POLYMORPHISM

Petr Beňovský

POLYMORPHISM

The ability of a solid material to exist in multiple forms or crystal structures known as polymorphs;
Polymorphs have different energy of their crystal lattices, and consequently different melting points, solubilities etc.

Do not mix up polymorphism with **crystal morphology** – a compound under different conditions crystallizes in different shapes – **habits**, but a polymorph is still the same;

Pseudopolymorphs – the crystal lattice contains some amount of solvent (solvates, hydrates)

POLYMORPHISM

Polymorphs are crystalline materials that have **the same chemical composition**, but **different molecular packing**

POLYMORPHISM VS. ALLOTROPY

ALLOTROPY – the existence of two or more different physical forms of a chemical element;

Example – graphite, diamond, fullerene

DOES IT MATTER?

When Napoleon invaded Russia, the soldiers' tin buttons disintegrated in the cold. They had to survive the Russian winter with open jackets!! (**tin pest**)

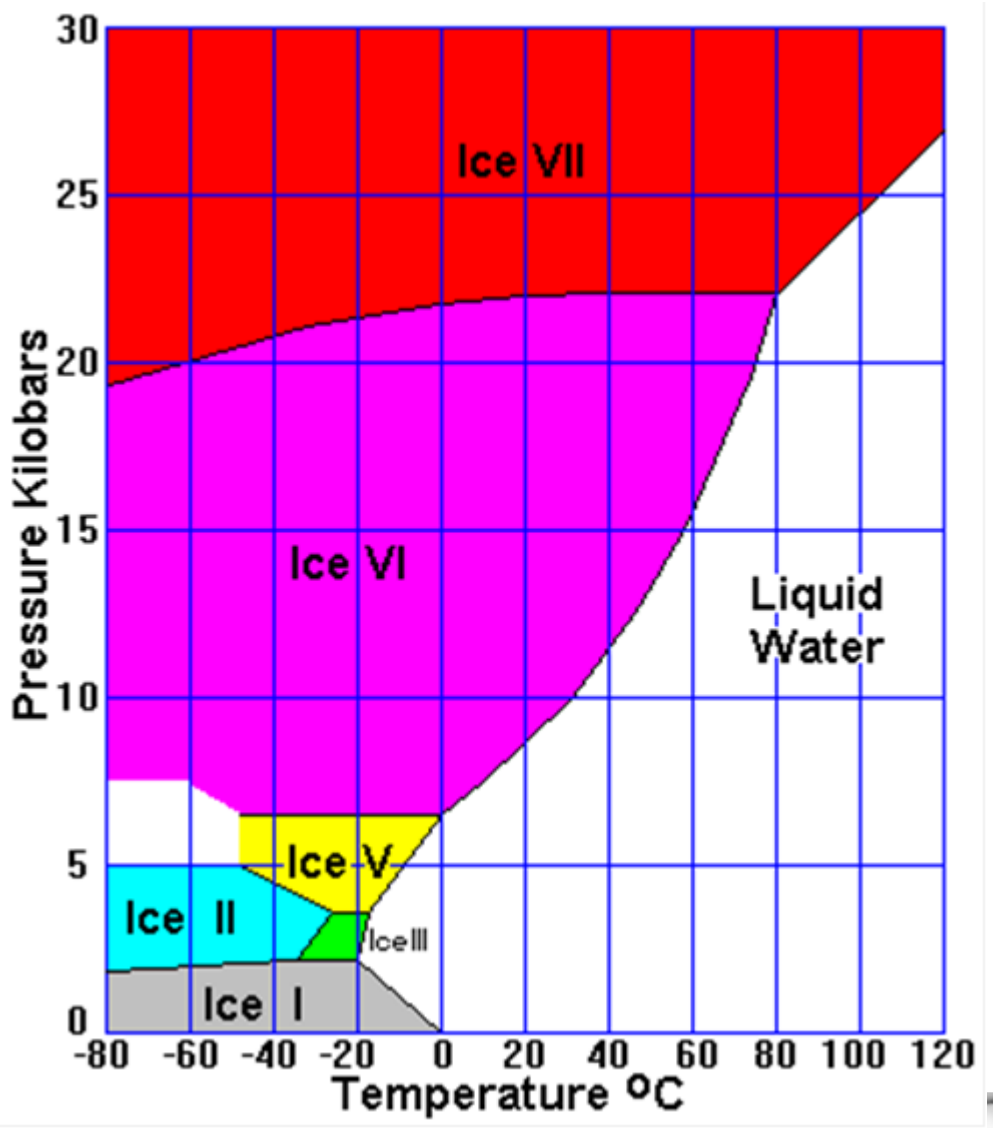
Some say it is only a legend

POLYMORPHISM

Some polymorphs of ice

Kurt Vonnegut – Cat's Cradle - New water modification - **Ice Nine** – supposedly inspired by Irving Langmuir (General Electric Co.)

Ice IX really exists, it is stable at T below 140 K and pressure between 200 – 400 MPa;
Ice IX fortunately does not have properties described in the novel!



POLYMORPHISM

McCrone criterion – Polymorphs differ in crystalline structure, but molecules are identical in liquid and gaseous states;

McCrone's statement – every compound has different polymorphs, and that, in general, the number of forms known for a given compound is proportional to the **time** and **money** spent in research on that compound.

Polymorphs of cocoa butter

Crystal form	*Formation conditions*	*m. p. [°C]*
I	rapid cooling of the melt	17.3
II	rapid cooling of the melt at 2 °C/min	23.3
III	crystallization of the melt at 5–10 °C, converts into II at 5–10 °C	25.5
IV	crystallization at 16–21 °C	27.3
V	slow crystallization of the melt	33.8
VI	from form V after several months at RT	36.3

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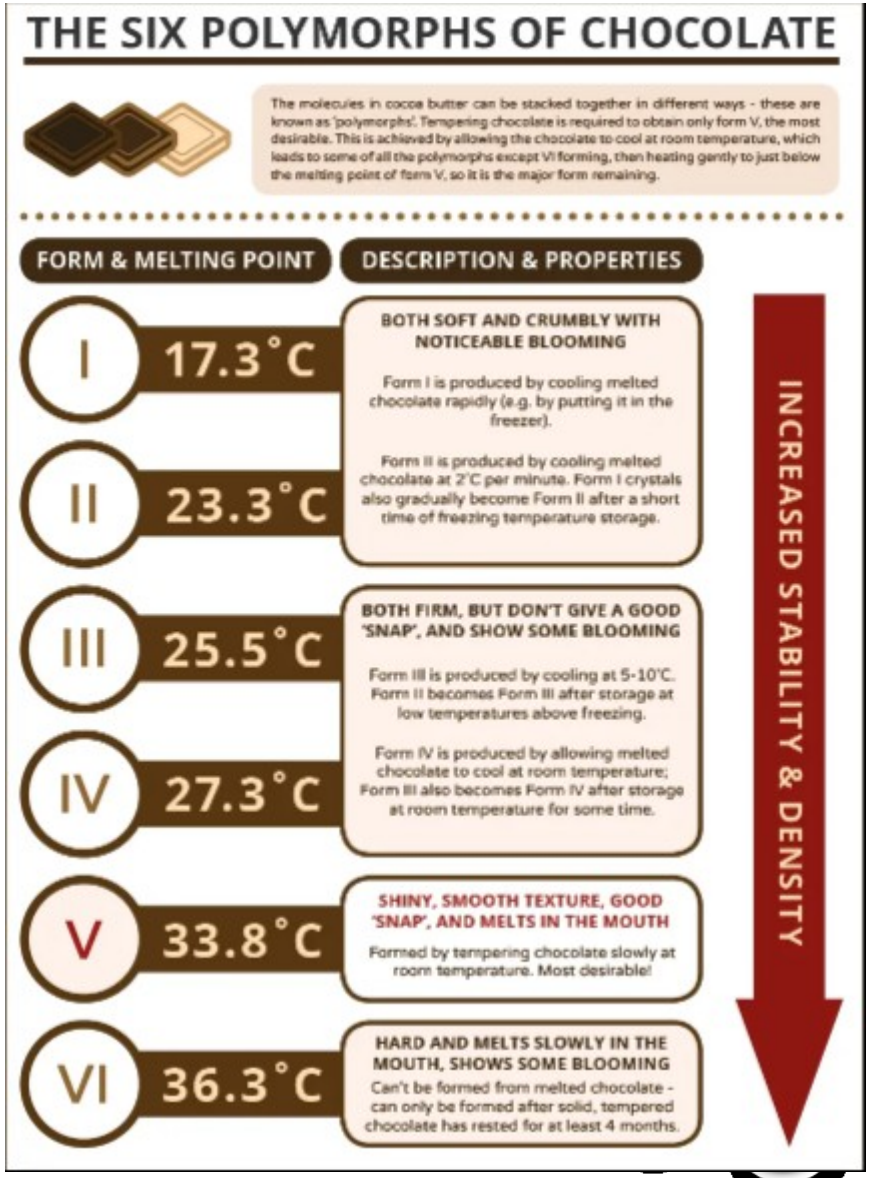
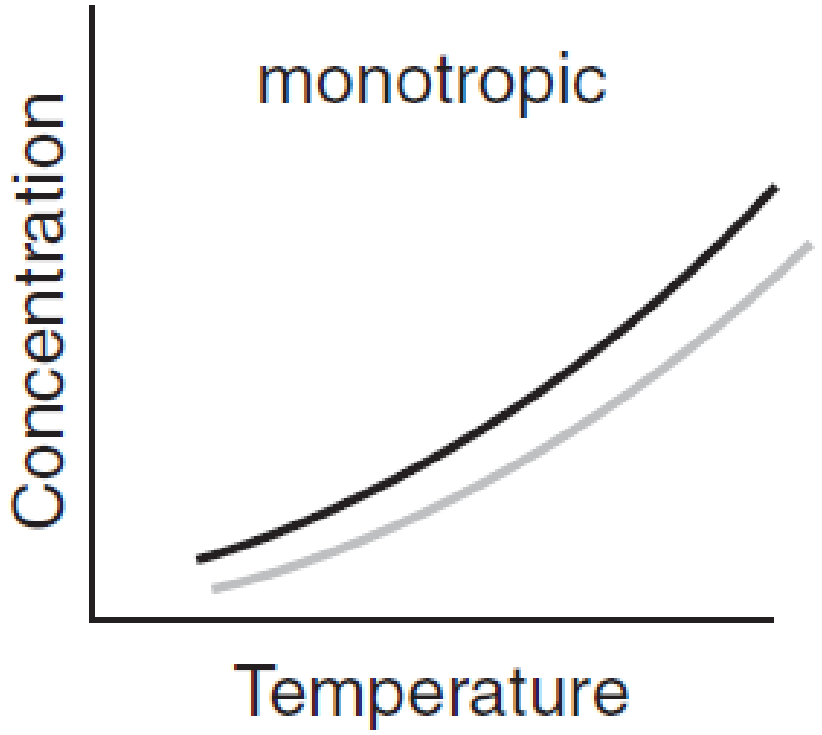
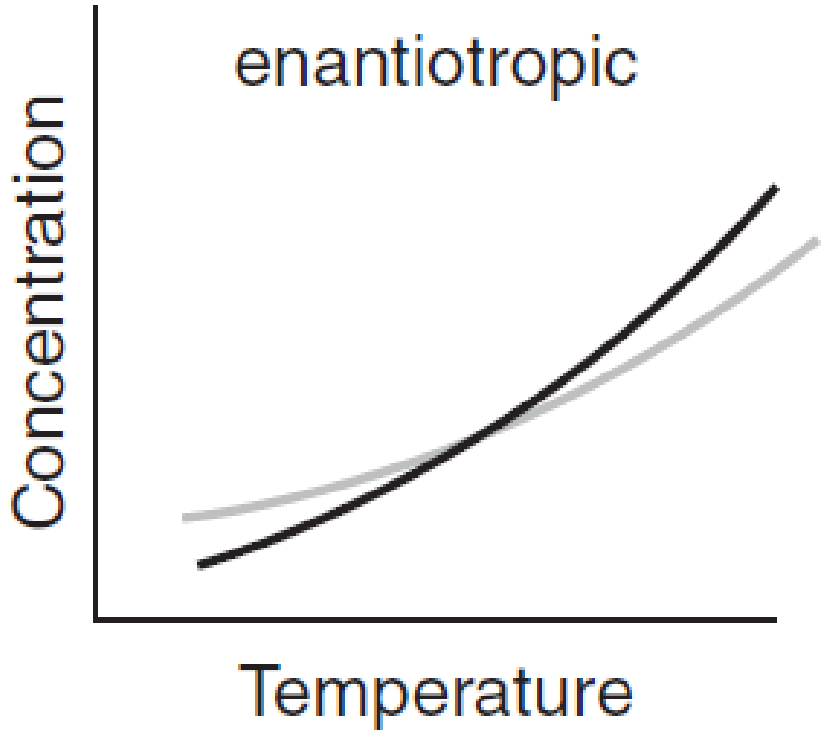


POLYMORPHISM

Monotropic polymorphs

Enantiotropic polymorphs – more stable form depends on temperature





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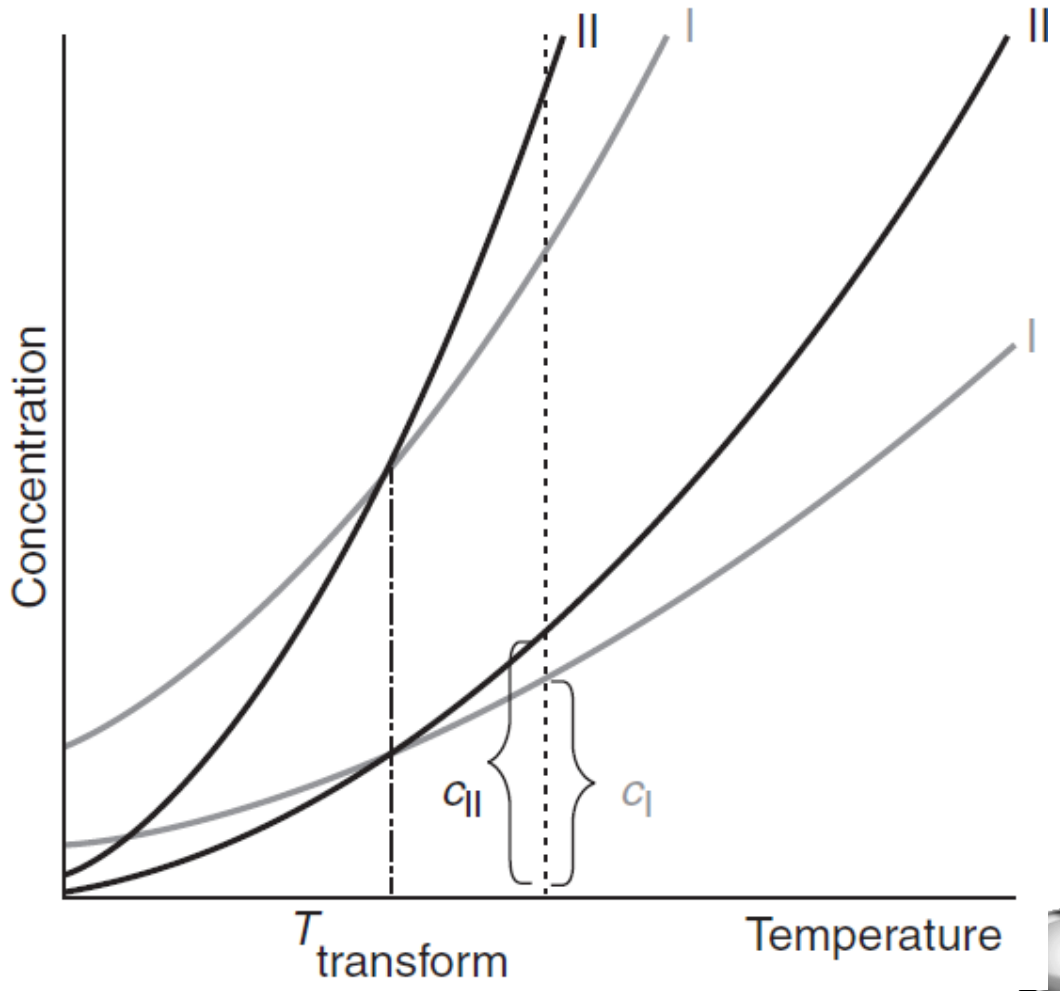
Transition temperature for enantiotropic polymorphs is **independent** on a solvent;



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At the transition point of a dimorphic enantiotropic system both polymorphs have the same thermodynamic potential and **the same solubility**;

The transition temperature is only related to the solid lattice structures and therefore independent of the solvent from which the polymorphs are crystallized.

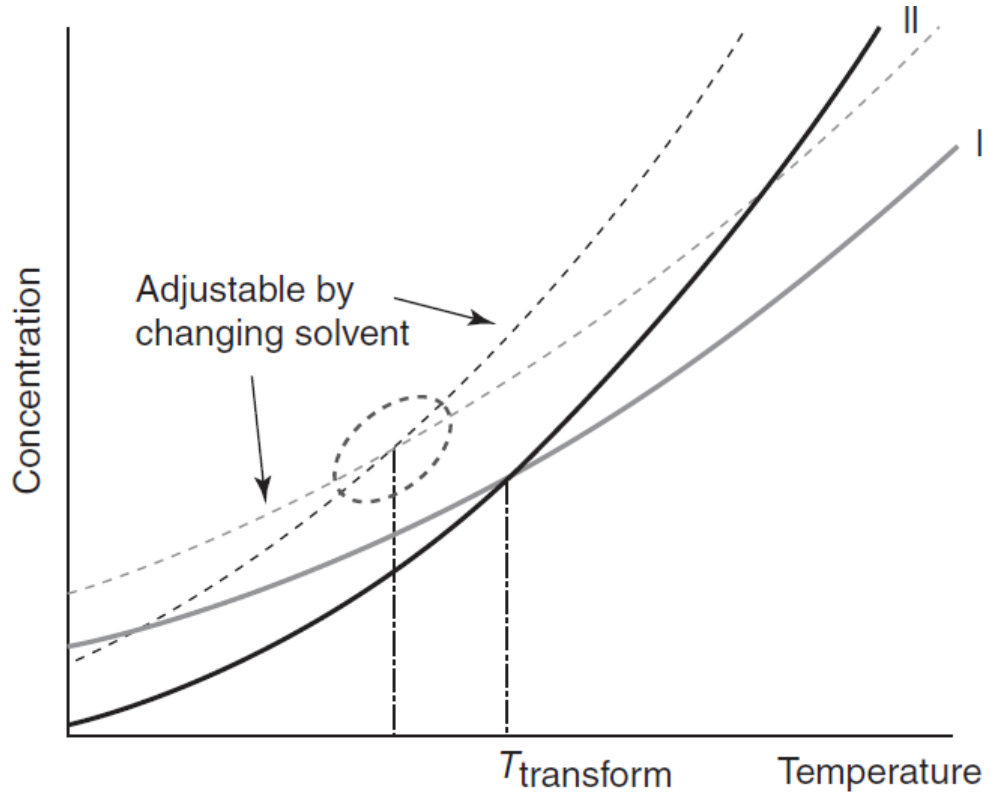
POLYMORPHISM

Metastable zone width is however strongly influenced by selected solvent;

Ostwald's step rule – for several possible polymorphs (in metastable zone) **less stable** polymorph is formed preferentially;

Possible formation of **different** polymorphs in **different** solvents;

Concomitant polymorphism



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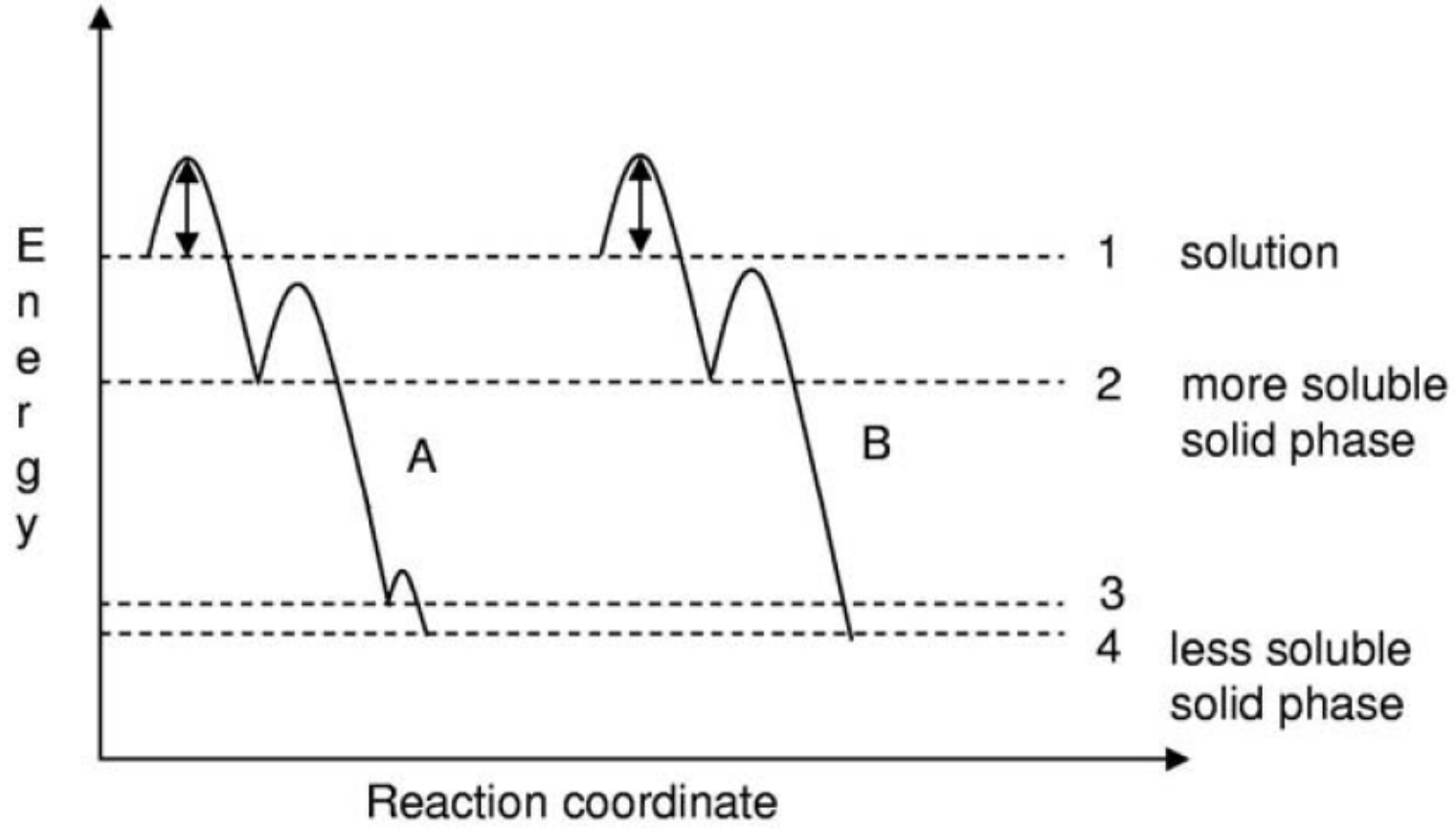
Ostwald's step rule – graphical description



POLYMORPHISM

Burger (Ramberg) rules

Heat of Transition rule

- Polymorphs are enantiotropically related if endothermic heat of transition from a lower melting form to a higher melting form is observed;

Heat of Fusion rule

- Polymorphic pairs are enantiotropically related if the low melting form has the higher heat of fusion, otherwise they are monotropically related;

Entropy of Fusion rule

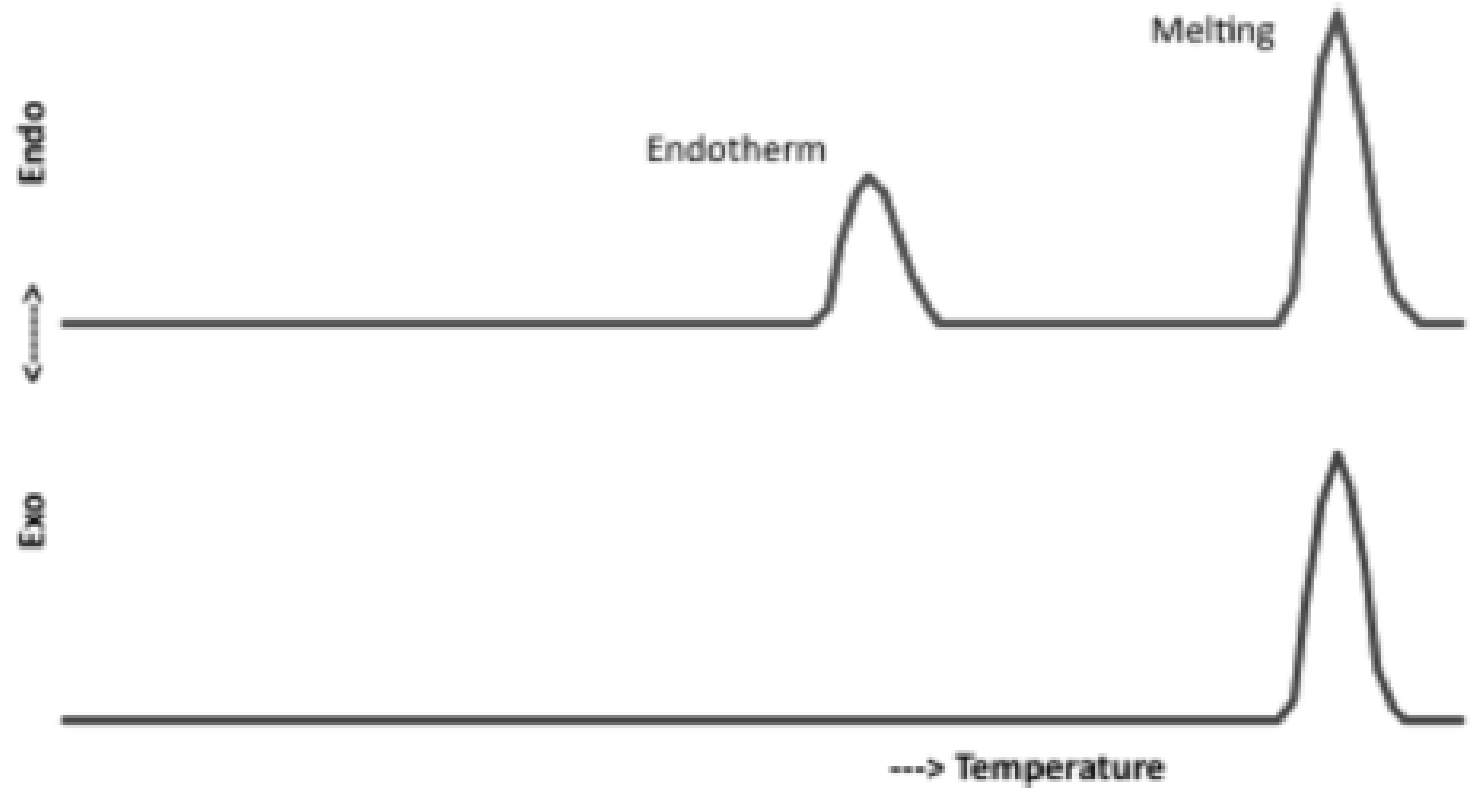
- Polymorphs are enantiotropically related if the high melting form has the lower entropy of fusion, otherwise they are monotropes;

It is recommended to confirm DSC results with experimental microscopic observations, solubility determination or slyrrying;

POLYMORPHISM

- **Burger (Ramberg) rules**

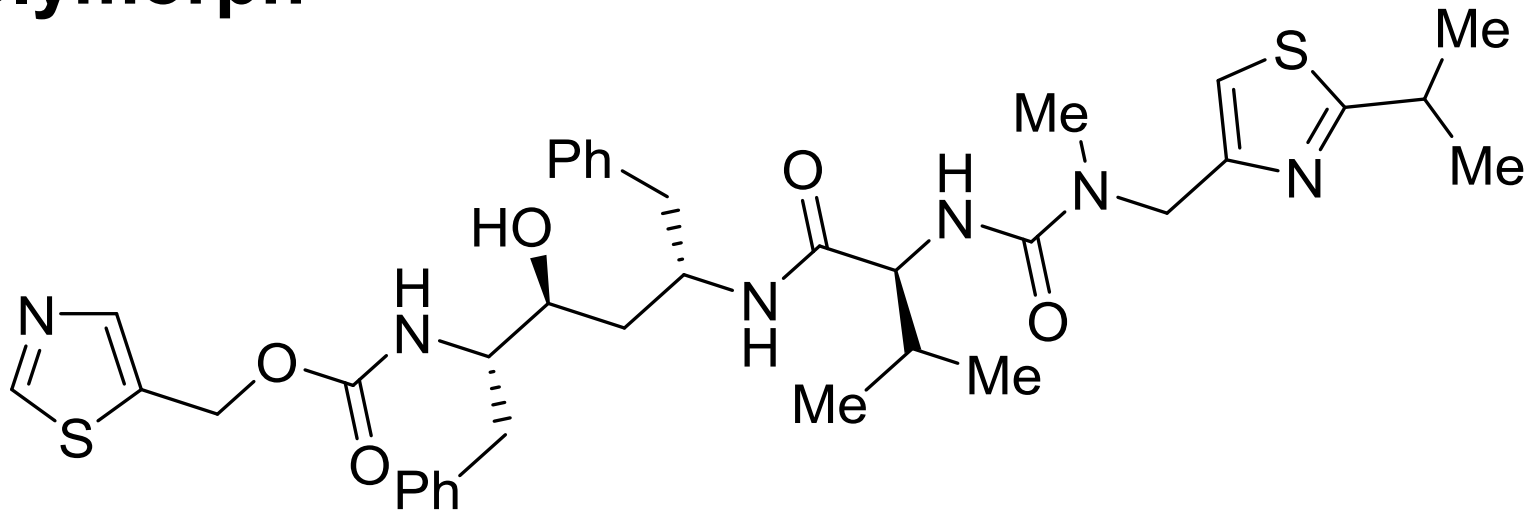
Heat of Transition rule



POLYMORPHISM

Disappearing polymorph

Ritonavir Case



Protease inhibitor for HIV (Abbott, Norvir™)

Chemburkar, S.R. *et al Org. Process Res. Dev.* ***4***, 413 (**2000**)

POLYMORPHISM

Disappearing polymorph

Ritonavir Case

NDA (New Drug Application) filed in December 1995;
Two years after some lots of the product (semisolid gel capsules with Form I) failed a dissolution specification;
The new crystal form (Form II) was found;
Form II is thermodynamically more stable than Form I
Samples of Form II brought to a laboratory to study – within a few days **all** of the lots of ritonavir turned to Form II;
Form I manufacturing failed from this point and “disappeared“

POLYMORPHISM

Disappearing polymorph

Ritonavir Case

Causes:

- Small amounts of impurity
- Residual solvent

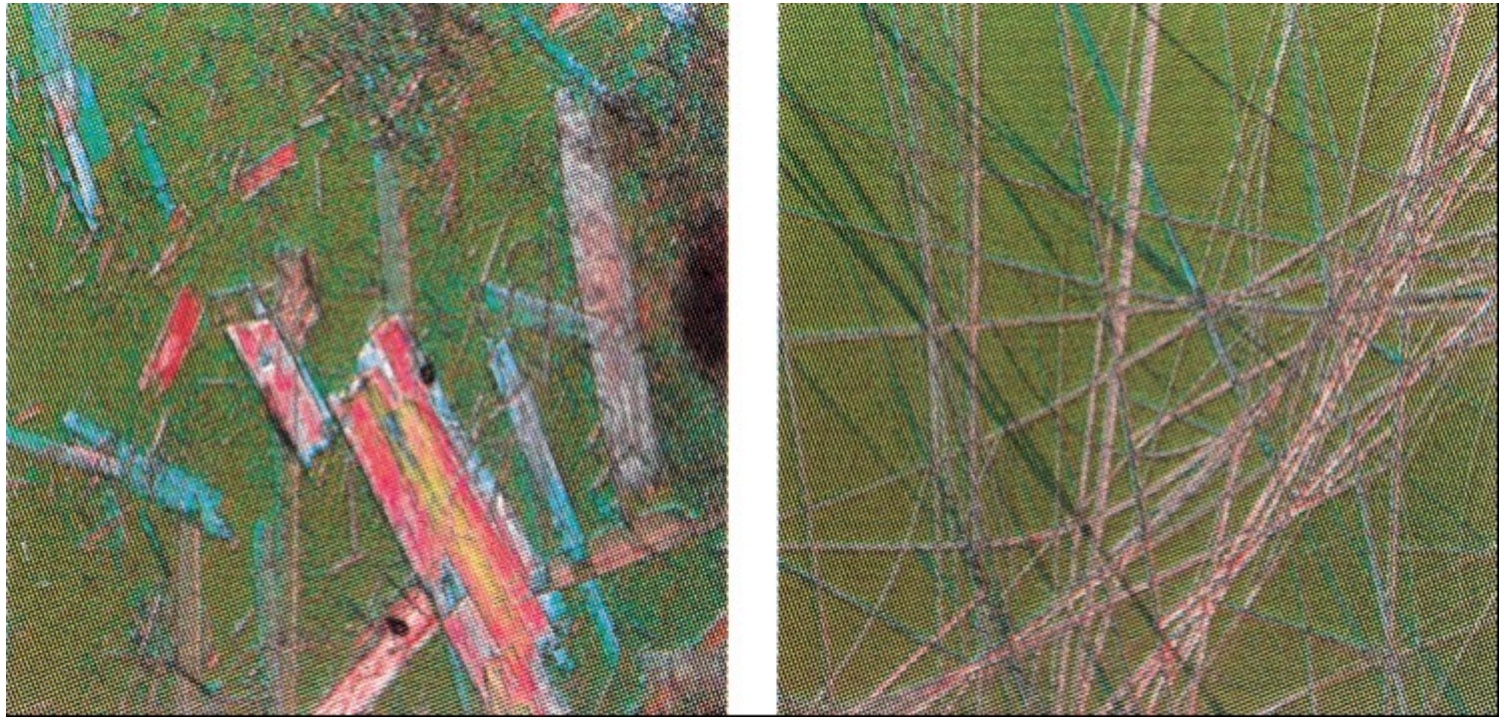
Solutions:

- Develop new manufacturing process for the preparation of Form I and also Form II;
- Develop new formulations with either Form.

POLYMORPHISM

Disappearing polymorph

Ritonavir Case



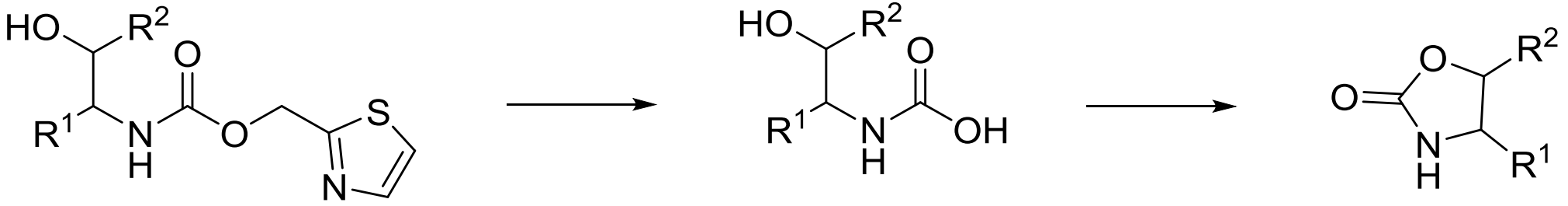
Form I

Form II

POLYMORPHISM

Disappearing polymorph

Ritonavir Case



POLYMORPHISM

Disappearing polymorph

Dunitz, J.D. *et al Acc. Chem. Res. 28*, 193 (**1995**)

Bučar, D.-K. *et al Angew. Chem. Int. Ed. Engl. 54*, 6972 (**2015**)