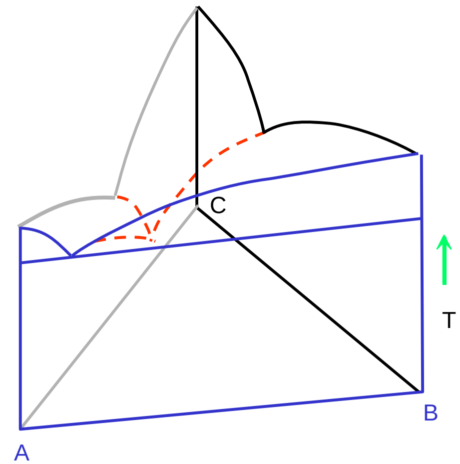
Outline

- Ternary Phase Diagram:
  - Review
  - Alkemade's Lines
  - Crystallization Path Analysis
- Vertical Sections
- Isothermal Sections

Ternary Systems: *Review*

A ternary temperature-composition "phase diagram" at constant total pressure may be plotted as a three-dimensional "space model" within a right triangular prism with the equilateral composition triangle (……… triangle) as base and temperature as vertical axis.

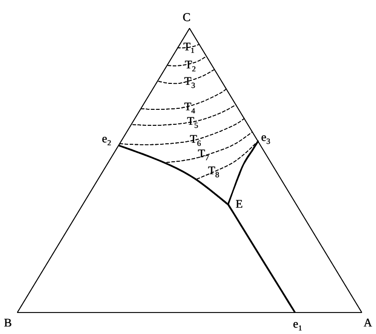
- The three binary subsystems such as A-B, B-C, and C-A, can be seen on the vertical faces of the prism. The three binary eutectic points are e_1, e_2, and e_3.
- Within the prism, the three liquidus surfaces descending from the melting points of pure A, B, and C and make the ternary eutectic point E.



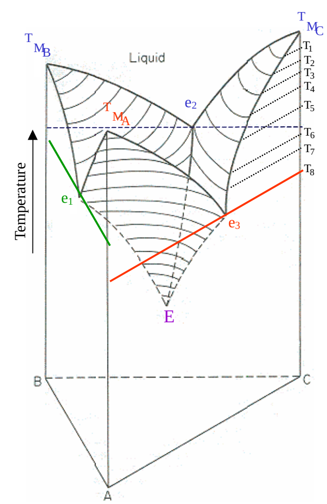
Space model for a simple eutectic ternary system A-B-C

Ternary Systems: *Review*

The lines on the liquid surface are the constant temperature lines called isotherms.



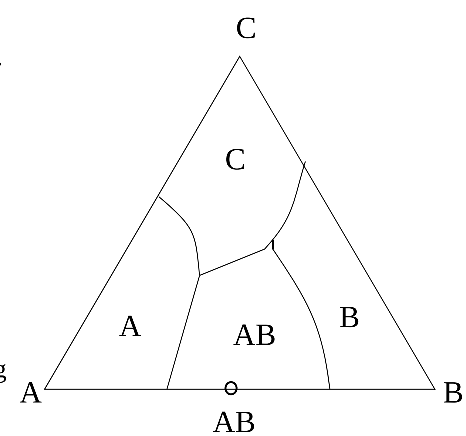
The plan view of the ternary space model with the important points



Space model for a simple eutectic ternary system A-B-C

Alkemade Lines

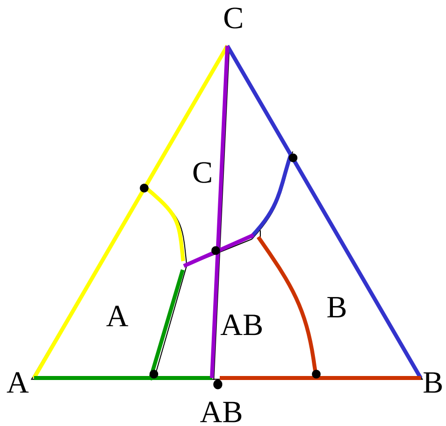
- Alkemade lines are the lines that connect the primary compositions of two phase fields which share a common boundary.
- Alkemade lines divide a phase diagram into compatibility triangles.
- This diagram is divided into two compatibility triangles: A-C-AB and B-C-AB.
- Alkemade's theorem can be used to determine the direction of decreasing temperature on a phase diagram, as we will discuss later.



Each boundary line on the diagram has an Alkemades line associated with it.

Alkemade Lines: *Ternary Invariant Points*

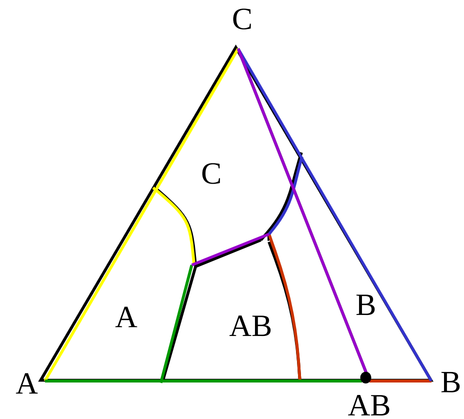
- The intersection of a boundary line (*or extended boundary line*) with its corresponding Alkemade line (*or extended Alkemade line*) is a maximum in temperature on the boundary line and a minimum in temperature on the Alkemade line. This point is labeled "**m**".
- This theorem can be used to draw arrows on the diagram showing the direction of decreasing temperature.
- The "m" on the triangle edges are the binary invariant points – ………. *points* in this example
- The point that resulted from the intersection of AB-C Alkemede line and the boundary between C and AB is called ………. *point*.
- E_1 and E_2 are ternary eutectic points.



Ternary system with a ……… binary compound

Alkemade Lines: *Ternary Invariant Points*

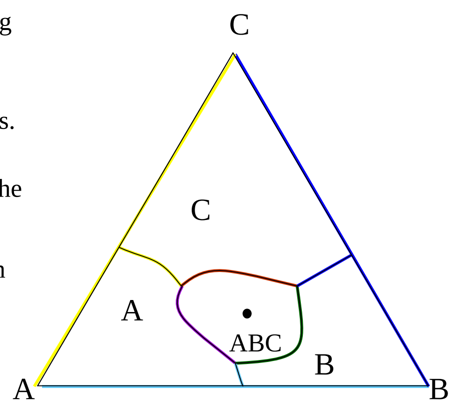
- The Alkemade line between C and AB, in this diagram, does not cross the boundary line that its end components share.
- This phase diagram is also divided to two compatibility triangles.
- First draw an extension of the boundary line so that it will intersect the Alkemade line.
- Then use the intersection point where the lines meet as a guide for drawing the temperature arrows. The temperature arrows on the Alkemade line will go towards the intersection point.



Ternary system with a ………… binary compound

Alkemade Lines: *Ternary Congruent Compound*

- As usual, we begin by highlighting each boundary line and the Alkemade line associated with it.
- Identify the compatibility triangles.
- Label the max/min points.
- Draw the temperature arrows on the boundary and Alkemade lines.
- The binary invariant points are given their appropriate labels.
- And the ternary invariant points are labeled.
- The diagram is finished.



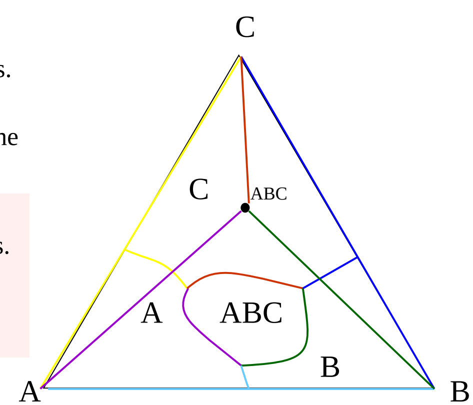
Ternary system with a congruent ternary compound

Alkemade Lines: *Ternary Incongruent Compound*

- As usual, we begin by highlighting each boundary line and the Alkemade line associated with it.
- Identify the compatibility triangles.
- Label the max/min points.
- Draw the temperature arrows on the boundary and Alkemade lines.

The ABC/A,B,C boundary lines and the associated Alkemade lines ……….. cross. To correct for this, draw a temporary extension of the ABC-C Alkemade line and of ABC/A and B boundaries .

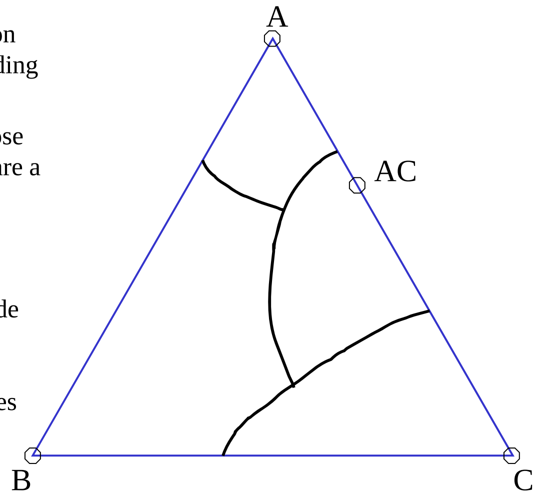
- The binary invariant points are given their appropriate labels.
- And the ternary invariant points are labeled.
- The diagram is finished.



Ternary system with a incongruent ternary compound

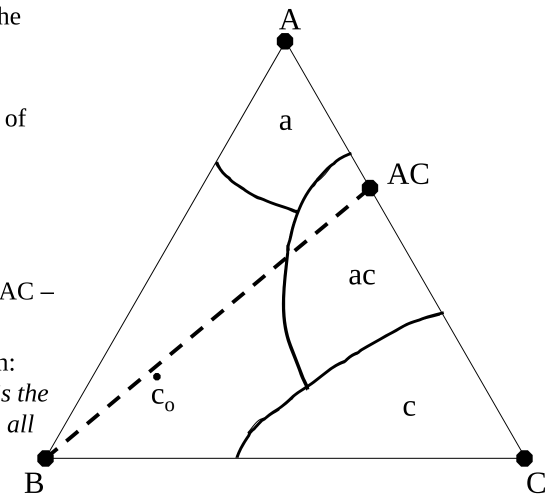
Crystallization Path Analysis

- First, identify the compounds on the diagram and their corresponding primary crystallization fields.
- Then connect compounds, whose primary crystallization fields share a boundary, with Alkemade lines.
- The Alkemade lines form compatibility triangles.
- Remember that where Alkemade lines cross boundary lines the boundary lines are at a local maximum and the Alkemade lines are at a local minimum in temperature



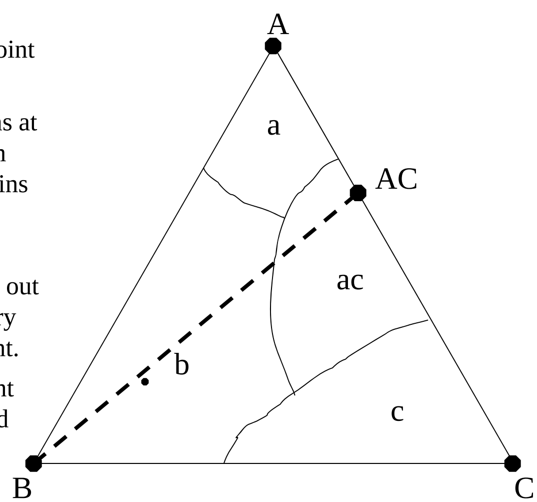
Crystallization Path Analysis

- Now we are ready to trace the cooling path of any ternary composition.
- First locate the composition of interest (c_o) on the diagram.
- Next determine its primary crystallization field.
- Identify the compatibility triangle: in our example, it is AC – B – C
- And final liquid composition: *The final liquid composition is the ternary invariant point where all three compounds in the compatibility triangle meet.*



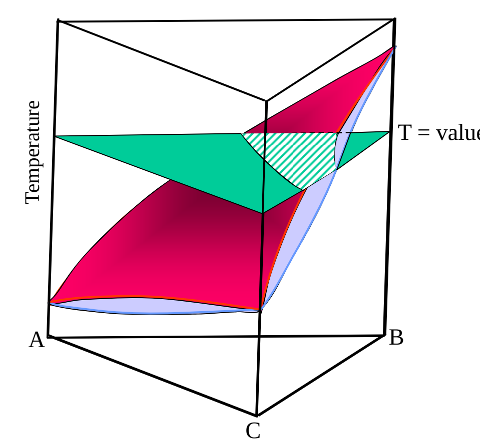
Crystallization Path Analysis

- Now draw a tie line from the primary phase B through the point to the boundary with ac.
- The crystallization path begins at the point and moves away from the the primary phase as B begins to crystallize out of the composition.
- Now AC begins to crystallize out as the path follows the boundary line to its ternary invariant point.
- Finally, at the ternary invariant point all of the remaining liquid crystallizes.

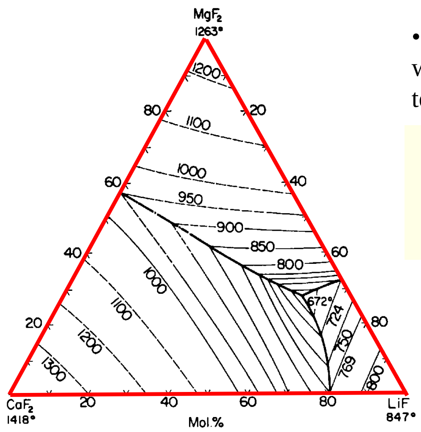


Ternary Isothermal Sections

- ✓ Isothermal sections in ternary phase diagrams are horizontal slices through the three dimensional diagram. All points on the section are at the same temperature, unlike the normal view of the ternary diagram where the liquidus surface is seen.
- ✓ A Ternary diagram is a flat representation of the curved liquidus surface. Therefore, in a normal ternary diagram, everything shown is liquid.
- ✓ In an isothermal section both liquid and solid can be present.



CaF_2-LiF-MgF_2 Isothermal Section at 1100°C

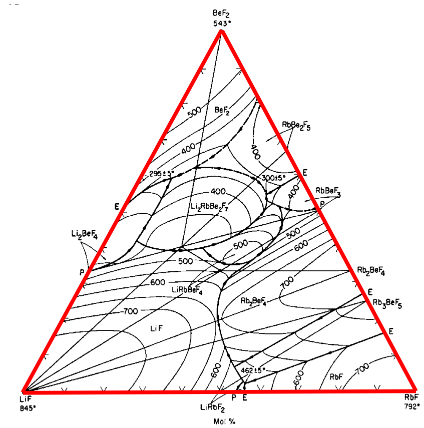


- Identify and trace all of the isotherms for the temperature for isothermal section of 1100°C.
- Then fill in for the region of the diagram where the liquidus area is still below the temperature of 1100°C.

Two phase regions occur when the intersection between the isotherm and a single phase region (e.g. liquid) is a line (not a point).

- Draw both lines that intersect with the phase boundary line and surround the two-phase region.
- Finally, draw in dashed tie lines from the composition to the liquidus region of 1100°C.

LiF-RbF-BeF_2 Isothermal Section at 700°C



- Trace all isotherms on this diagram at 700°C, and draw the tie lines.

Every phase field left at this point will consist of three phases. There will either be two solids and a liquid of a specific composition, or there will be three solid phases.

The three phase region shown here consists of $Rb_2BeF_4 – Rb_3BeF_5 – L_1$.

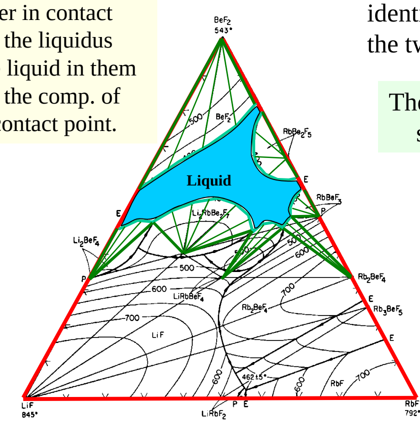
Ternary Isothermal Sections

- There are 4 types of phase fields in the isothermal section of a ternary system:
  - The ***single phase*** region. The phase can be a liquid or a solid solution. Liquid is more common. In the previous examples, this region is composed entirely of a liquid of varying composition.
  - The ***two Phase*** region, containing both solid and liquid. The composition of the liquid is found using the tie lines that were drawn in on the second slide. The solid is of a single, unvarying composition. This region shares a border with the liquid region.
  - The ***three Phase*** region, composed of two solid compositions and one unvarying liquid composition. This region is easily recognized by its sole point of contact with the liquid region, labeled L_1 in the previous slide.
  - The ***solid*** region, contains three distinct solids. This region is triangular, and has **no** contact with the liquid region.

None that the previous examples do not contain all four types of phase fields. Therefore the next example will be at 400°C.

Three-Phase Regions
LiF-RbF-BeF_2 Isothermal Section at 400°C

Remember that the regions with one corner in contact with the liquidus have liquid in them with the comp. of the contact point.

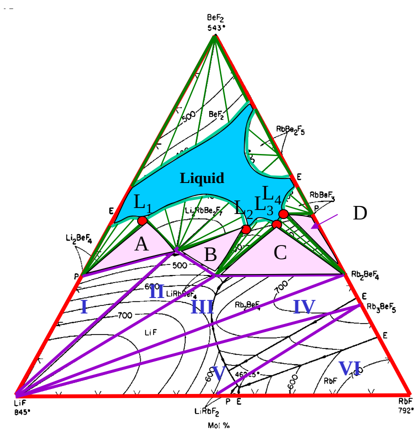


- Trace all isotherms on this diagram at 400°C, identify the liquid and draw the tie lines in the two phase regions.

The remaining portion has either three solids, or a liquid and two solids.

- Trace all Alkemade lines that do not come into contact with the liquidus lines, or cross any of the tie lines.
- Identify all the regions that contain ……..
- Everything that is left is all ……. (*three-………. region*).

LiF-RbF-BeF$_2$ Isothermal Section at 400°C



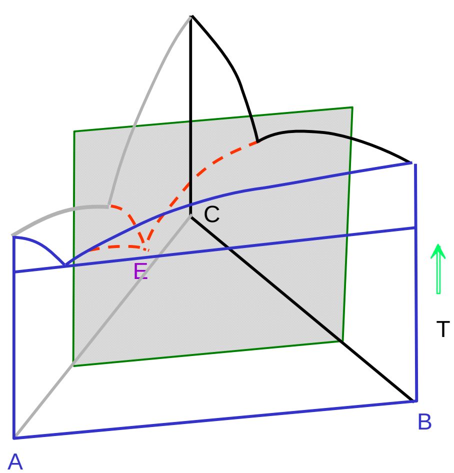
- Liquid and two solids regions:
  - A) L_1 & Li_2BeF_4 & $Li_2RbBe_2F_7$
  - B) L_2 & Li_2RbBeF_7 & $LiRbBeF_4$
  - C) L_3 & $LiRbBeF_4$ & Rb_2BeF_4
  - D) L_4 & $RbBrF_3$ & Rb_2BeF_4
- Three solids regions :
  - I) LiF & $Li_2RbBe_2F_7$ & Li_2BeF_4
  - II) LiF & $RbBe_2F_7$ & $LiRbBeF_4$
  - III) LiF & Rb_2BeF_4 & $LiRbBeF_4$
  - IV) LiF & Rb_2BeF_4 & Rb_3BeF_3
  - V) LiF & $LiRbF_2$ & Rb_3BeF_5
  - VI) RbF & $LiRbF_2$ & Rb_3BeF_5

10 minutes ***Break***

Ternary Vertical Sections: *Introduction*

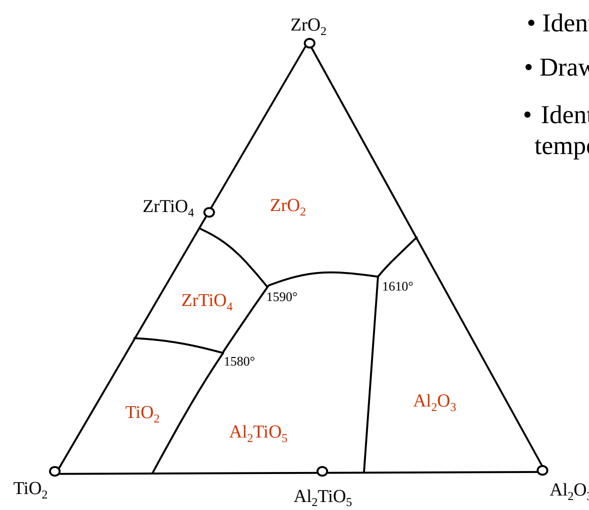
- Vertical sections are two dimensional representations of the crystallization paths for a series of points that lie along a chosen line on a ternary phase diagram.
- There are three main lines in a vertical section which divide the various solids and liquid phases. These three lines are called the liquidus, subliquidus, and solidus lines, and will be explained in more detail later.

Vertical sections in ternary systems can be very complicated due to the crossing of Alkemedes' lines and changing crystallization paths.



Space model for a simple eutectic ternary system A-B-C

Constructing Vertical Sections

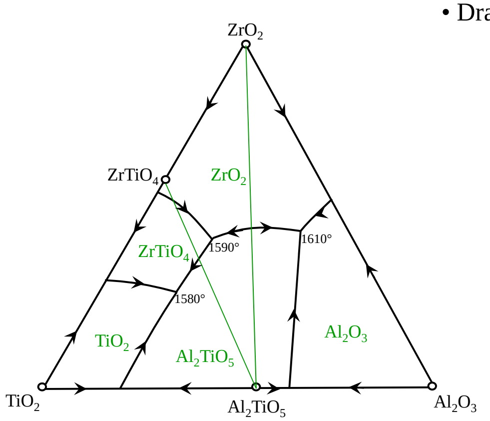


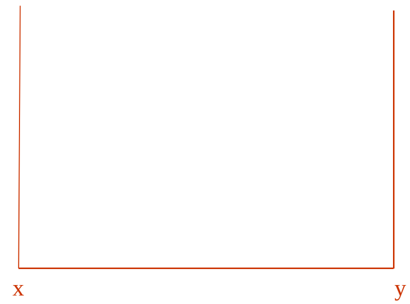
- Identify primary phase fields
- Draw Alchemades lines
- Identify direction of falling temperature on boundary lines.

Constructing Vertical Sections

• Choose the section line (x - y).

• Draw diagram framework.





Constructing Vertical Sections

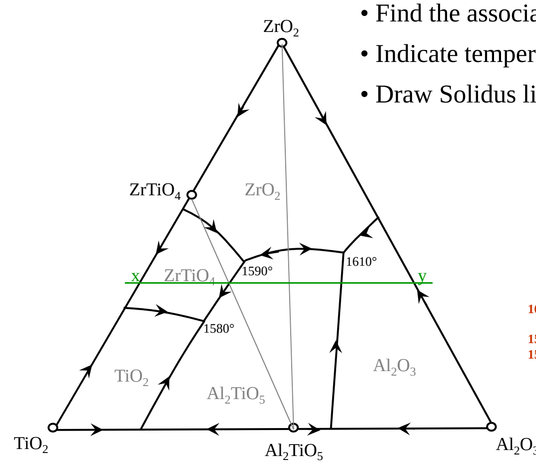
Step 1 - Solidus lines

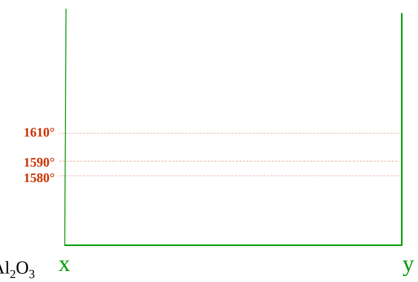
• Which compatibility triangles are crossed?

• Find the associated ternary invariant points.

• Indicate temperatures on (x - y) diagram.

• Draw Solidus lines on (x - y) diagram.





Constructing Vertical Sections

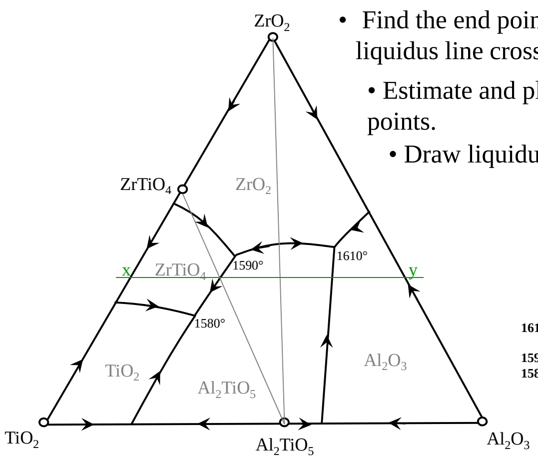
Step 2 - Liquidus line

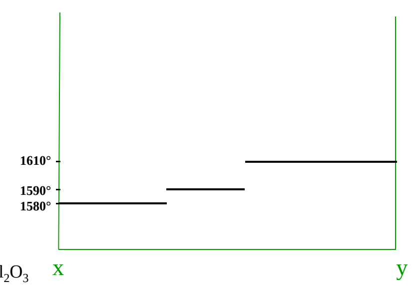
• The top view of the liquidus line can be seen on the ternary diagram.

  • Find the end points and points where the liquidus line crosses any boundary lines.

    • Estimate and plot relative temperatures of these points.

      • Draw liquidus line - estimate curvature.





Now we must Find and indicate all of the *important* compositions.

Vertical Section: *Important Compositions*

• The essential compositions used to develop the sub-liquidus line in a vertical section are called *important* compositions. The purpose of these important compositions is to reduce the work load on the investigator.

• These compositions separate regions of similar crystallization paths. Therefore, the crystallization paths of these compositions directly intersect important features of the ternary diagram. Some examples of these features are given.

Examples:

✓ Ternary Invariant Points

✓ m – Points

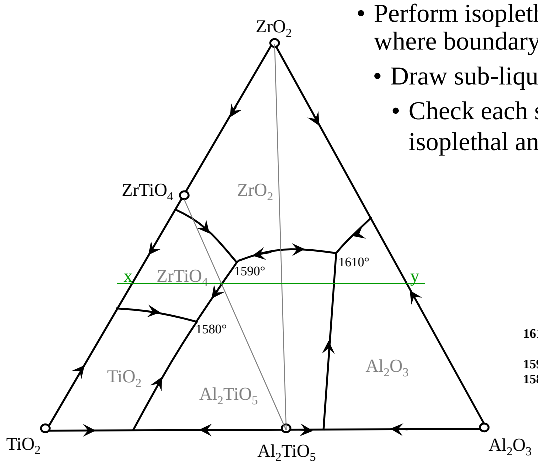
✓ Alchemades Lines

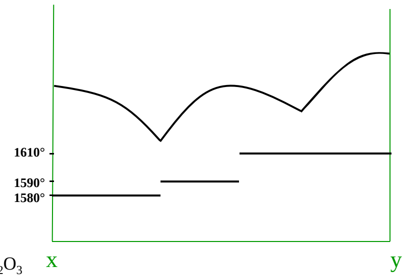
✓ Diagram Boarders

Constructing Vertical Sections

Step 3 - Sub-liquidus line

- Find and indicate all of the *important* compositions.
  - Perform isoplethal analysis - record temperature where boundary line is intersected.
    - Draw sub-liquidus line.
      - Check each segment with an intermediate isoplethal analysis.

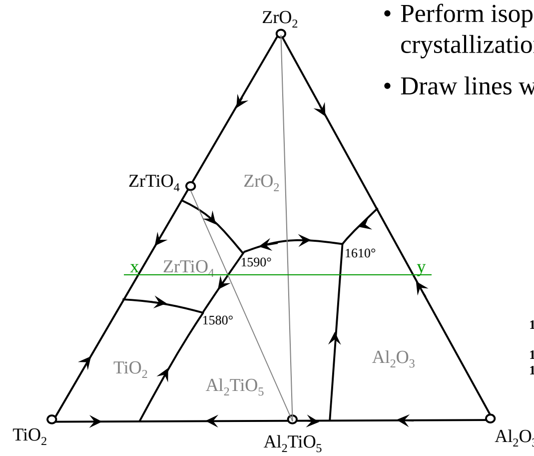


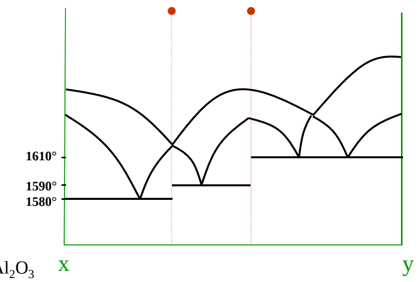


Constructing Vertical Sections

Step 4 - Alchemades line Intersection

- Find and indicate all compositions where section line crosses an alchemades line.
- Perform isoplethal analysis and plot final crystallization temperature.
- Draw lines which indicate material is all solid

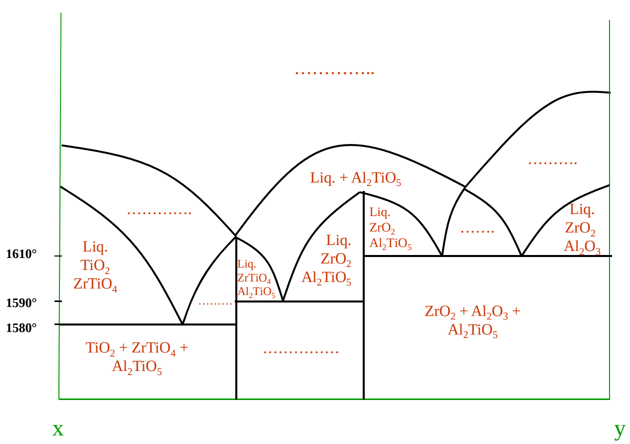




Constructing Vertical Sections

Step 5 - Labels

- Refer to the ternary diagram and label vertical section



The End

THANK YOU VERY MUCH