Eutectoid Cellular Precipitation

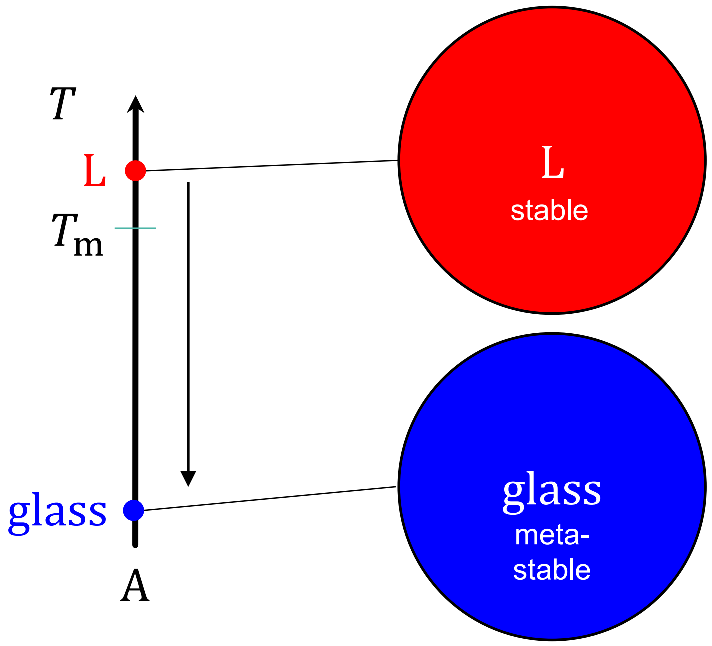
Solidification

- Materials undergo solidification by nucleation and growth when sufficiently super-cooled below the melting temperature.



Solidification

- When nucleation is sufficiently depressed, the material can also form a solid glass, a liquid of such low viscosity and can thus be considered solid.

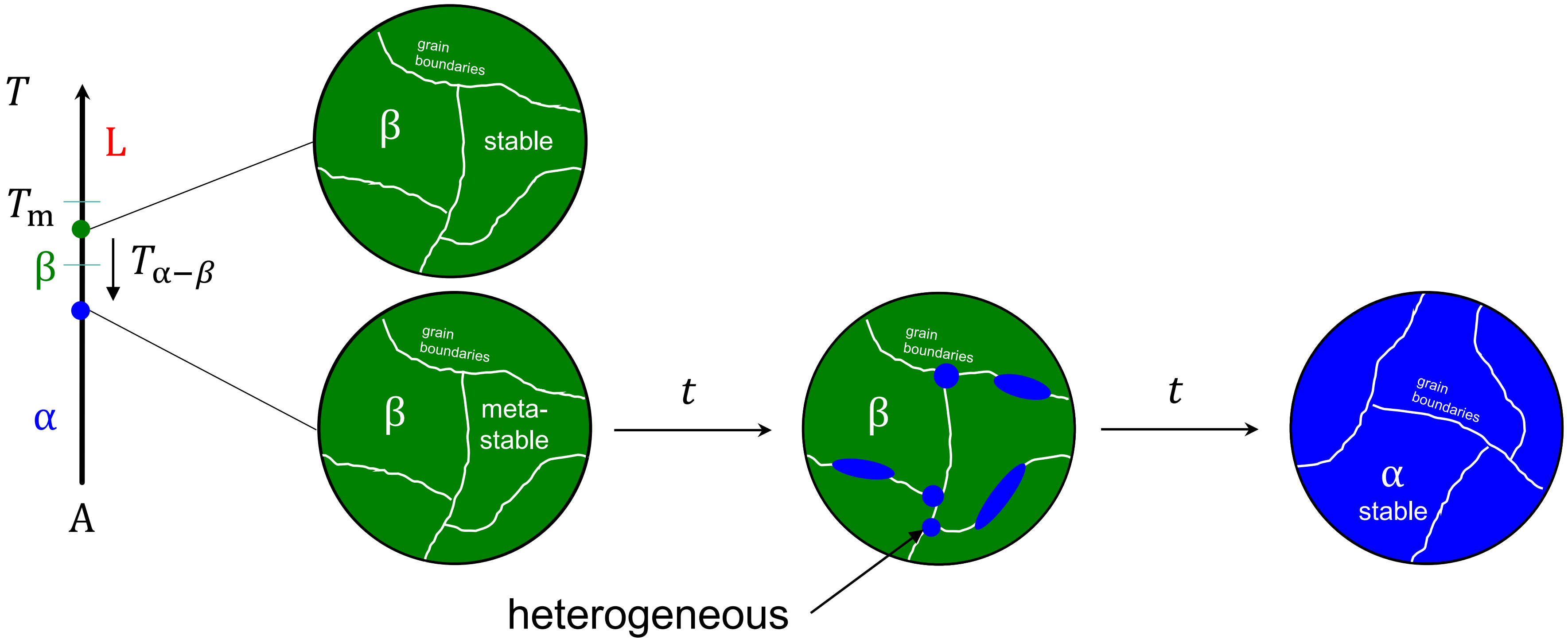


Glass = frozen liquid of such low viscosity that it appears solid

The freezing occurs quasi-instantaneous.

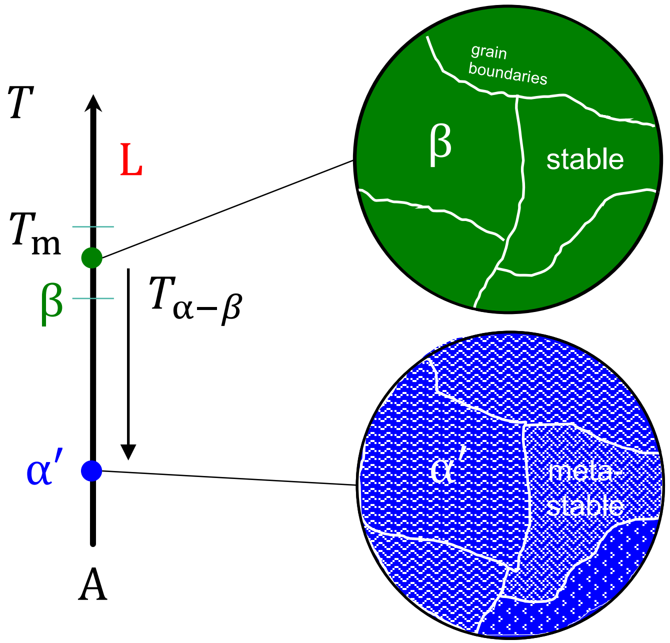
Allotropic Transformation

- Solid materials might exist in different stable crystallographic modifications as a function of temperature. The transformation by nucleation and growth following super cooling below the equilibrium transformation temperature is a reconstructive transformation.



Allotropic Transformation

- In the case of solid-solid transformation, a sufficient super cooling might suppress nucleation of the α phase and internal stresses increase up to a critical amount. When the critical stress is achieved, a displacive transformation to α' occurs.

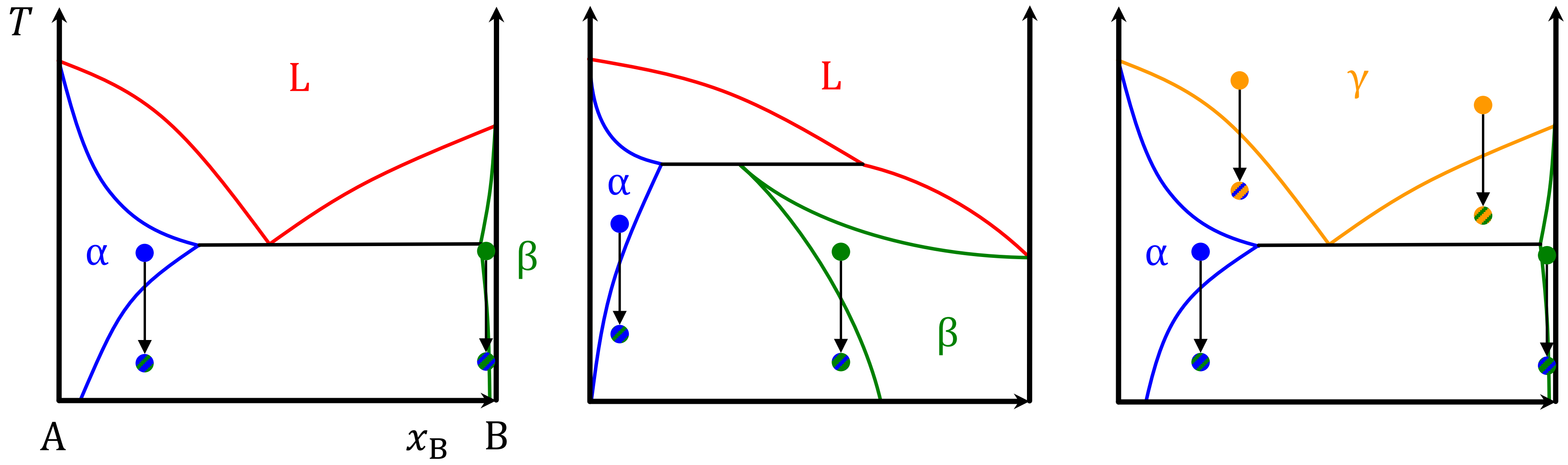


α' is the martensitic form of α that is rich in defects, like dislocations and variant/twin boundaries. Note that the symmetry break as in the case of Fe-C is not necessary for the term martensite.

The martensitic transformation occurs quasi-instantaneous.

Precipitation

- Precipitation reactions occur from a super-saturated condition into a two-phase state by a thermally activated nucleation and growth process and are controlled by long-range diffusion. Subsequent to precipitation to maximum volume fraction, coarsening is obtained to further reduce total interface energy of the system.



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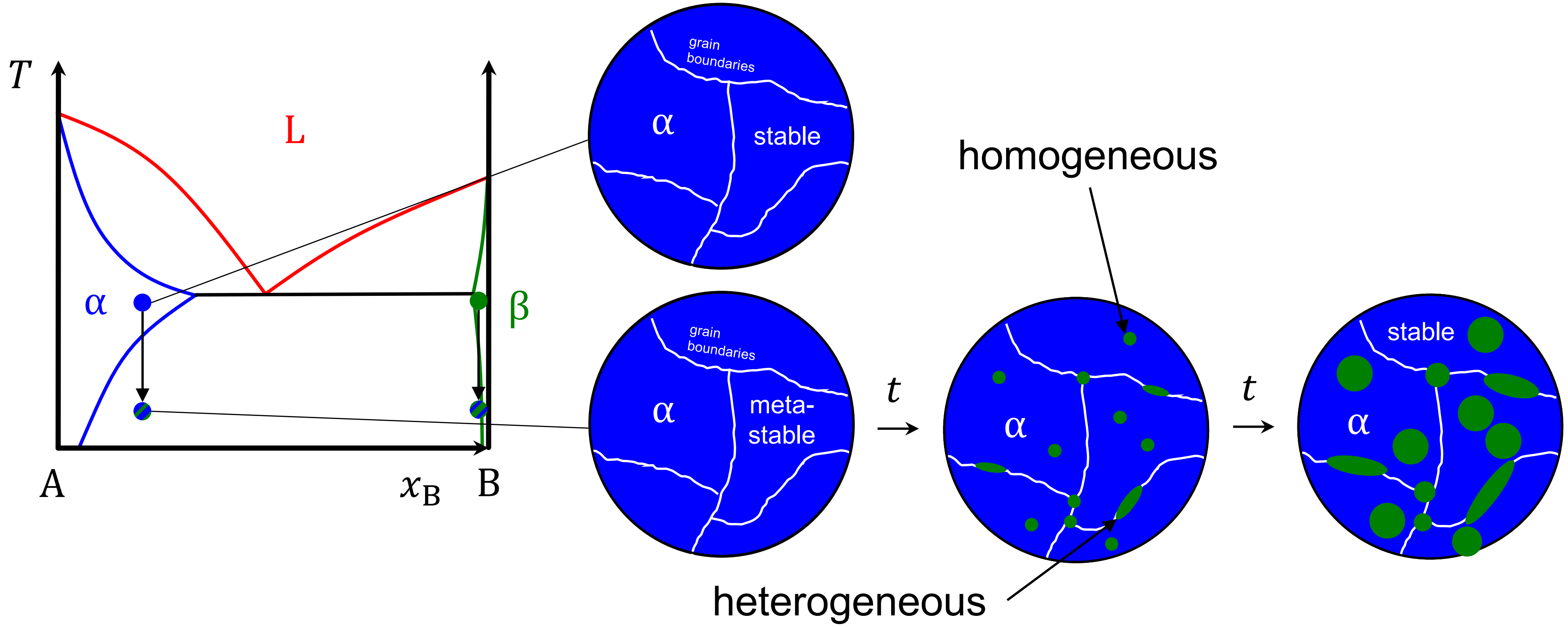

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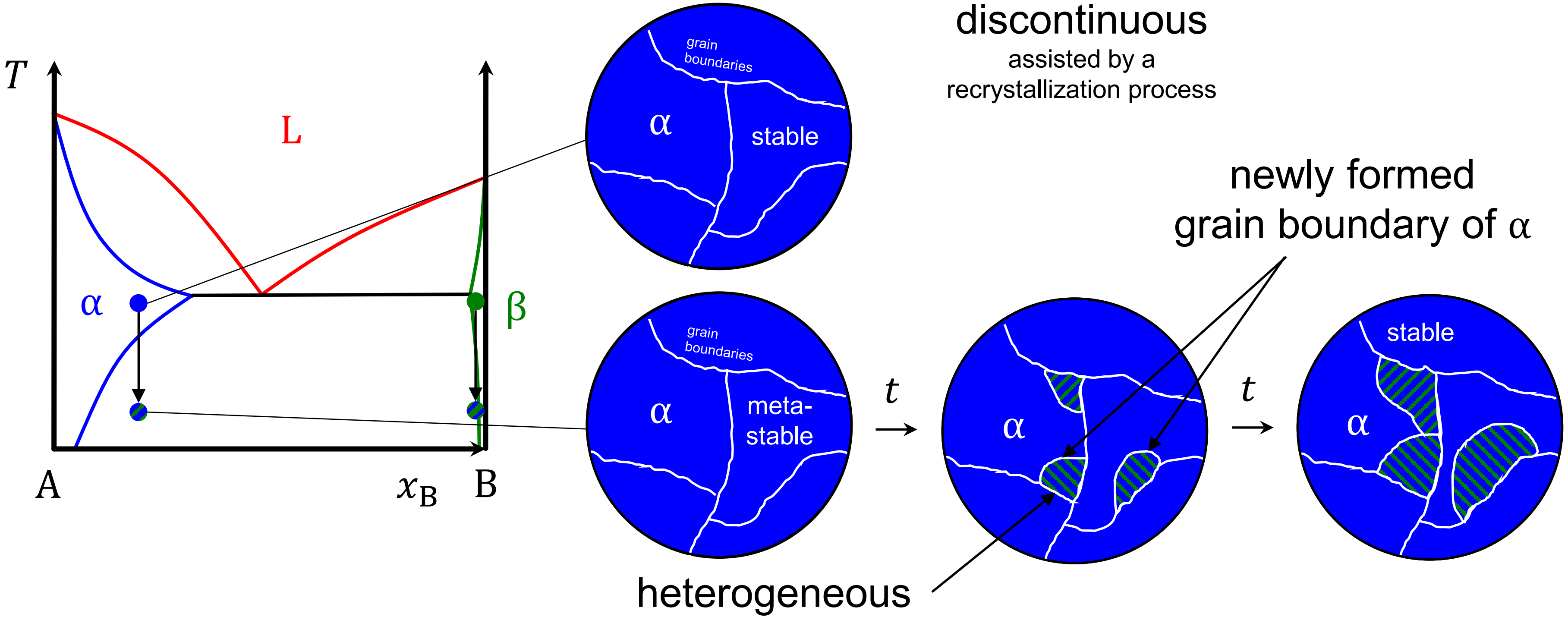

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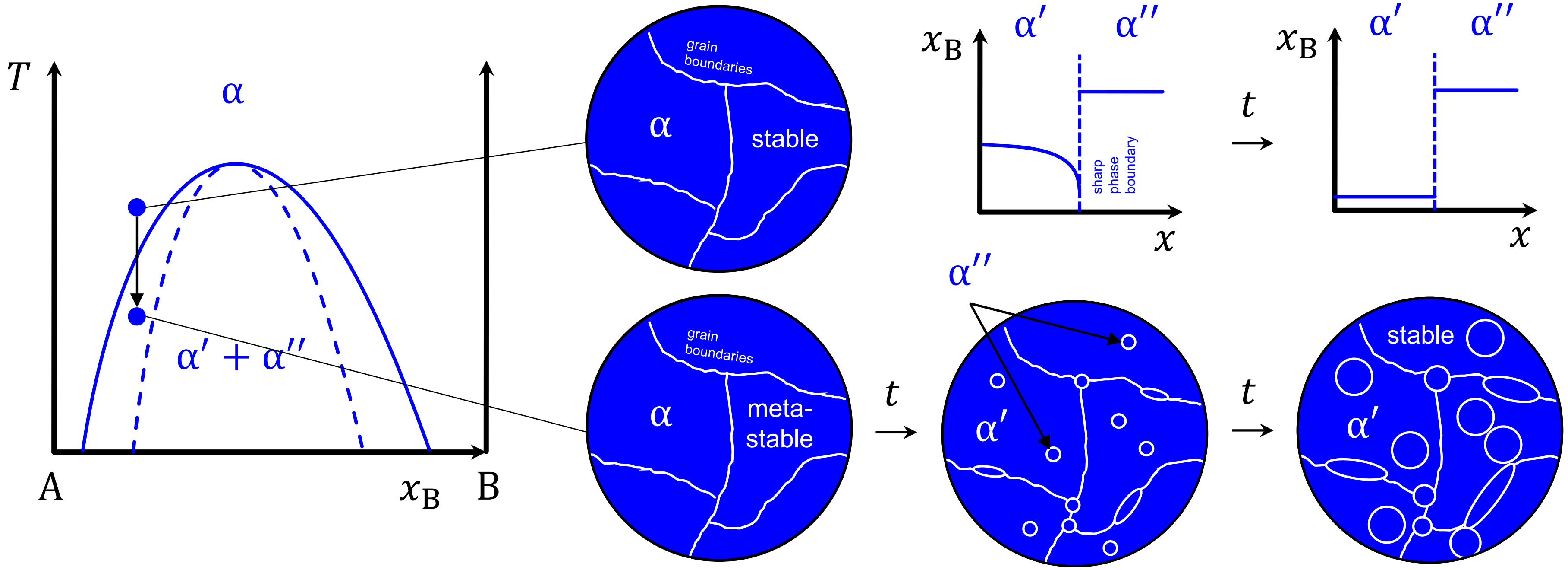
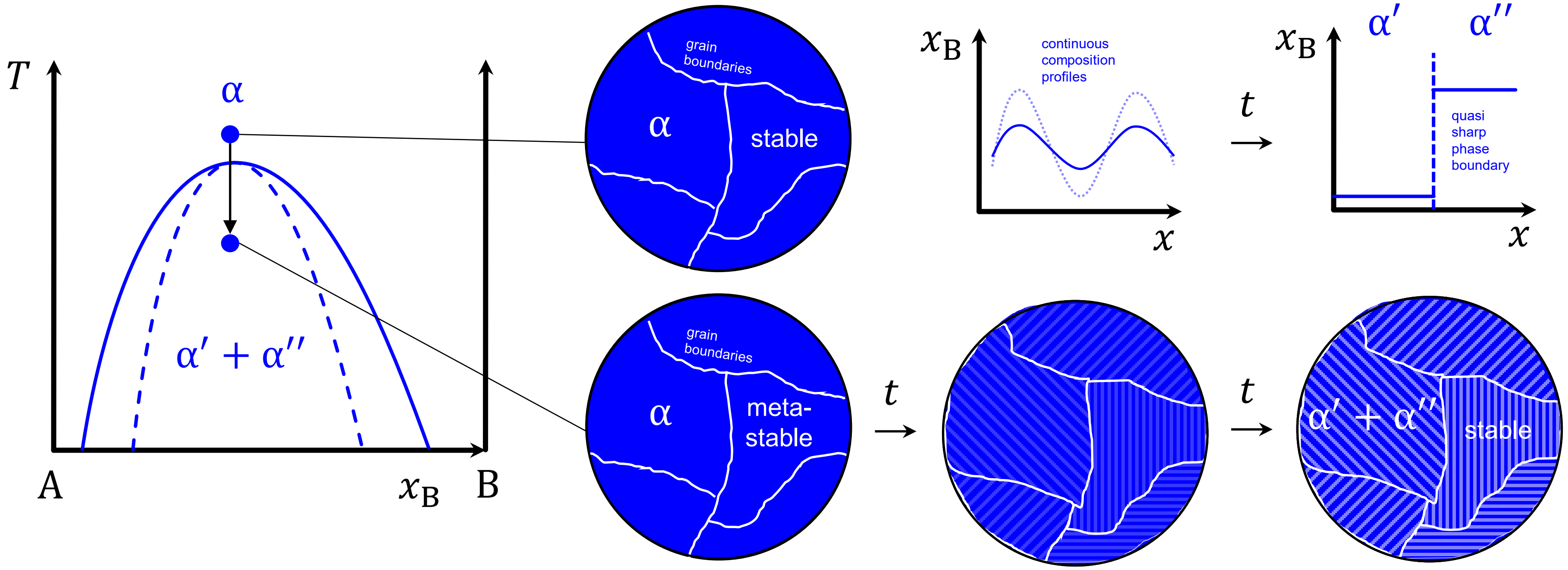


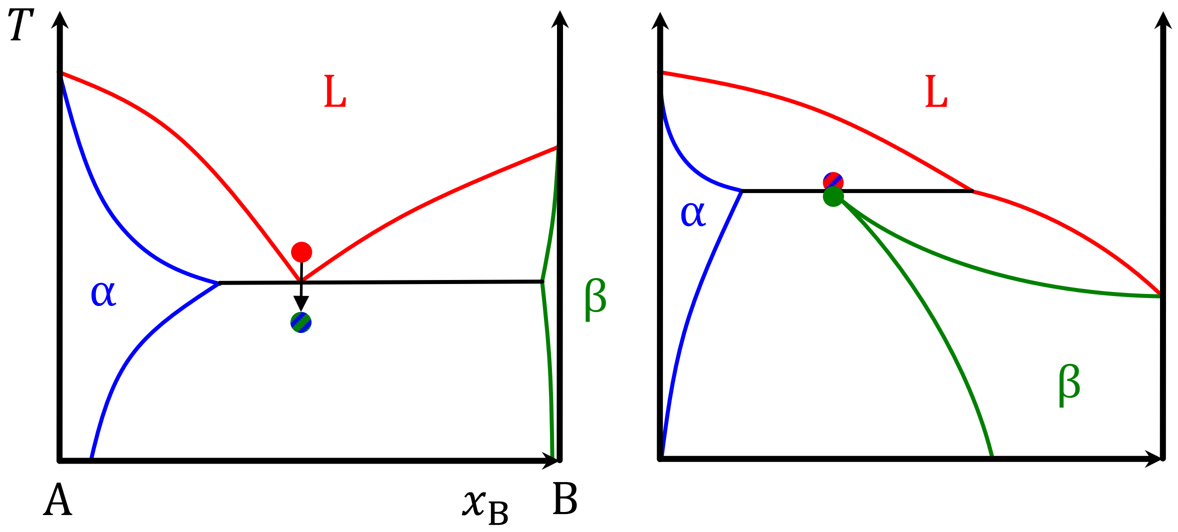
Spinodal Decomposition

- The spinodal decomposition is a reaction (often) free of nucleation and growth, only involving long-range "up-hill" diffusion. It occurs spontaneously without energy barrier.



Eutectic and Peritectic Reactions

- Other diffusion-controlled reactions involving thermally activated nucleation and growth are obtained by eutectic and peritectic reactions. During the eutectic decomposition, the metastable liquid is replaced by the stable two-phase solid condition. During the peritectic reaction, the stable phase is formed at the interface of the metastable solid and liquid high temperature phases with the restrictions of atomic flux through the phase formed.



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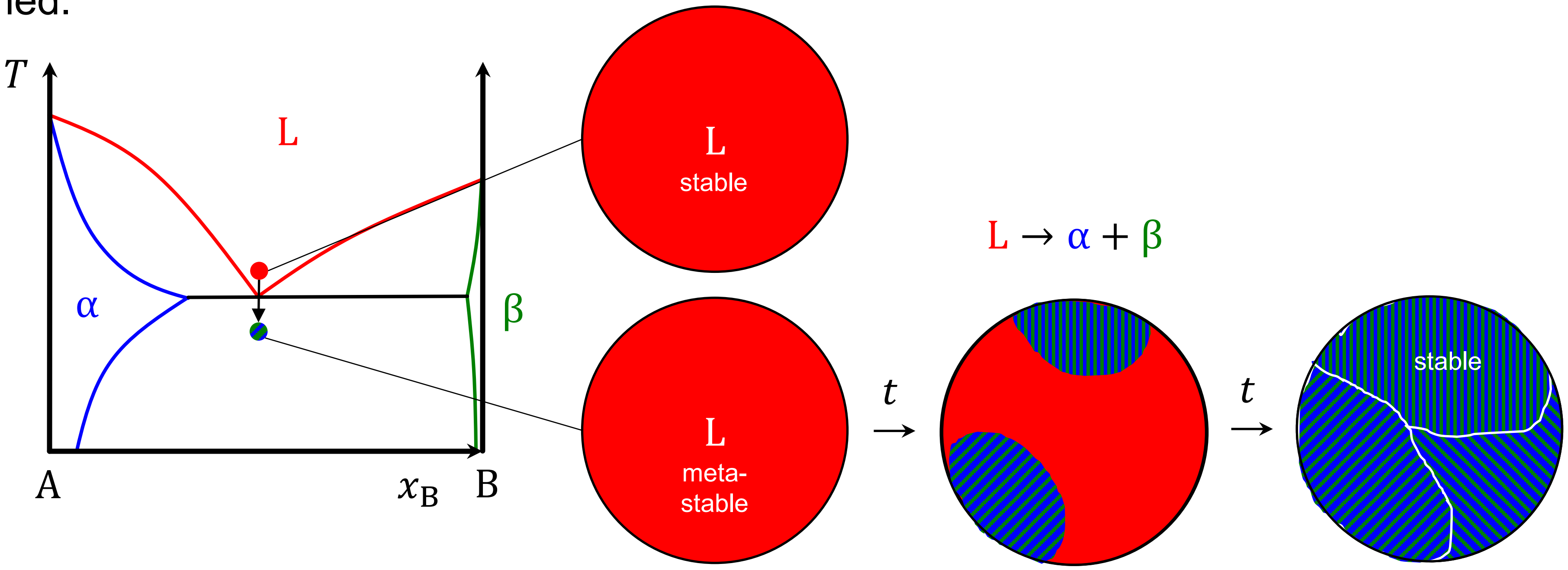

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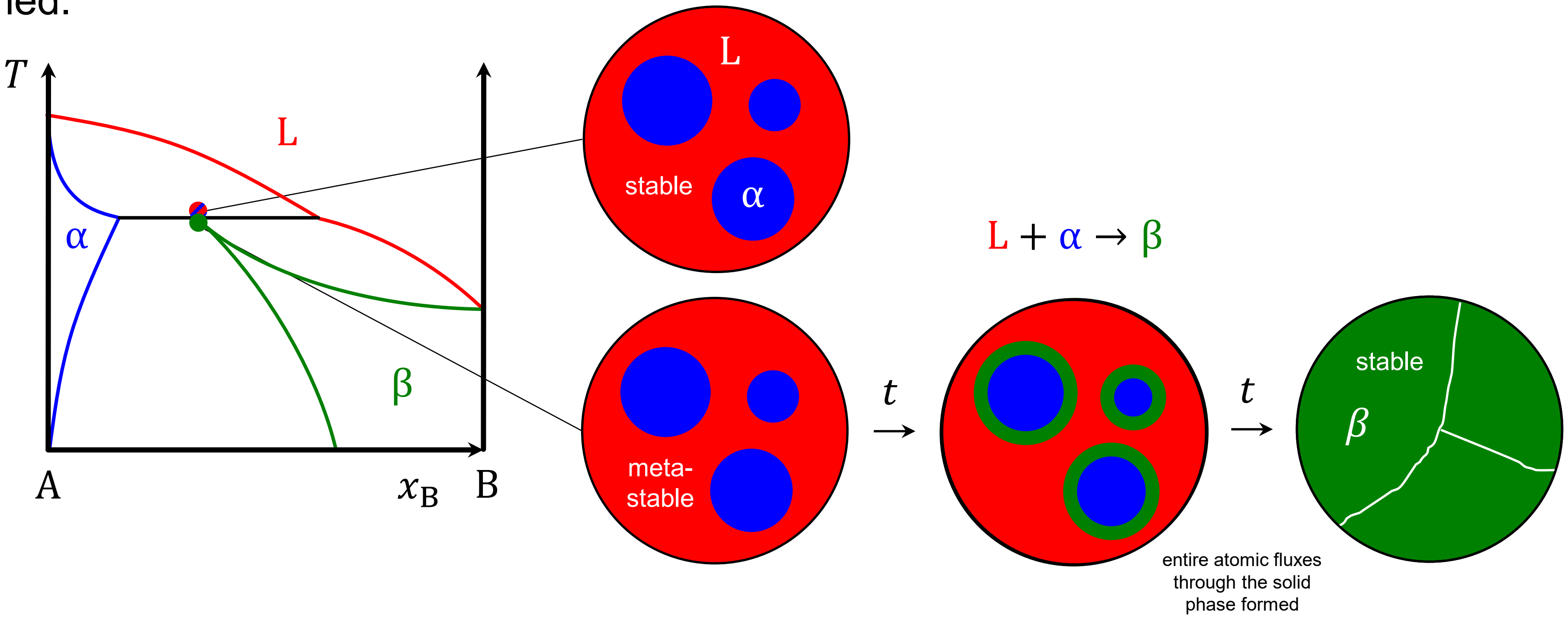

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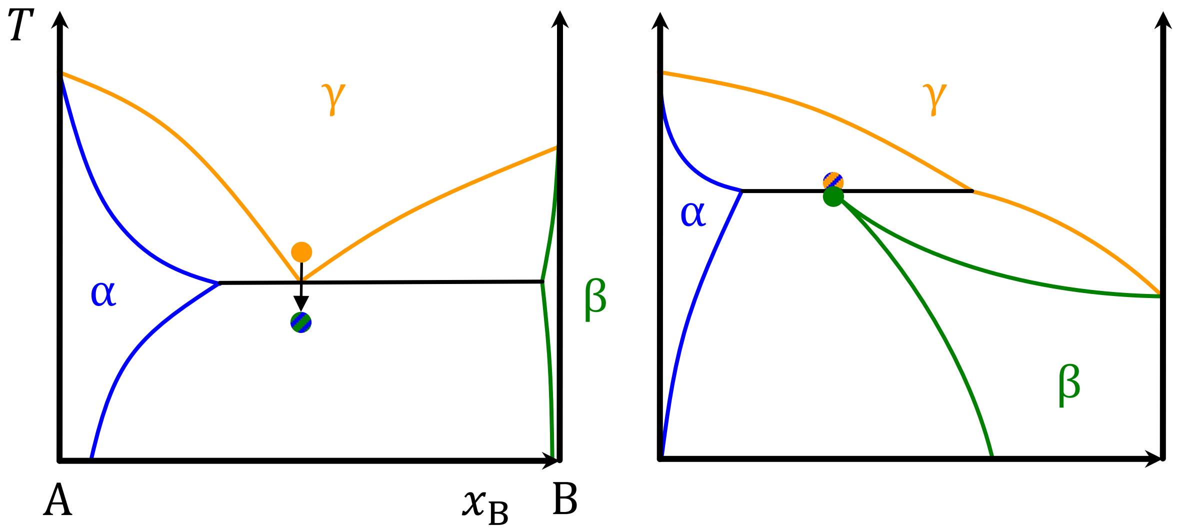

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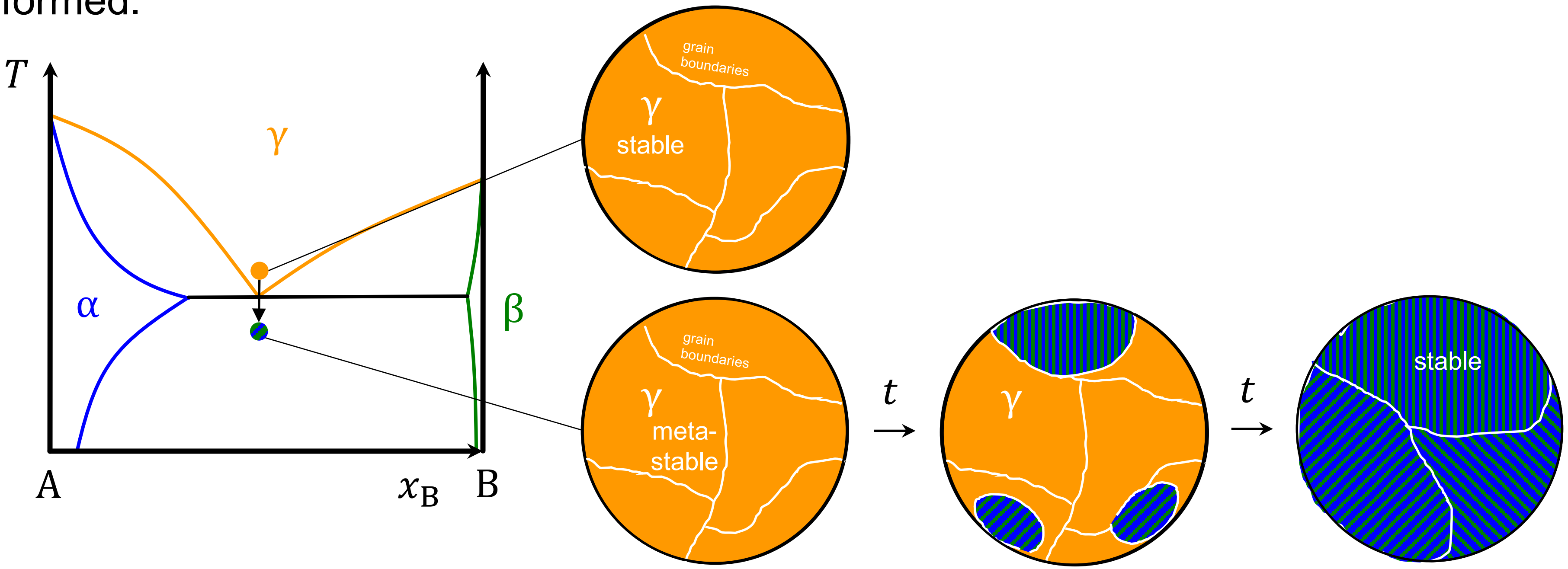

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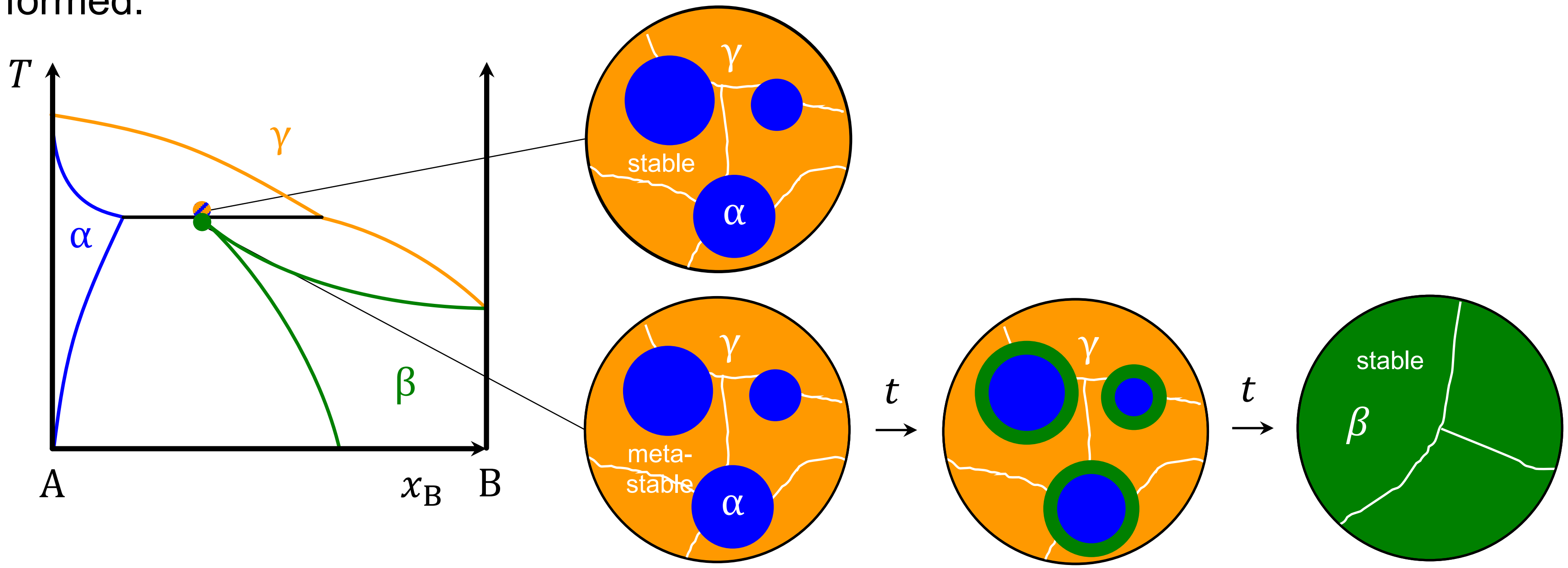
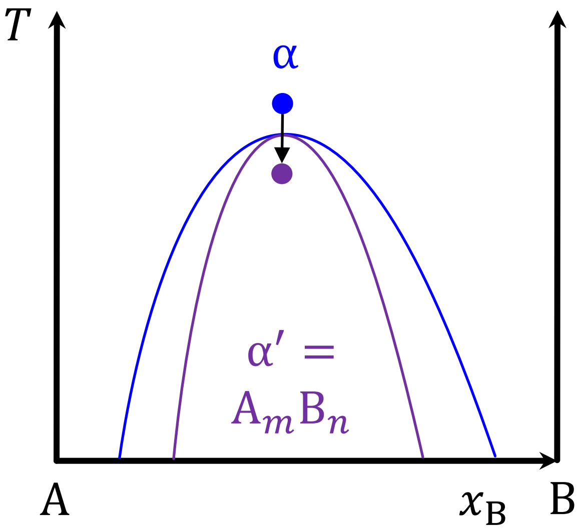
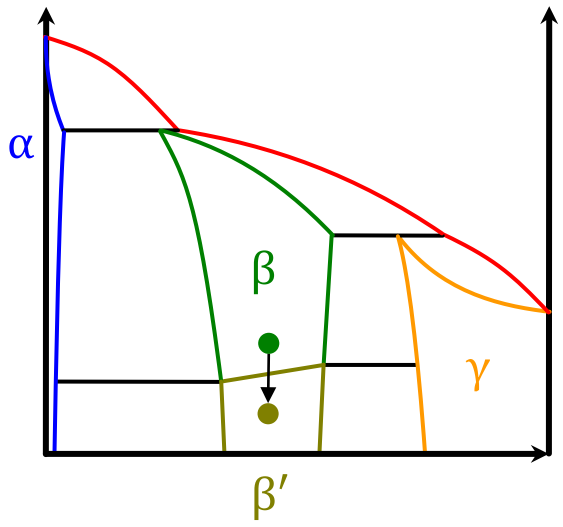


Ordering

- Disordered phases might undergo crystallographic ordering below certain temperatures. Since only rearrangement of atoms within unit cells are required to obtain the different site occupations, no long-range diffusion is required. The reaction can be discontinuous (1st order) by thermal activation due to domain growth or continuous (2nd order).



1st order with two-phase region



2nd order

Note that apart from variation in site occupation, slight modifications of the crystal structure (symmetry, dimensions) might be obtain as well. In contrast to pure elements (allotropic transf.), the transition from one crystal structure to another in alloys is usually referred to as polymorphic transformation.

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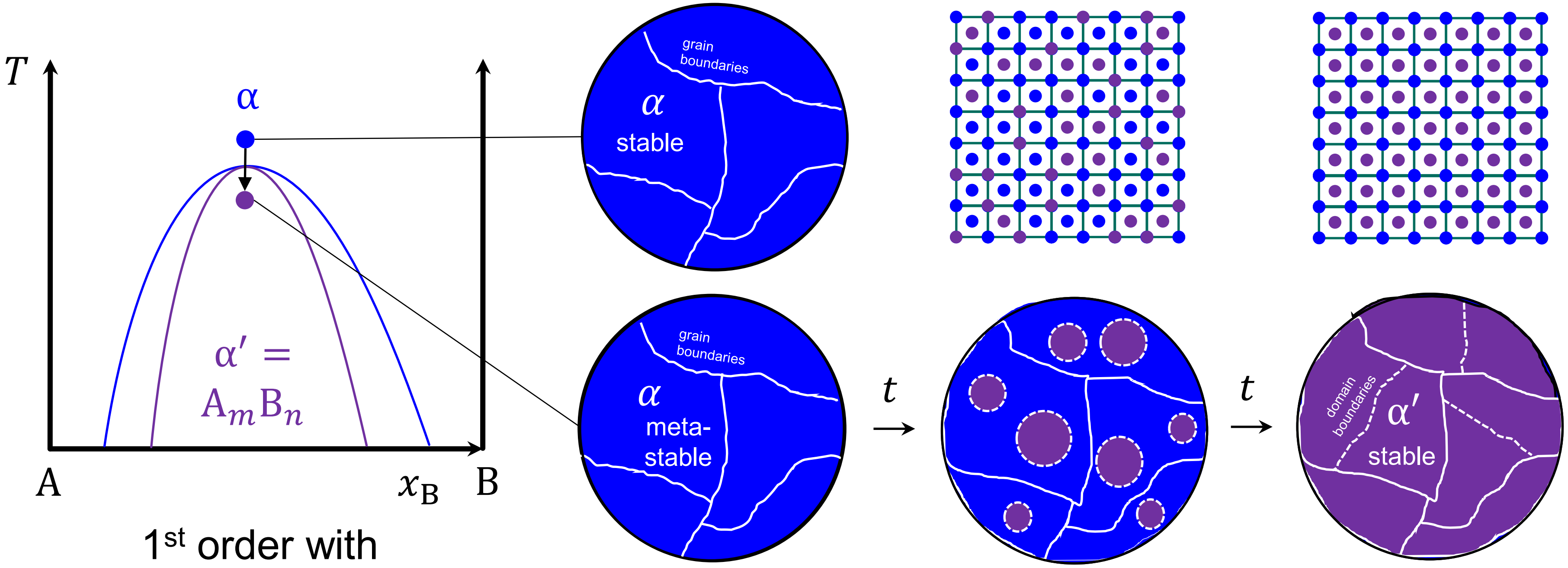

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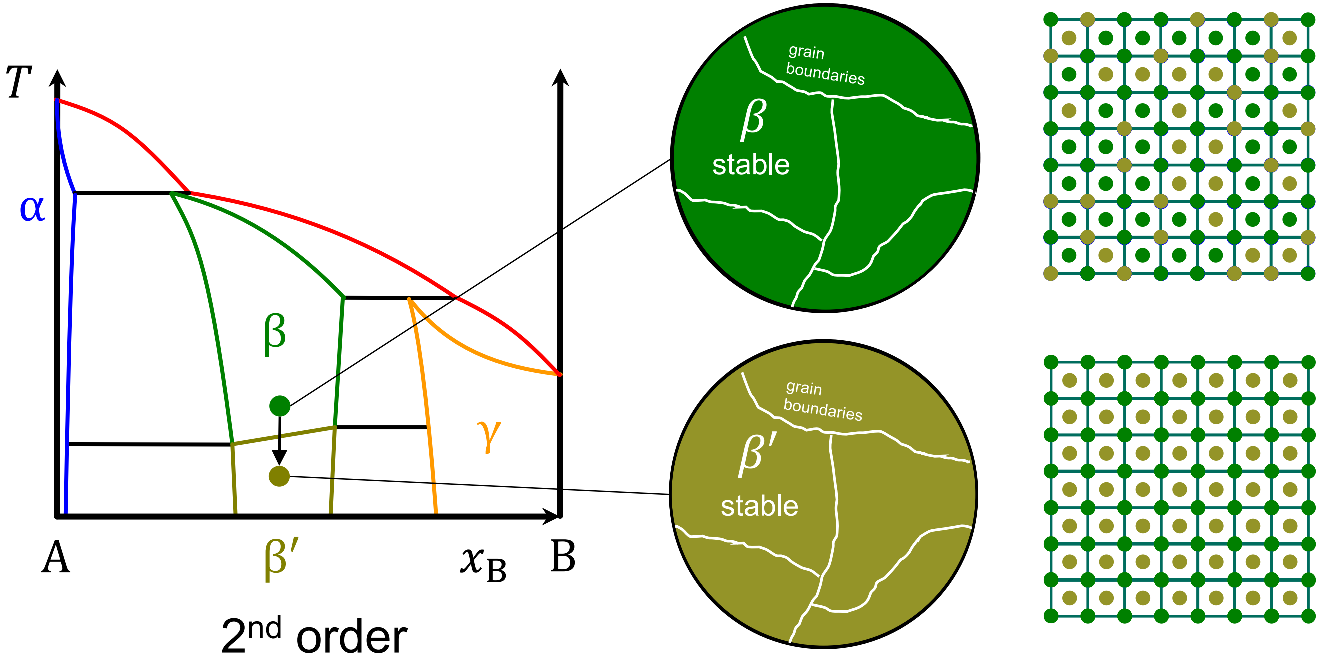
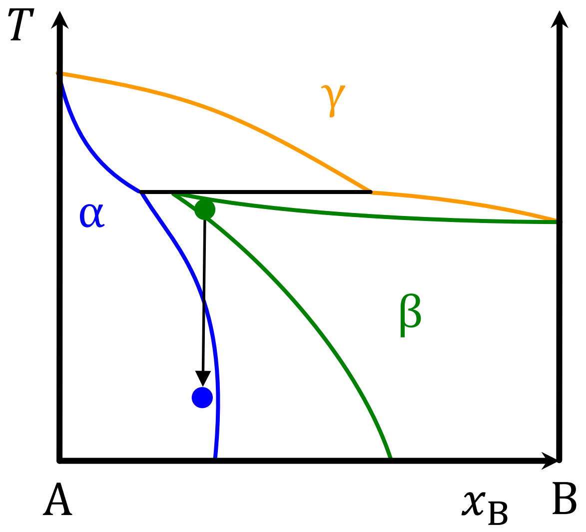
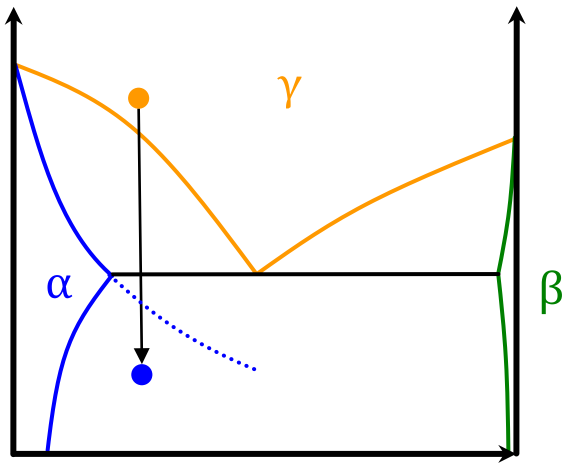


Massive Transformation

- During massive transformation, a single-phase condition transforms into one or several phases of the same composition. In contrast to the martensitic transformation where the structural change is obtained by deformation, the restructuring occurs by thermally activated short-range rearrangement of atoms during massive transformation.



stable
subs. to massive transf.



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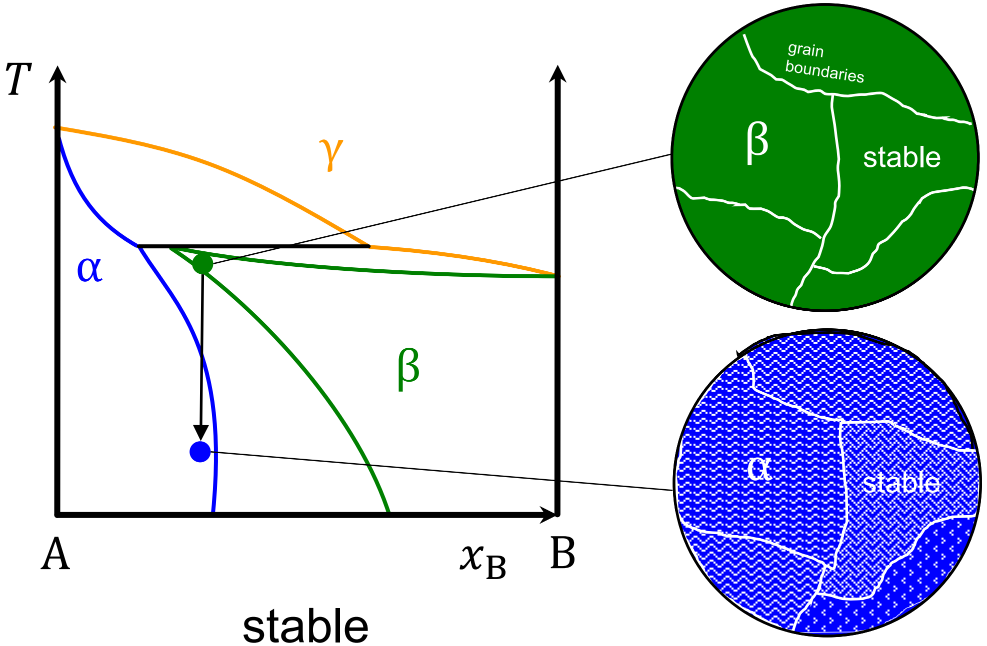

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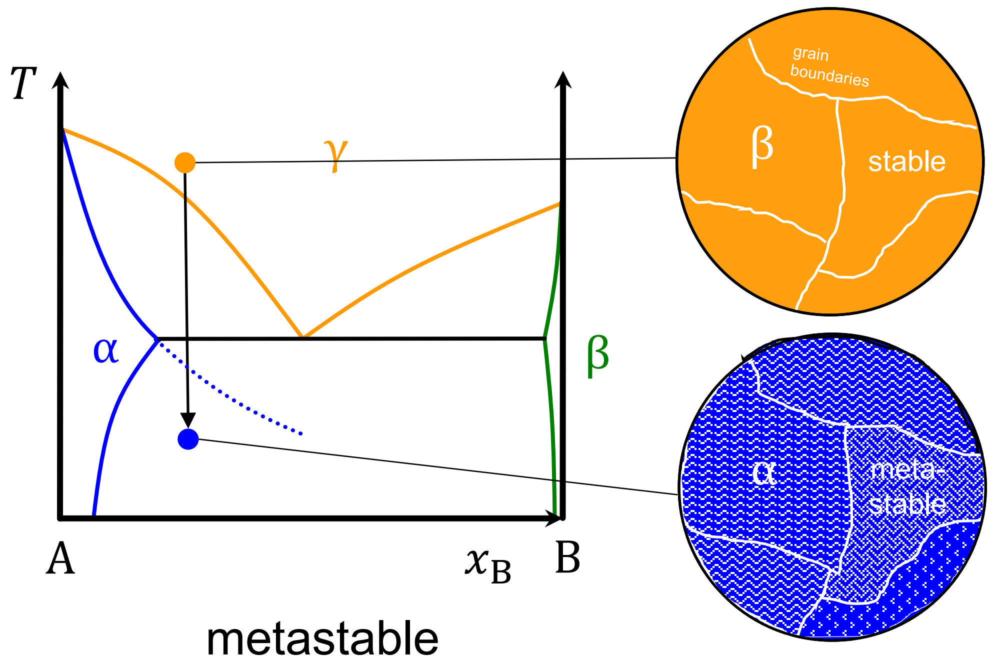

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