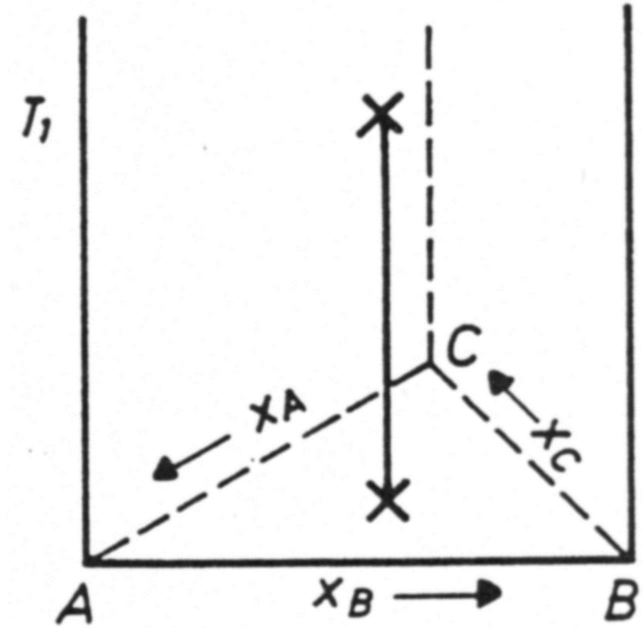
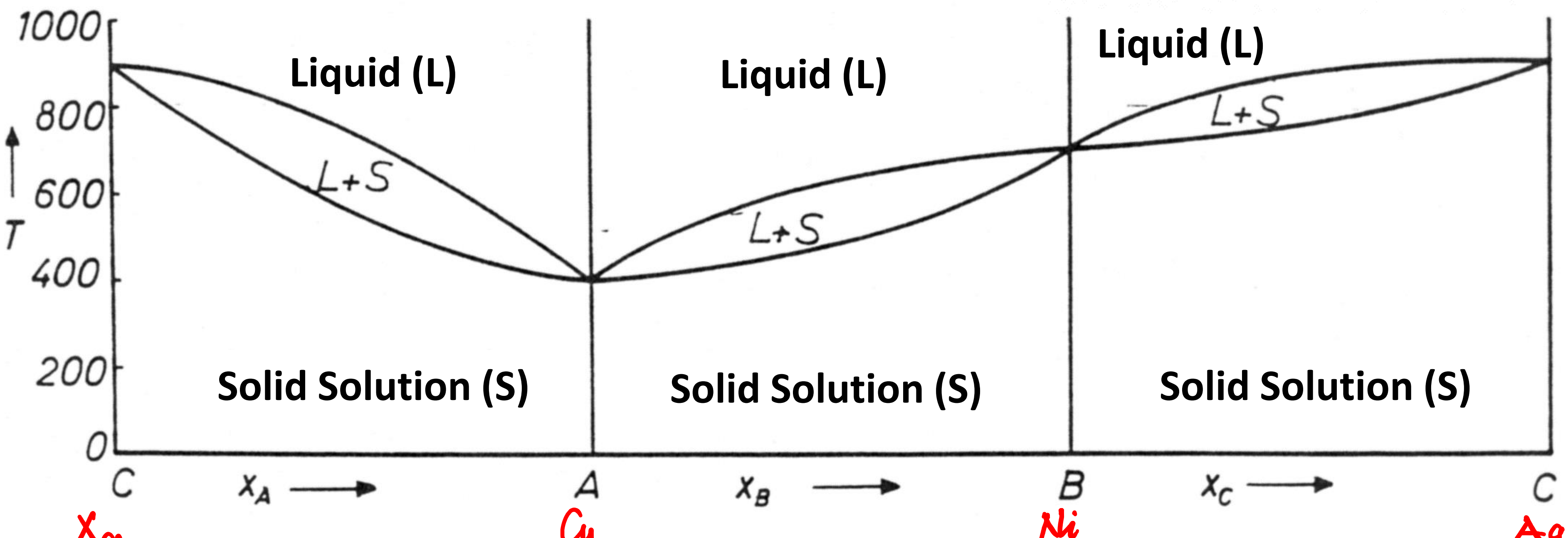
Ternary Phase Diagrams

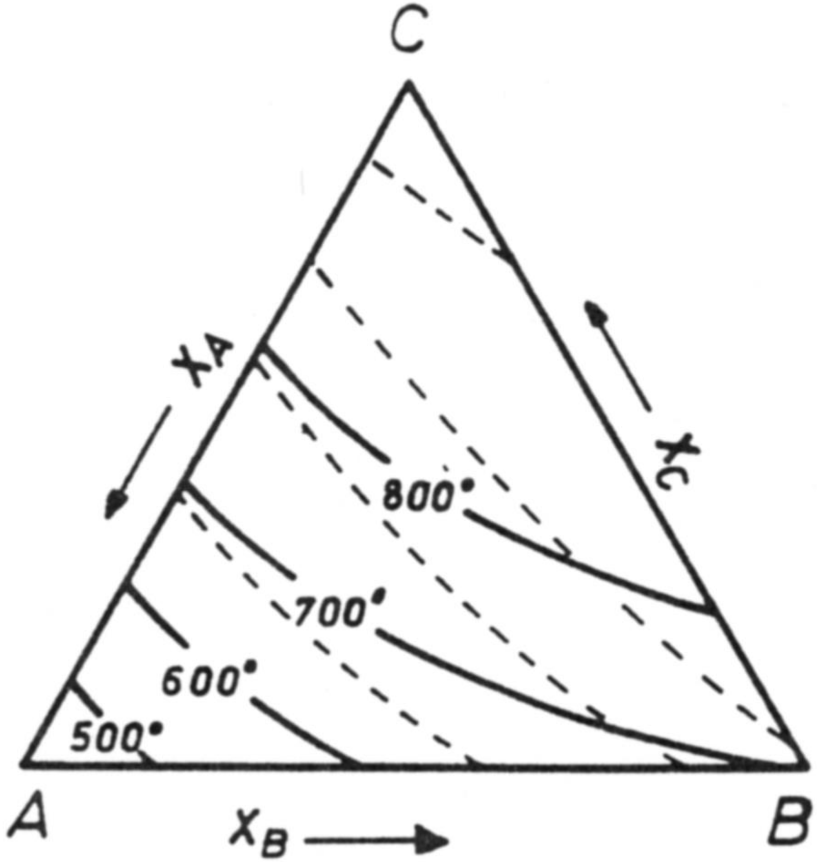
Dr. Nuri Solak

Complete Solid Solubility

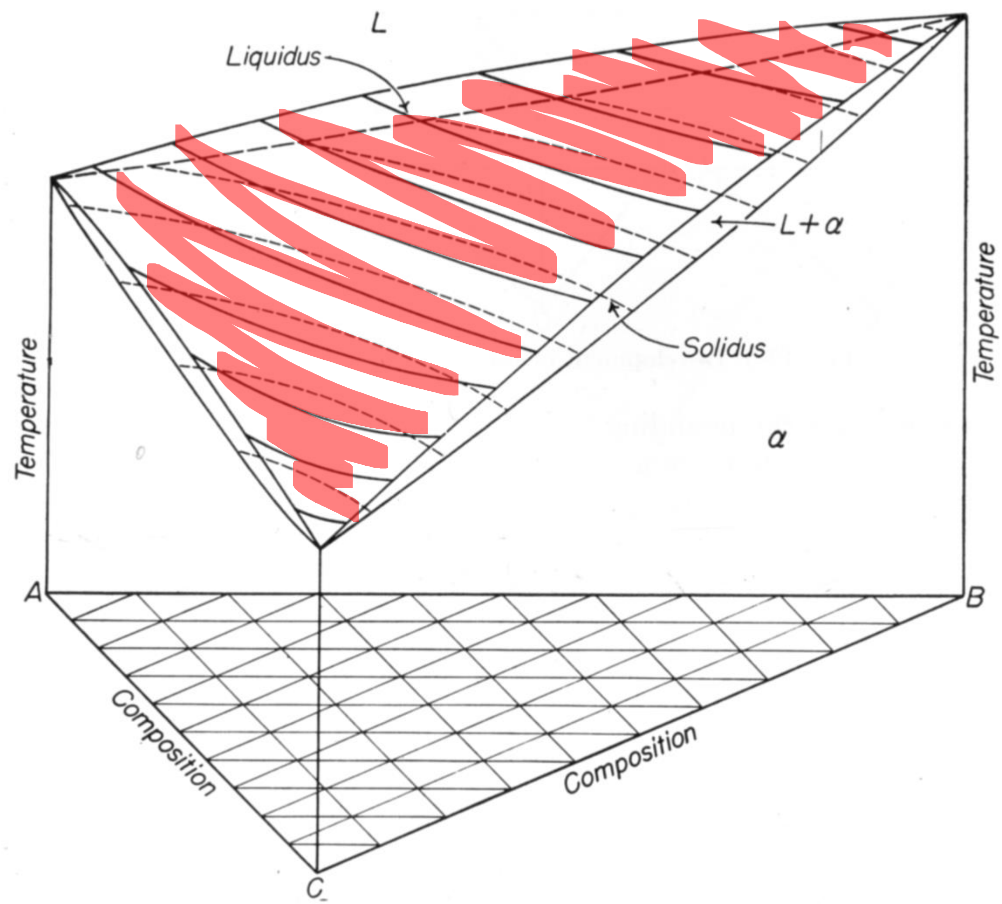




3D view

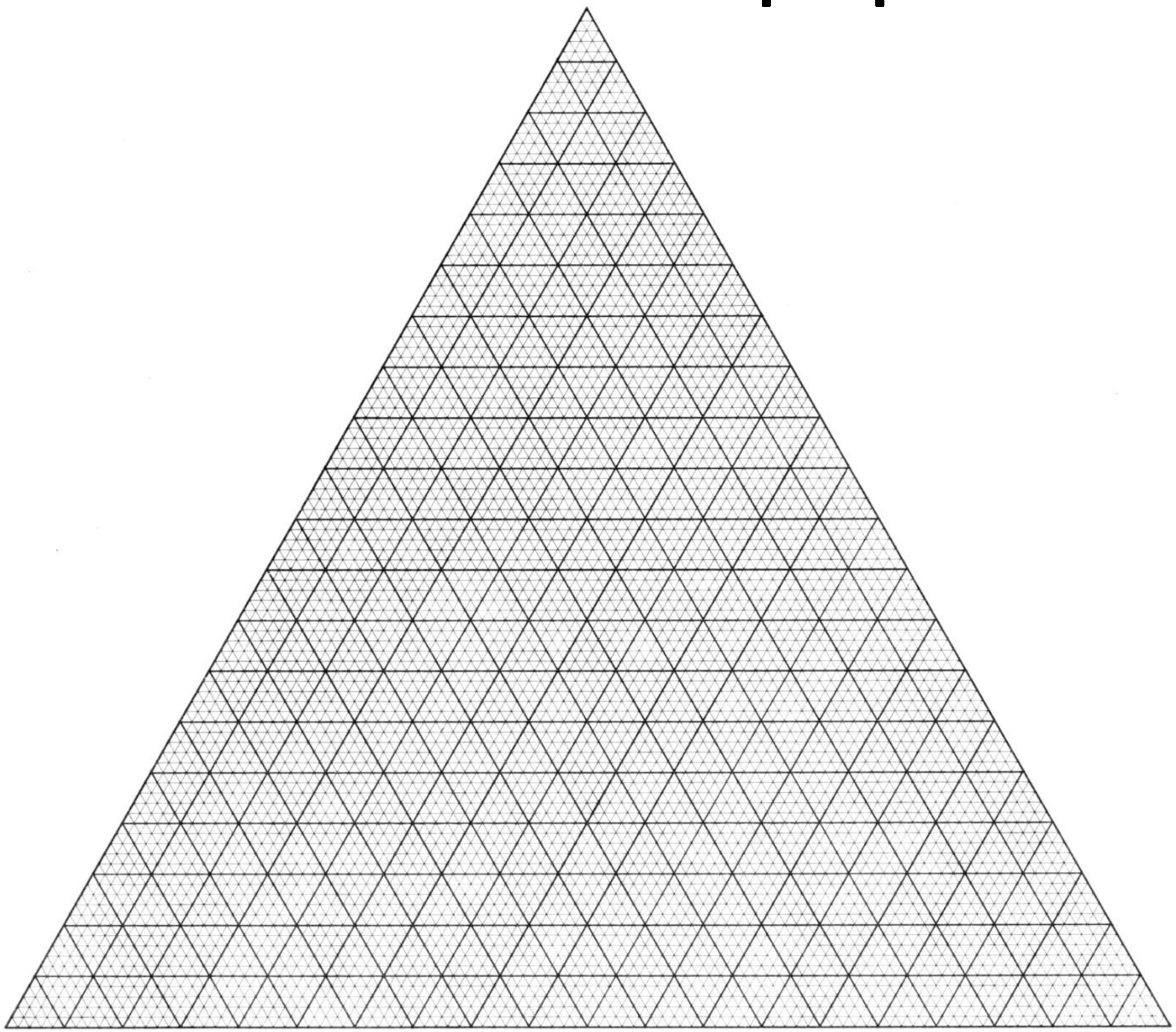


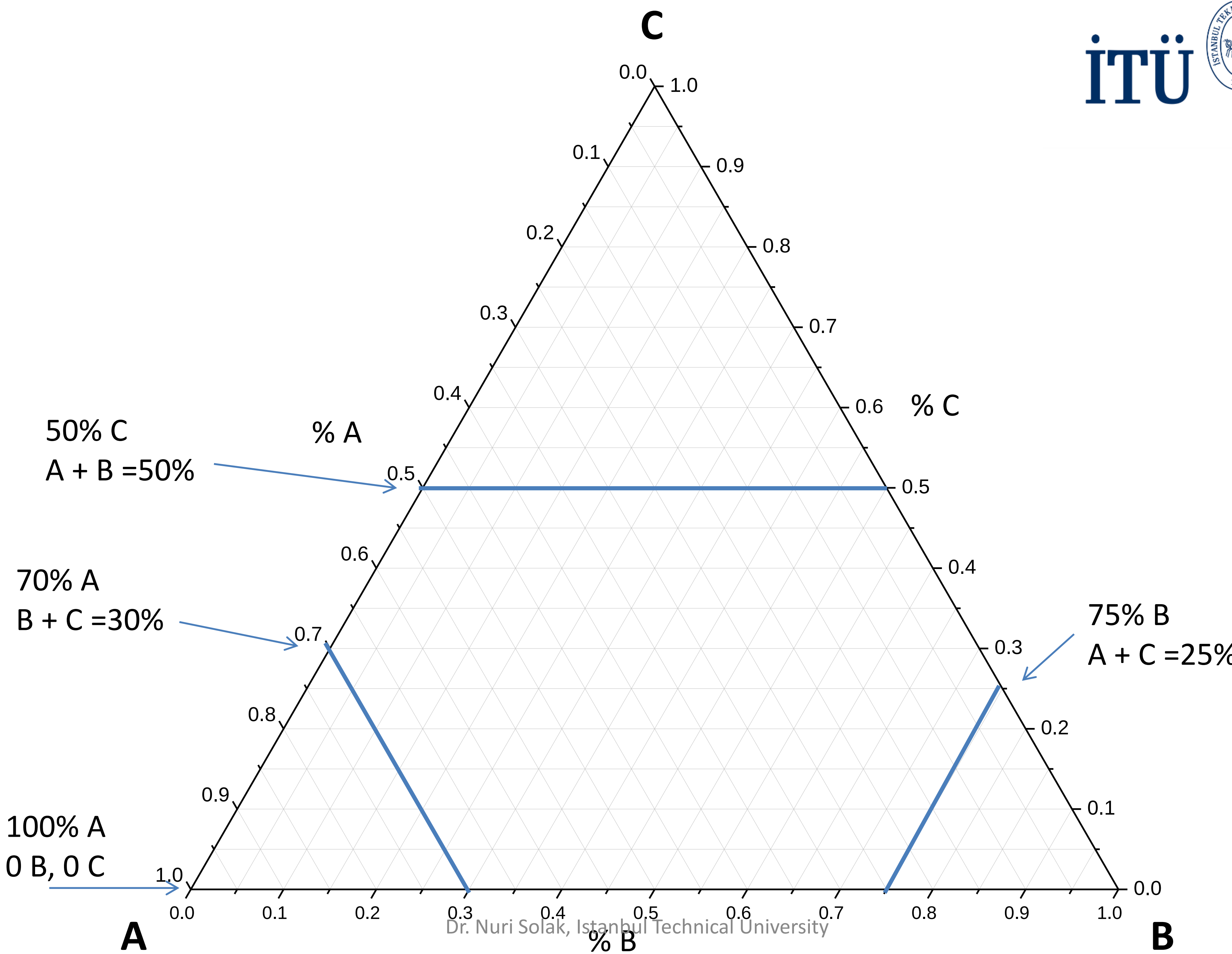
C
X_A
X_C
800°
700°
600°
500°
A
X_B
B



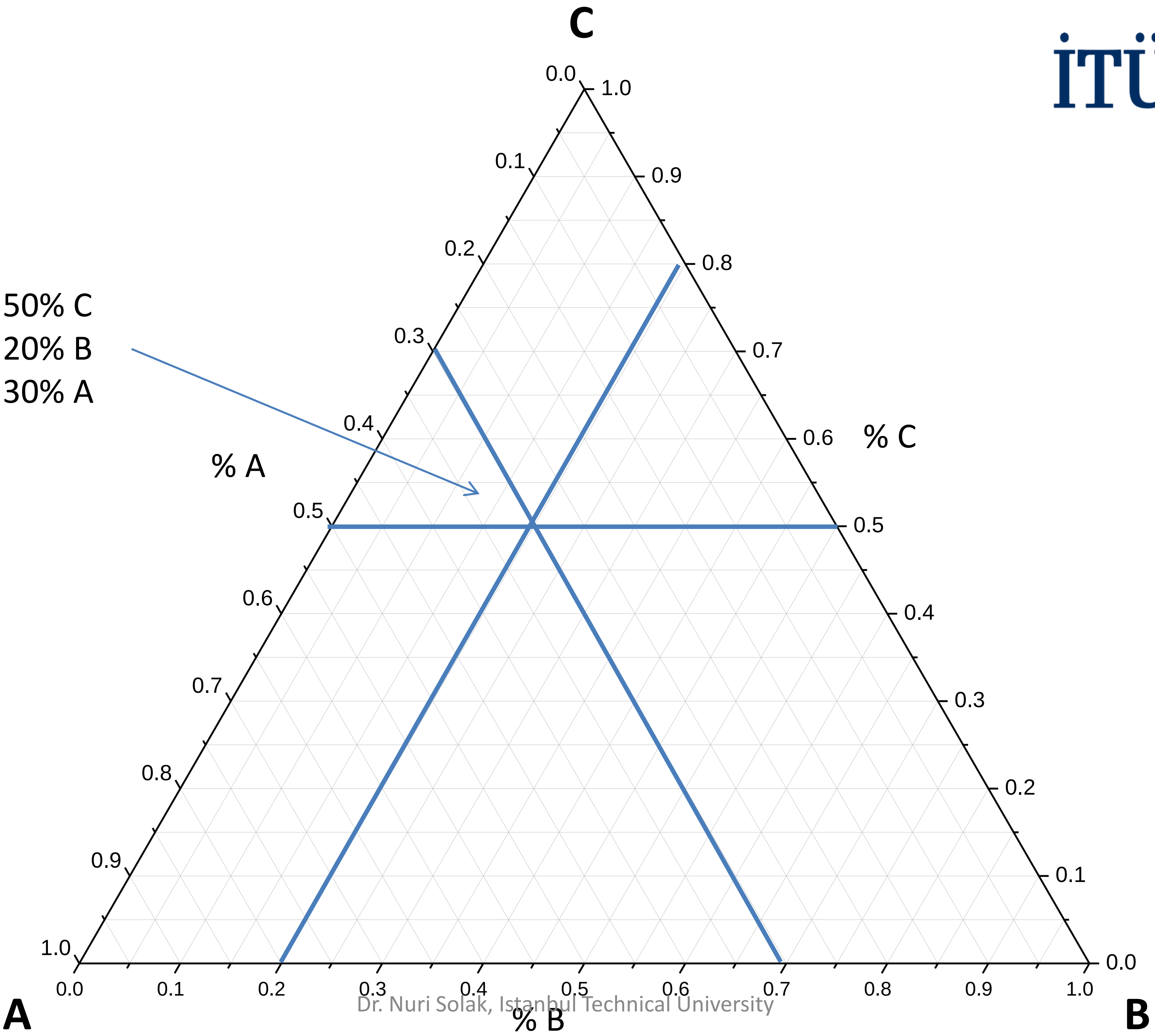
L
Liquidus
L+α
Solidus
α
Temperature
Temperature
A
B
C
Composition
Composition

Millimetric paper

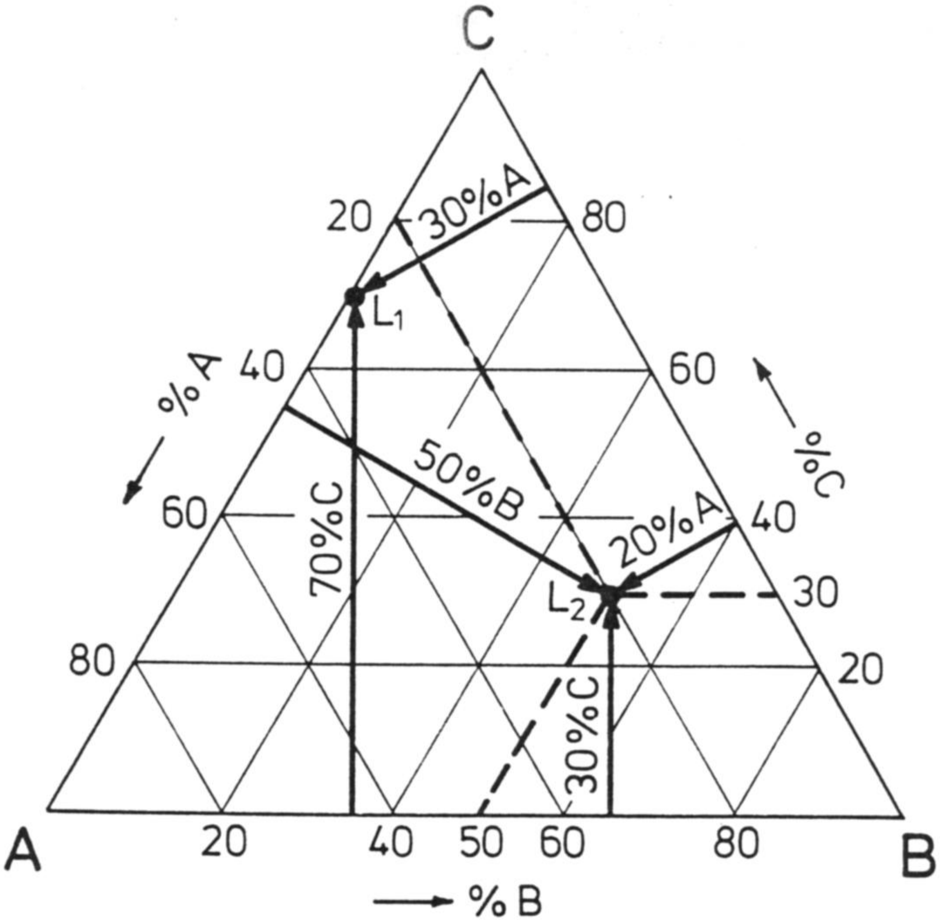


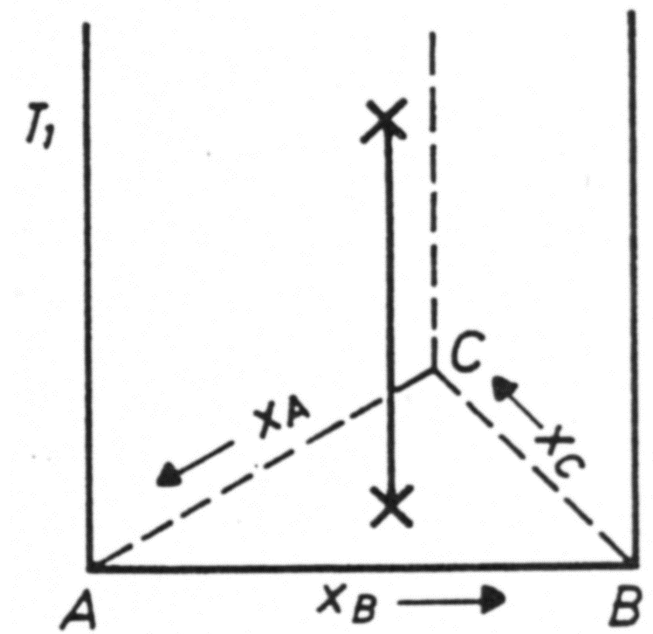

C
A
B
% A
% B
% C
50% C
A + B =50%
70% A
B + C =30%
75% B
A + C =25%
100% A
0 B, 0 C
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

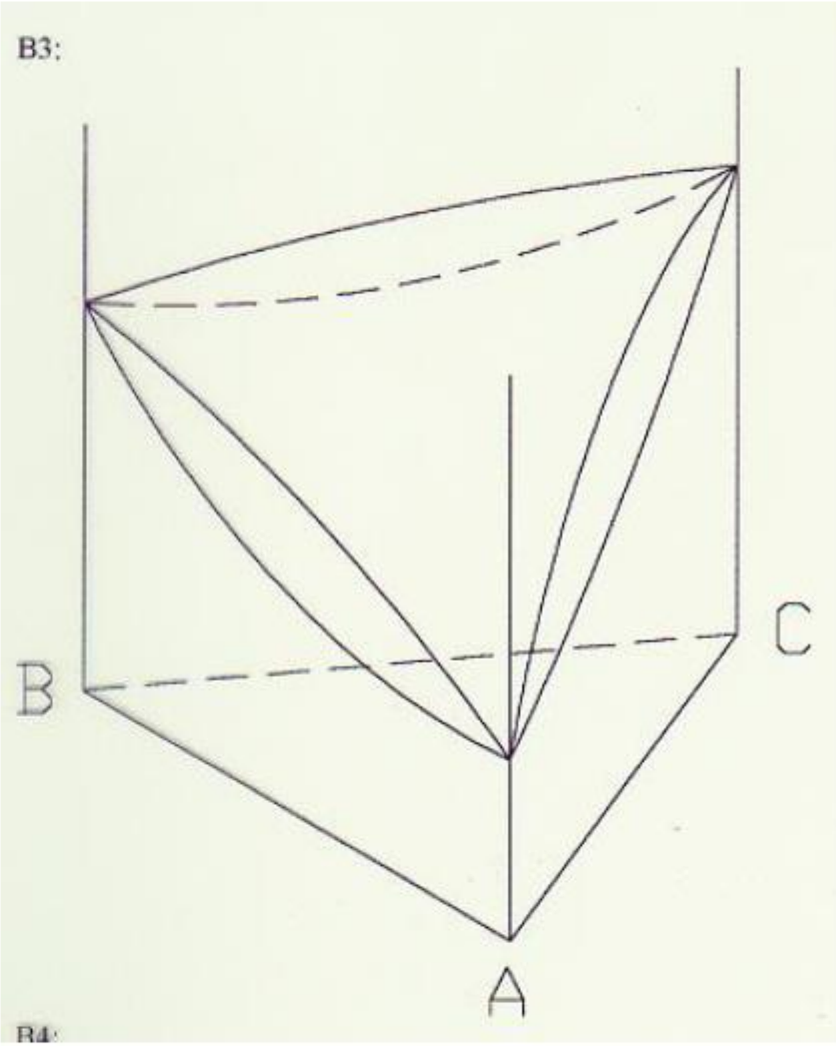
50% C
20% B
30% A



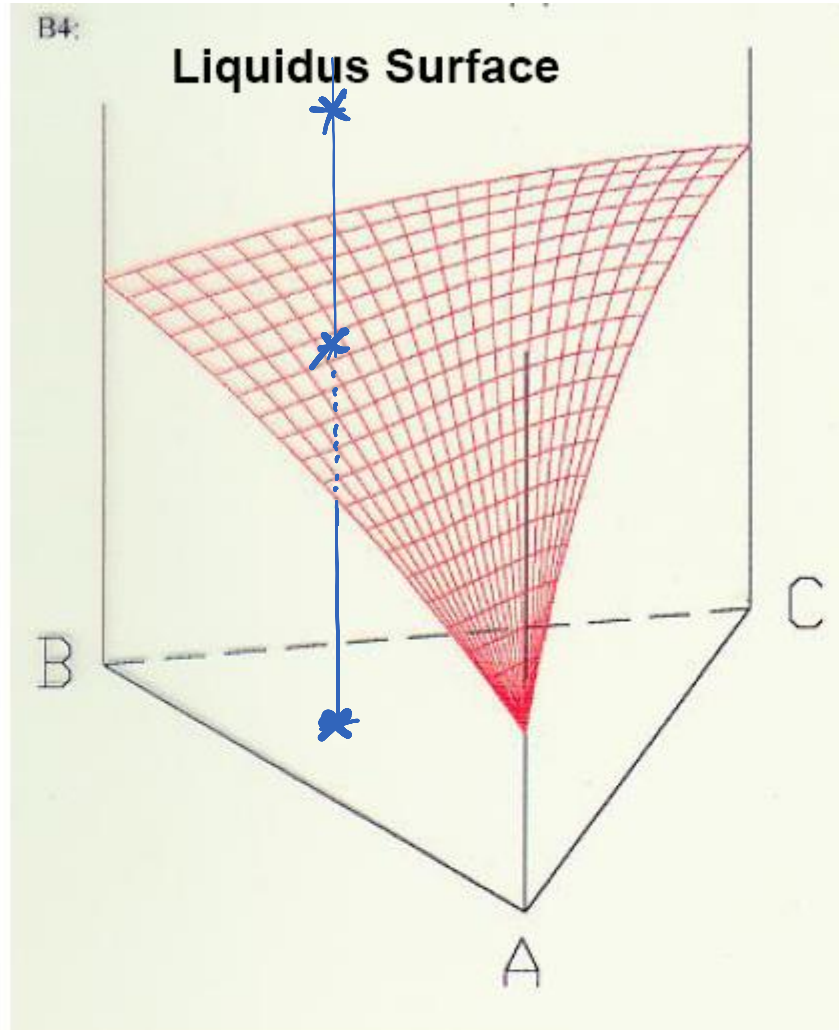
Ternary Phase Diagrams



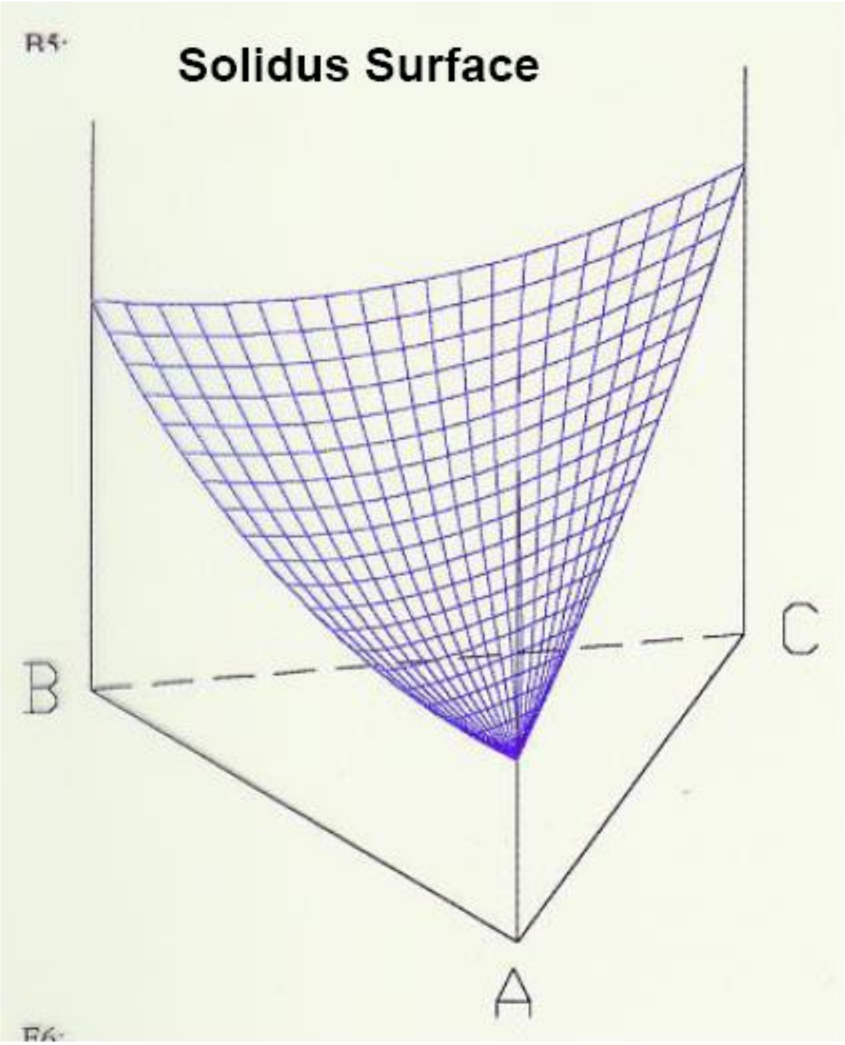


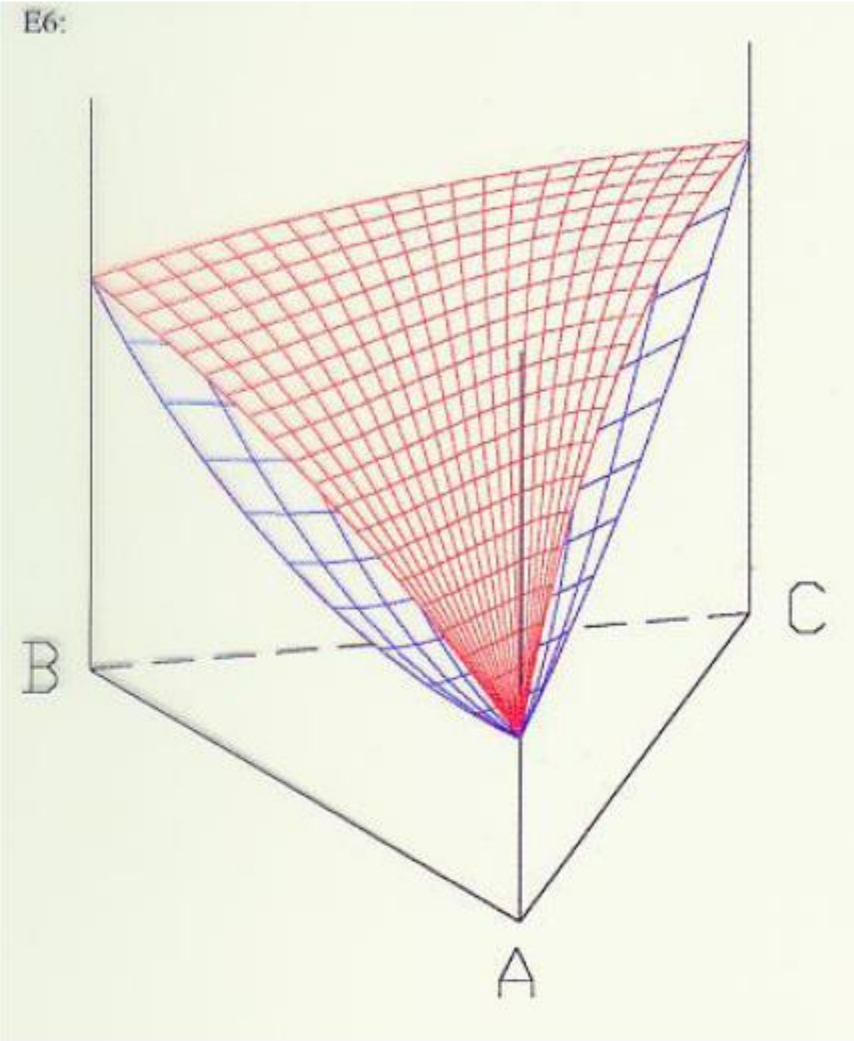


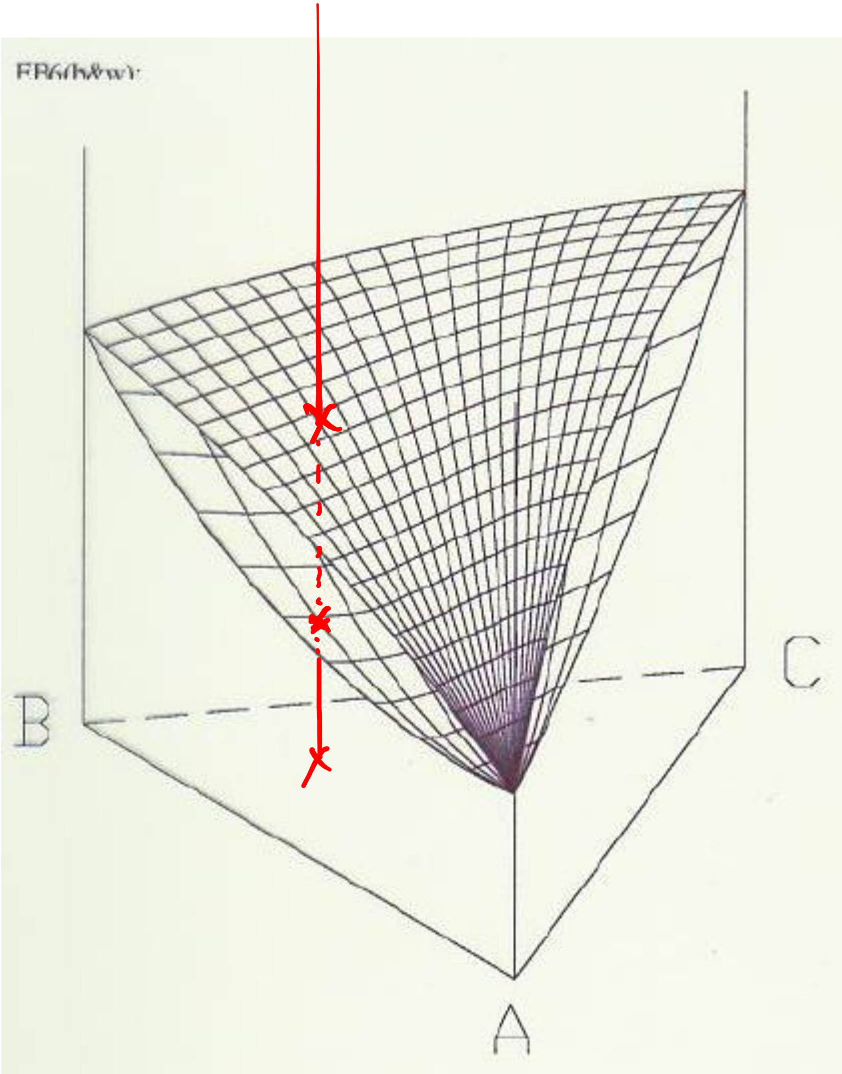
B3:
B
C
A
B4:



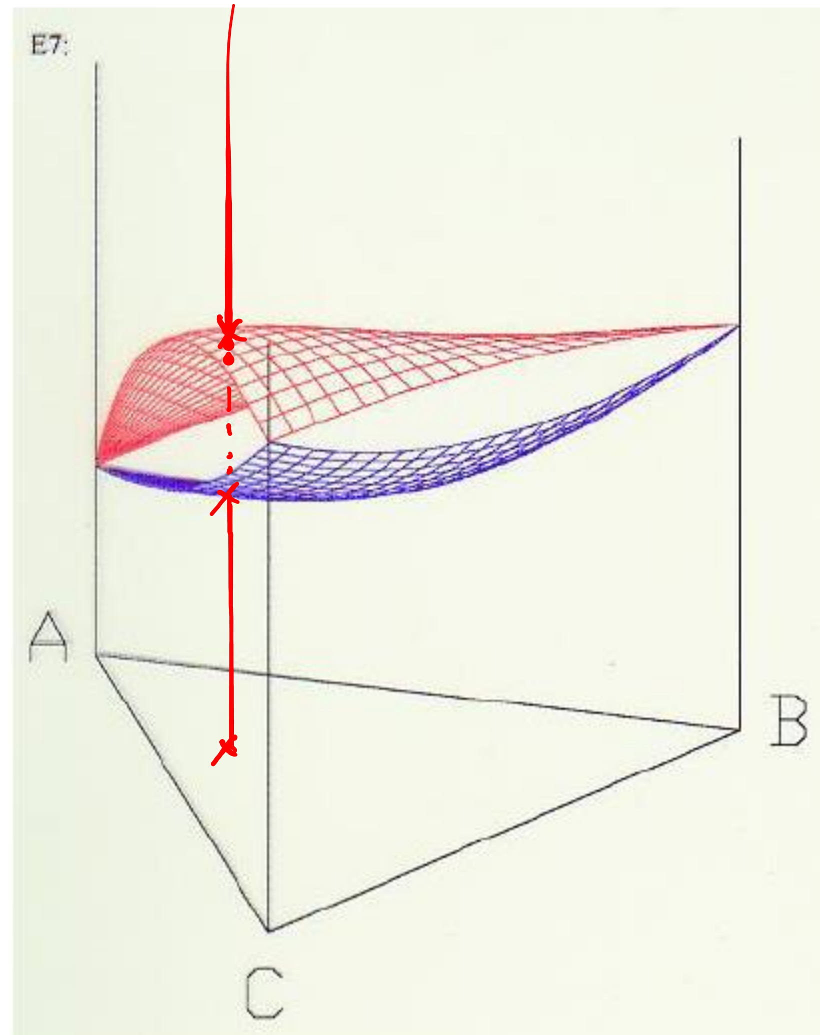
B4:
Liquidus Surface
B
C
A


Solidus Surface
B
C
A

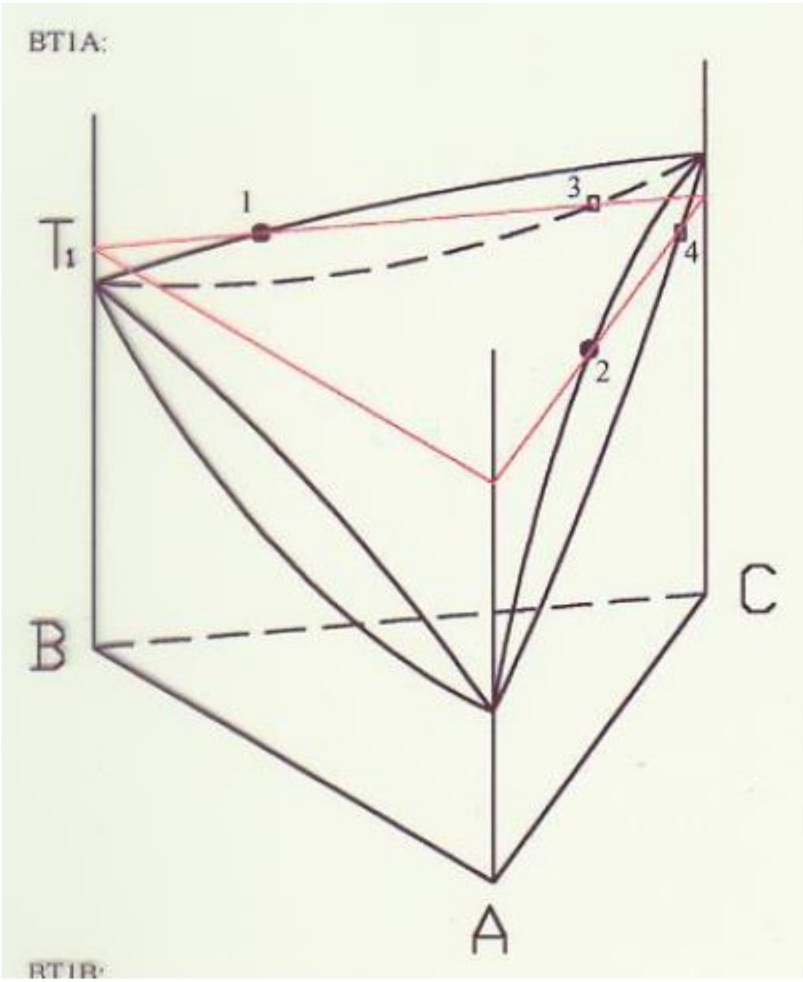

E6:
B
C
A

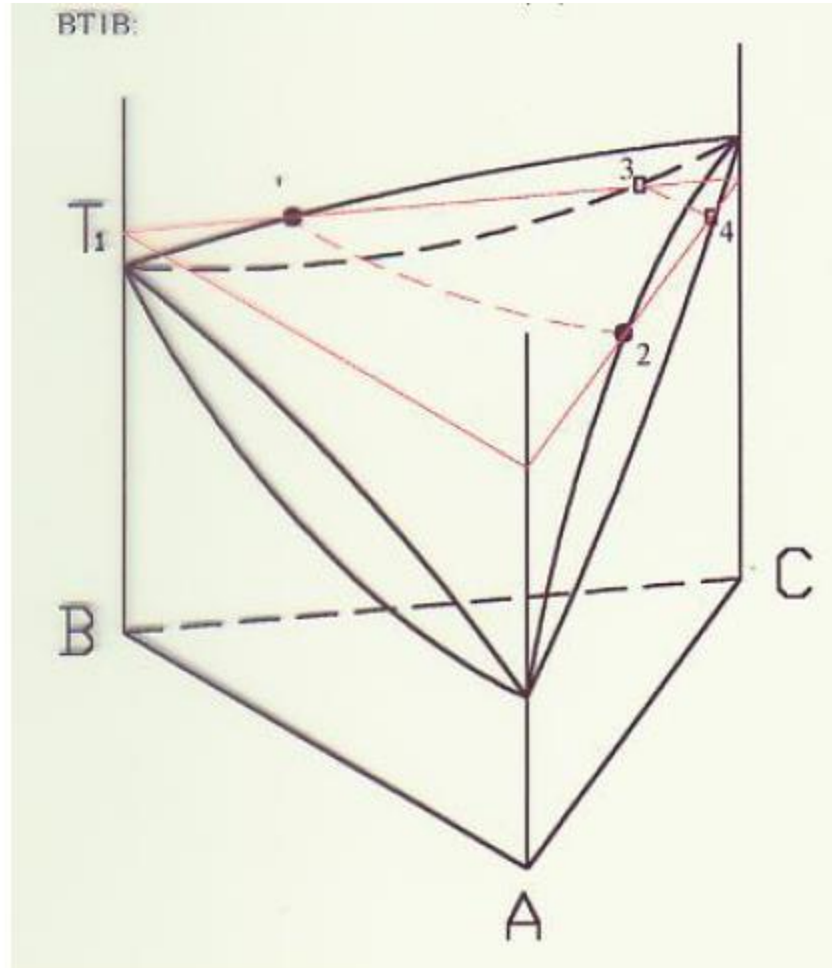


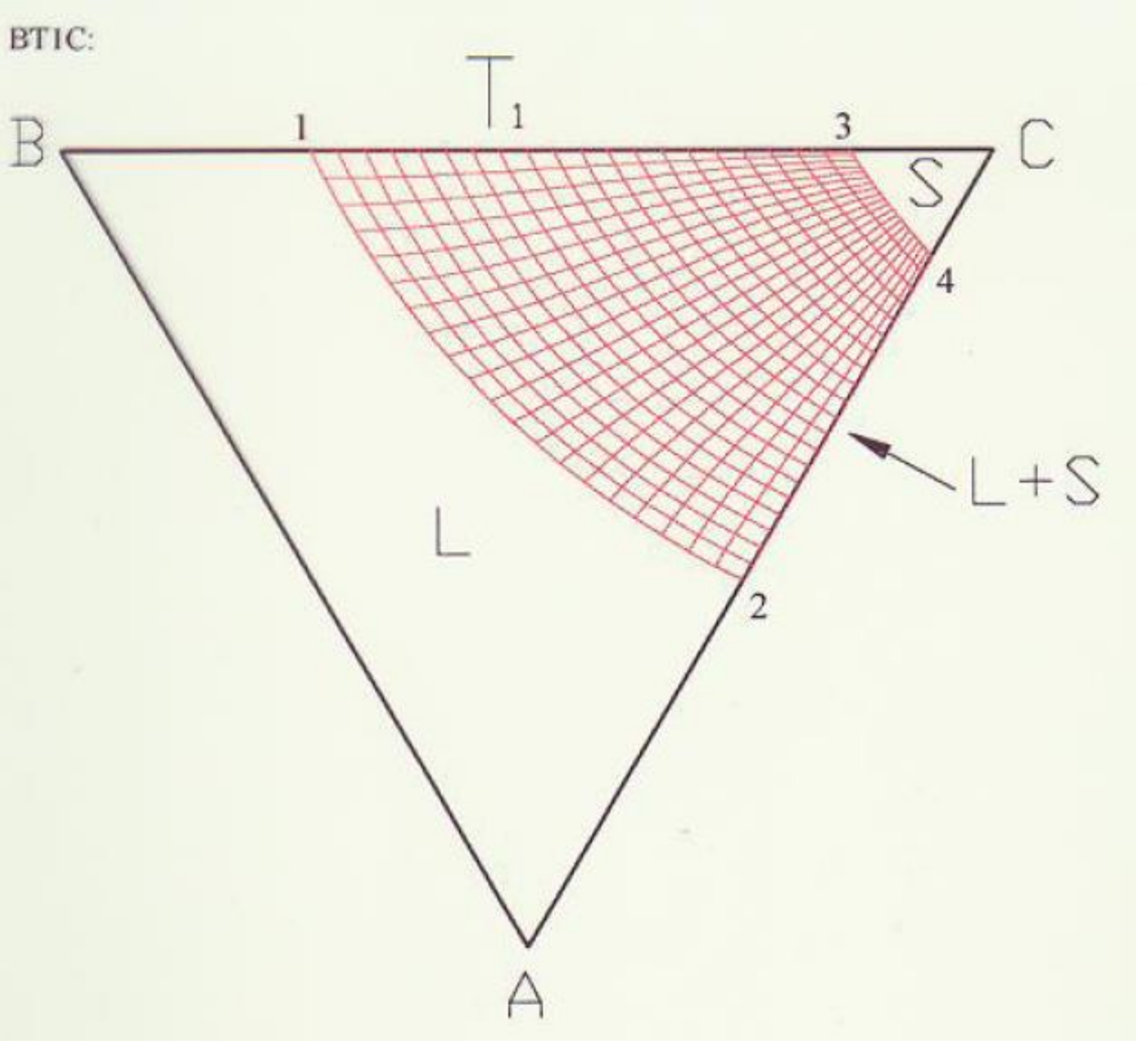
EB6(h&w):
B
C
A

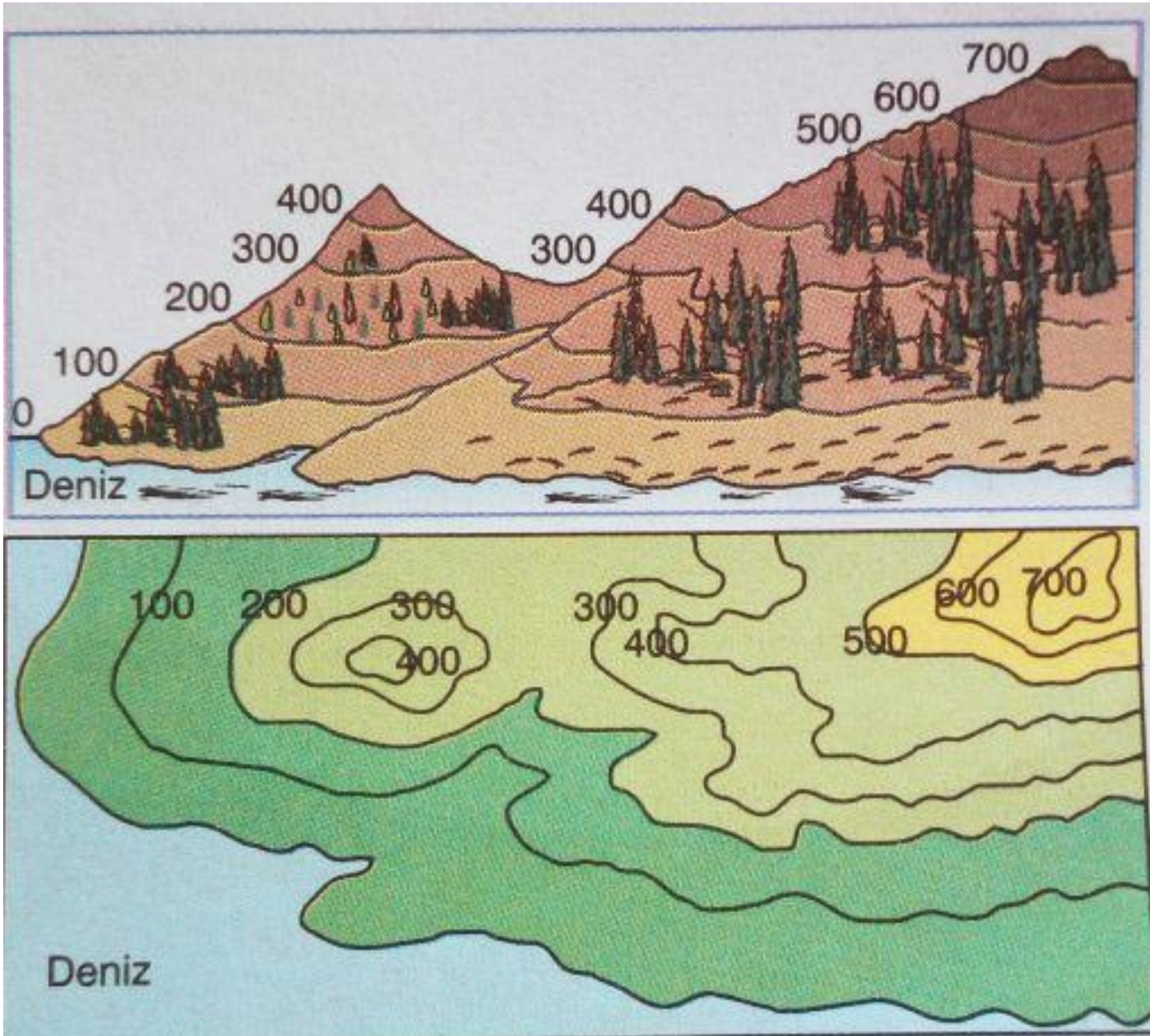


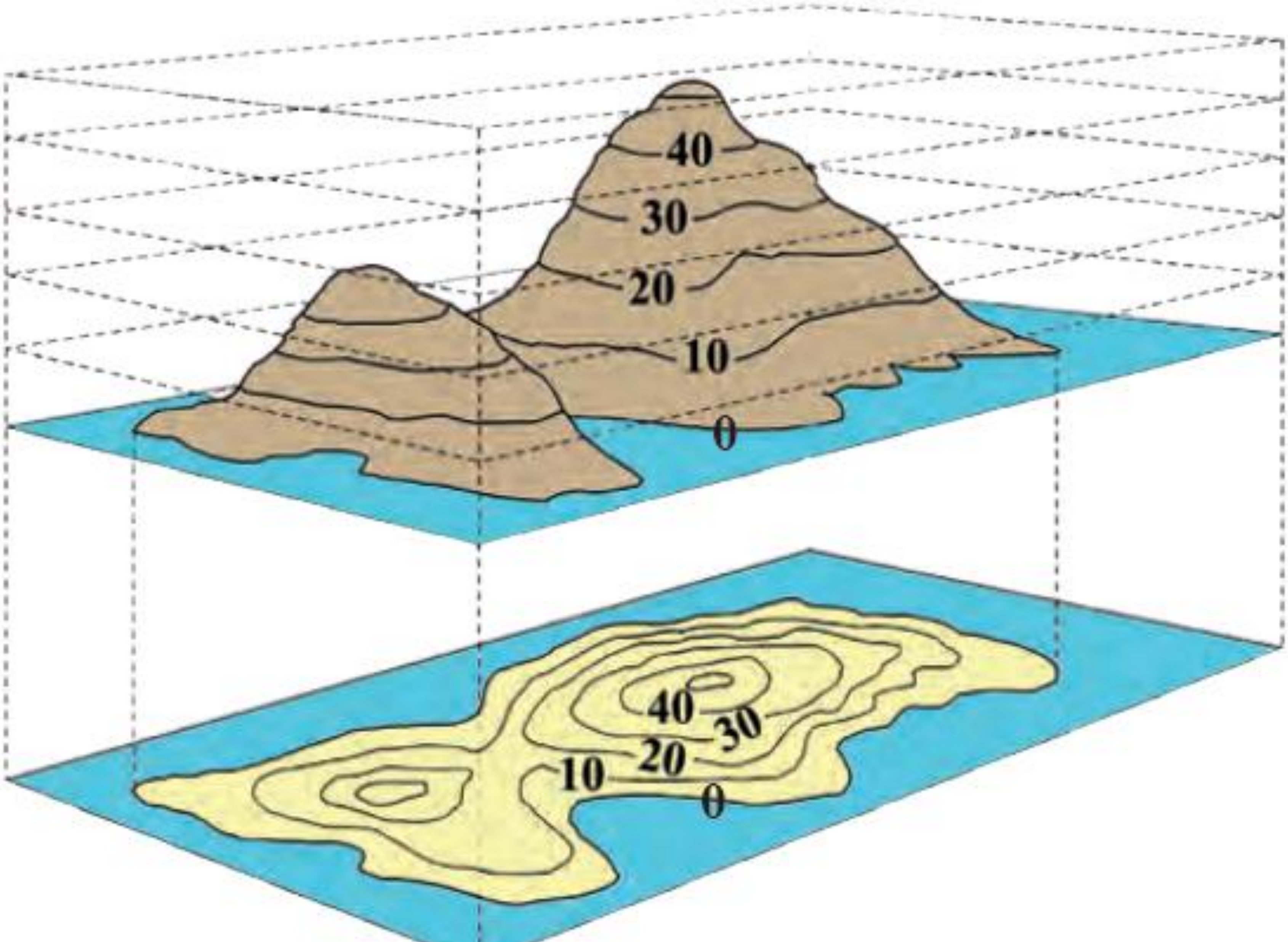
E7:
A
B
C

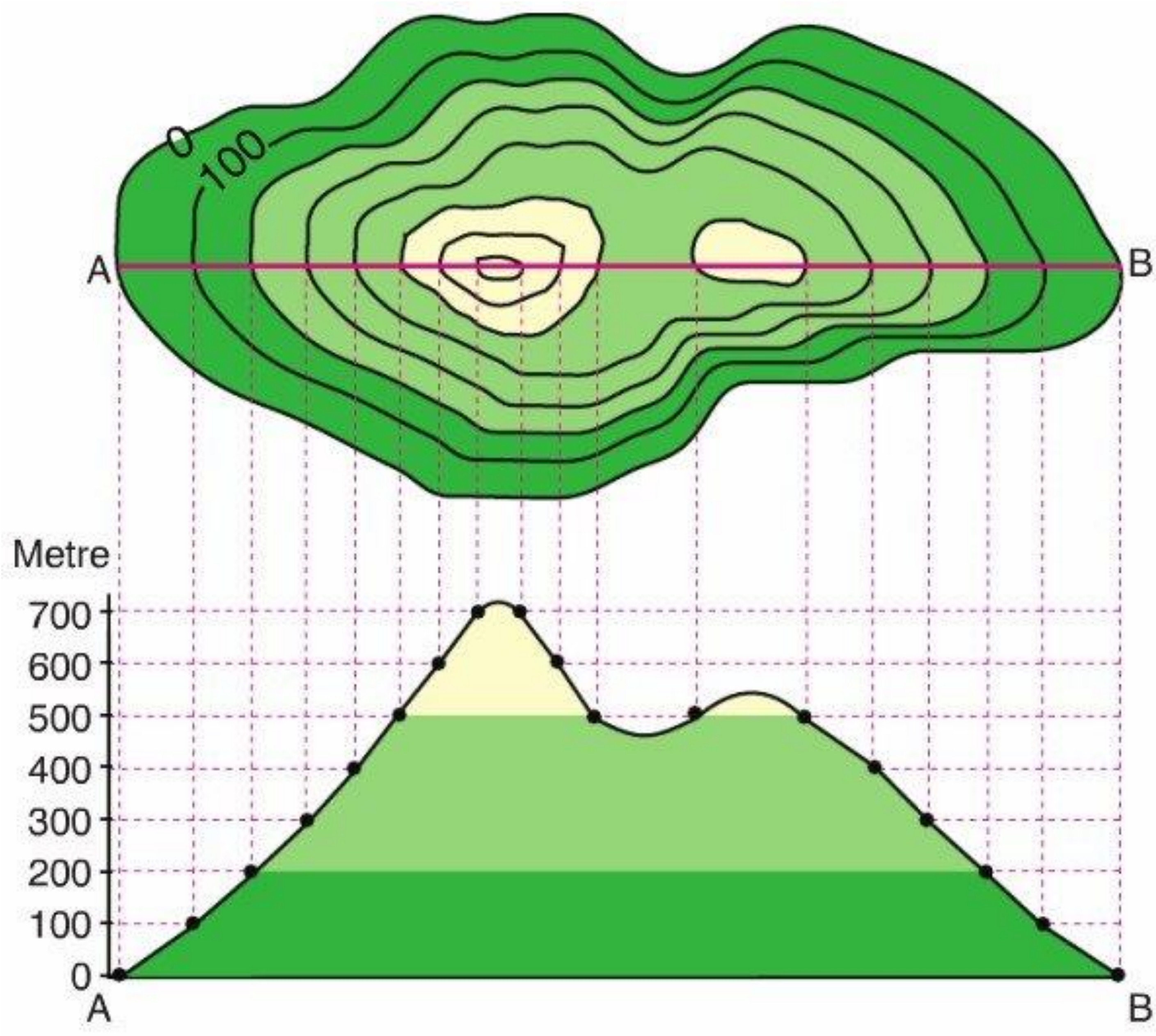

BT1A:
T1
1
3
4
2
B
C
A
BT1B:


BT1B:
T1
3
4
2
B
C
A

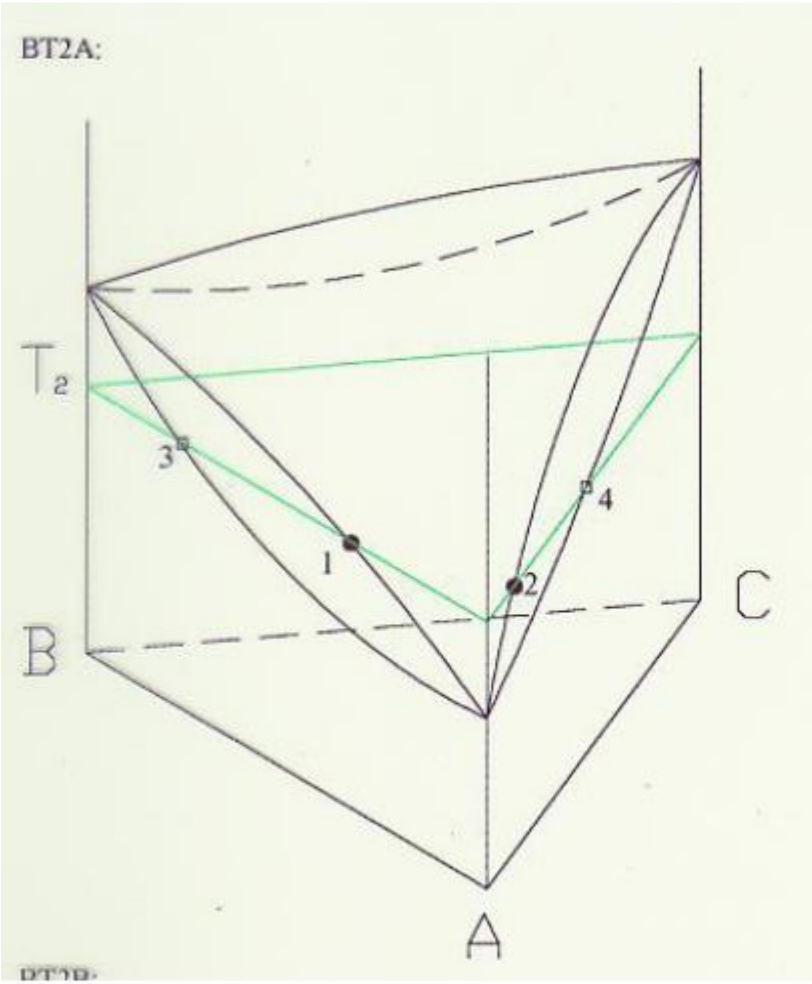

BT1C:
T_1
B
1
3
C
S
4
L+S
L
2
A

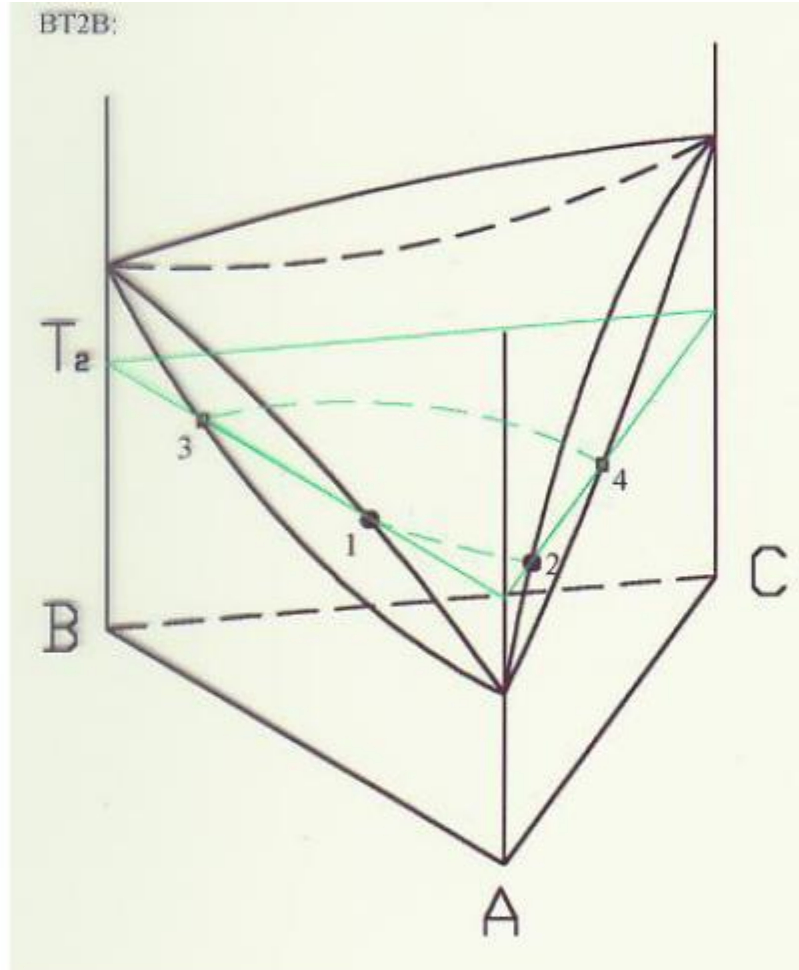

700
600
500
400
300
200
100
0
400
300
Deniz
100
200
300
400
300
400
500
600
700
Deniz

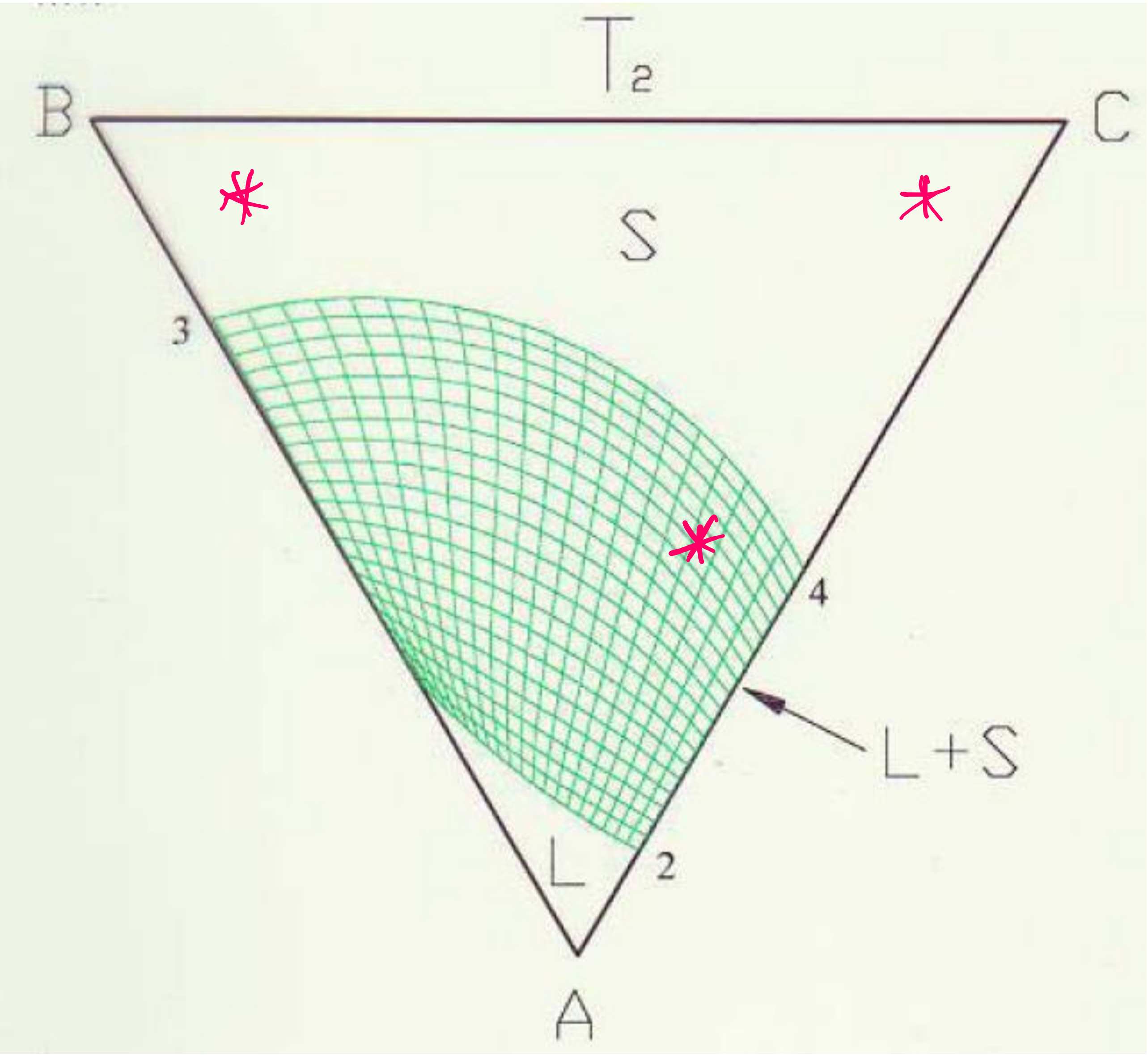

40
30
20
10
0
40
30
20
10
0



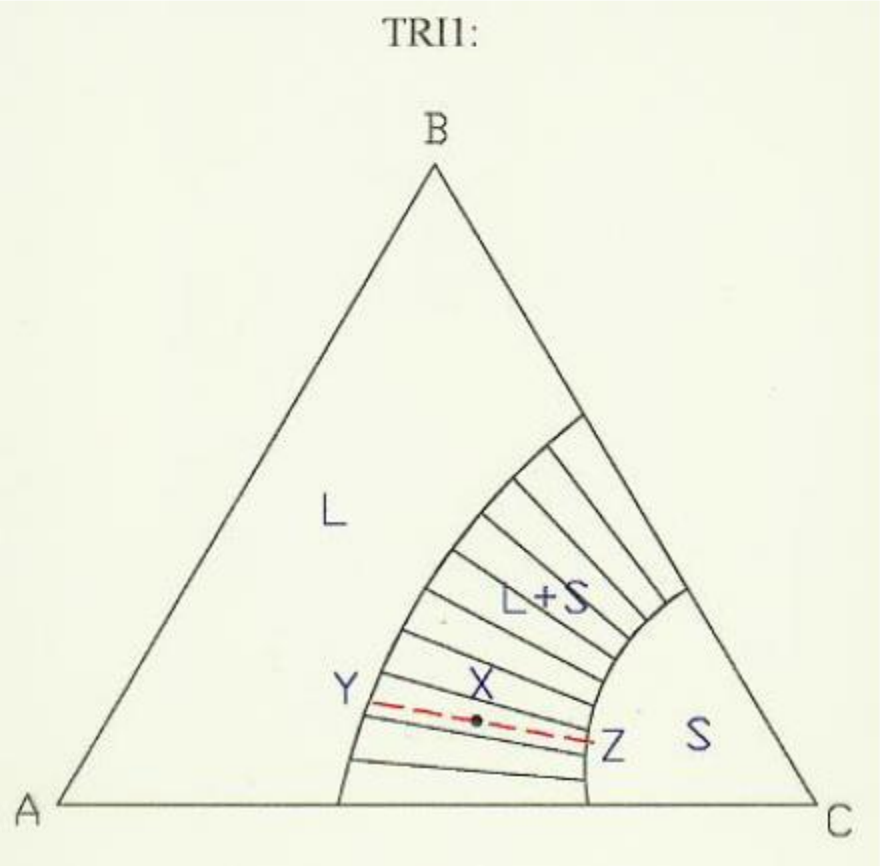
0
100
A
B
Metre
700
600
500
400
300
200
100
0
A
B

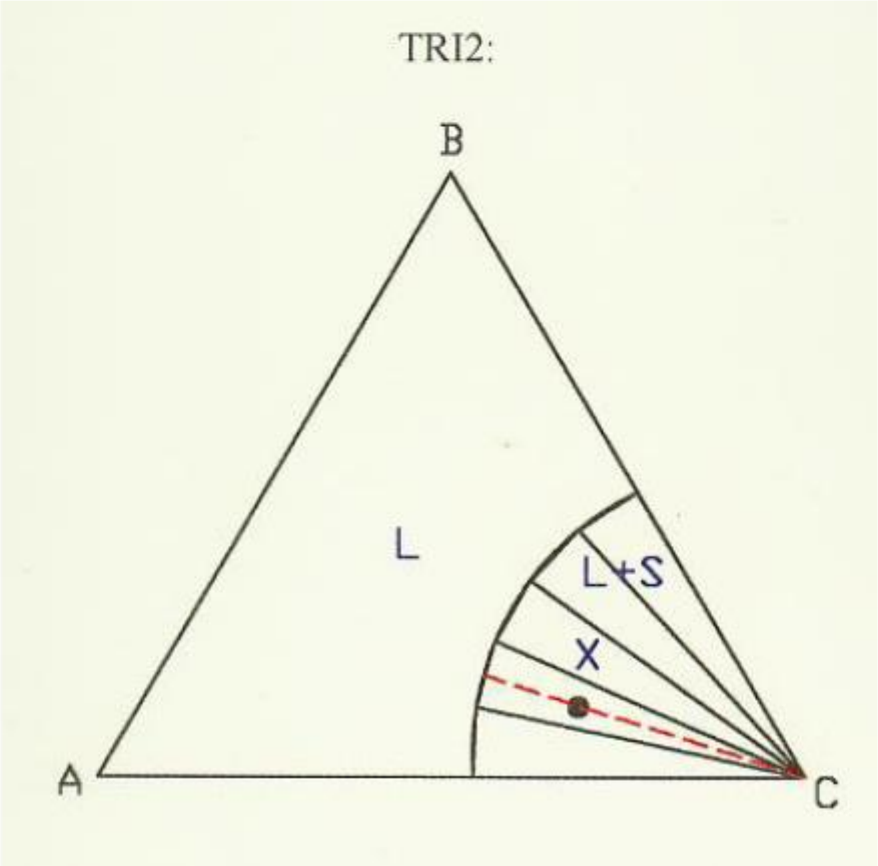

BT2A:
T2
3
4
1
2
B
C
A
BT2B:

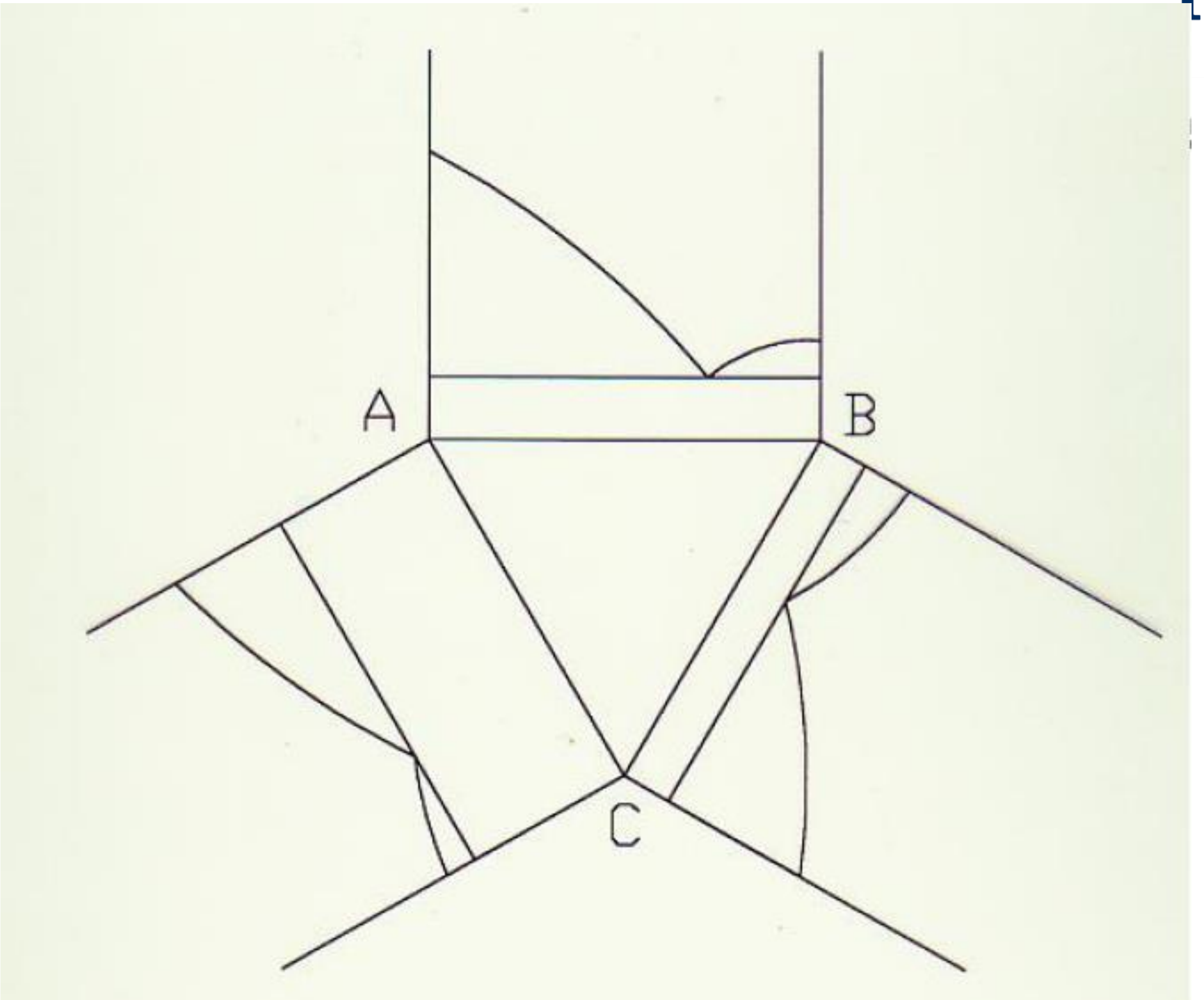

BT2B:
T2
3
4
1
2
B
C
A

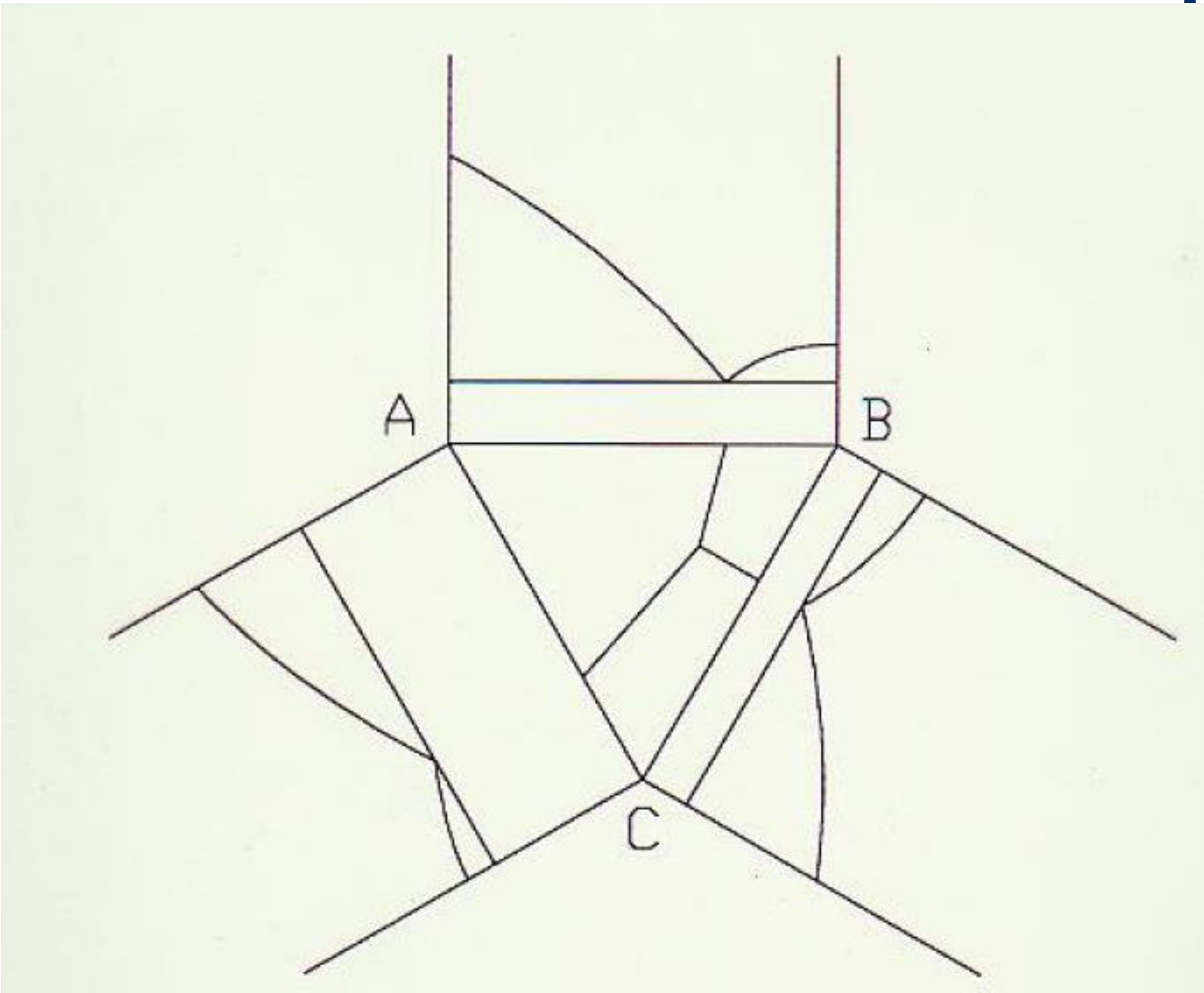


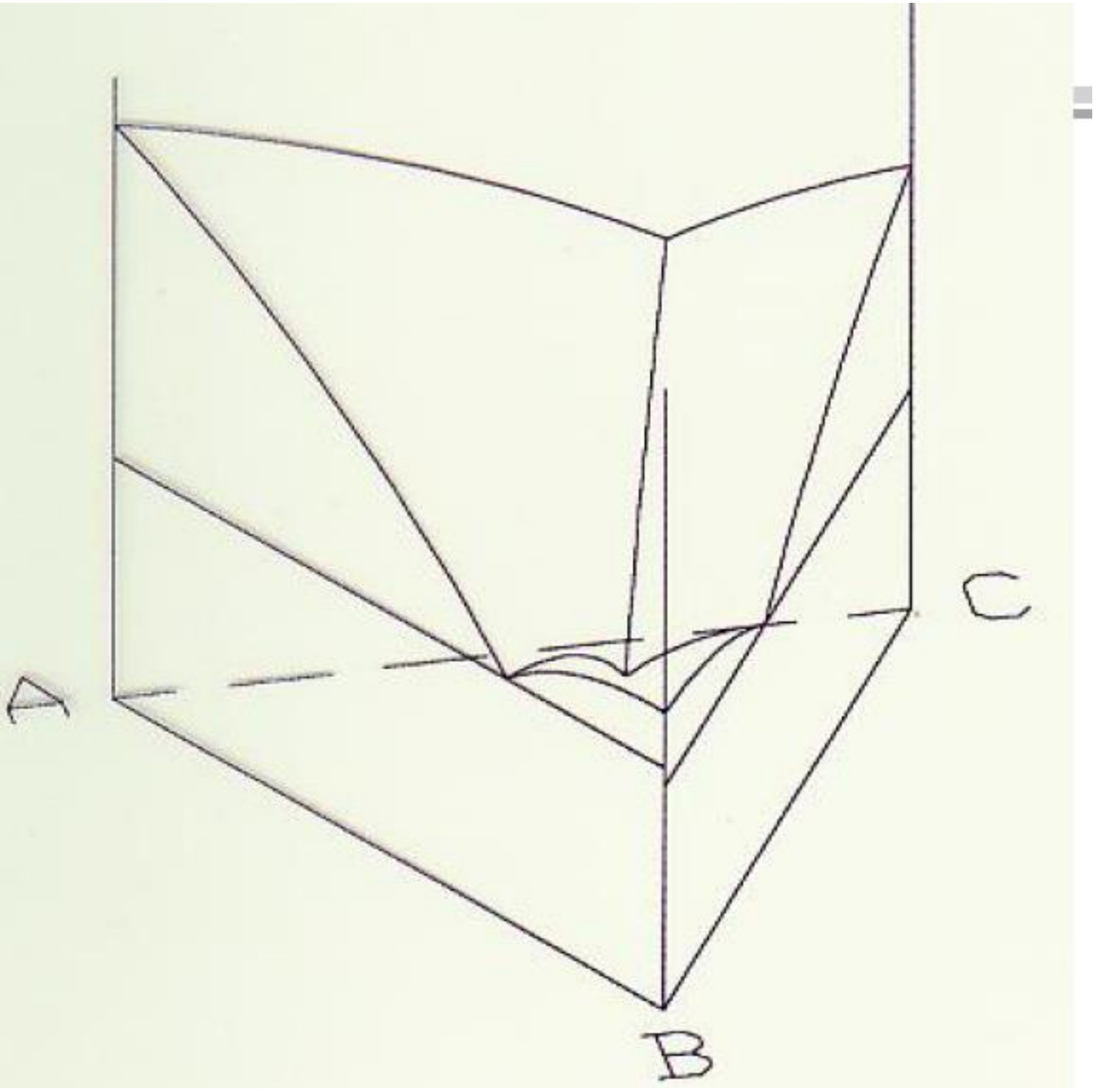
T2
B
C
S
3
4
L+S
L
2
A

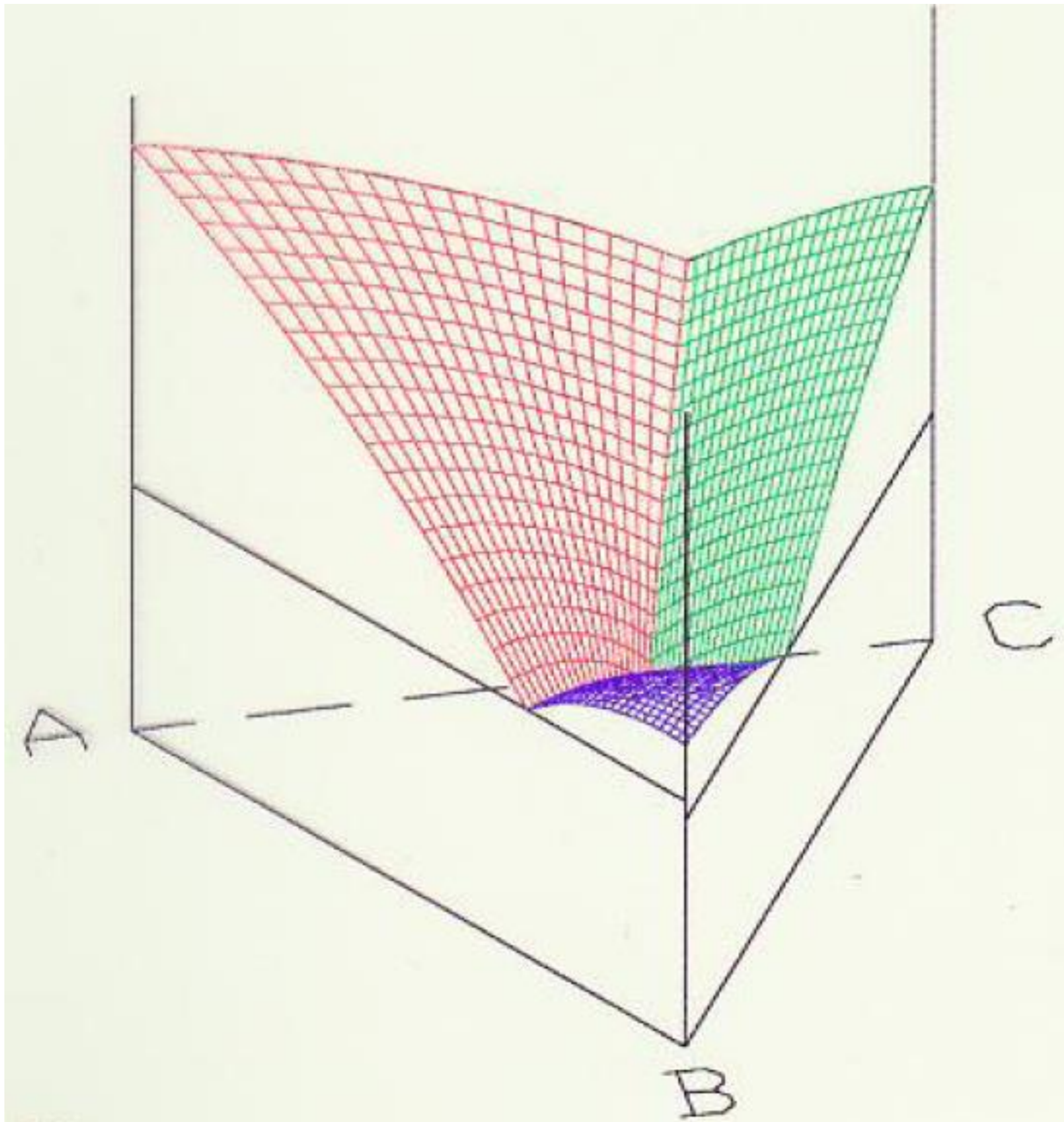

TRI1:
B
L
L+S
Y
X
Z
S
A
C

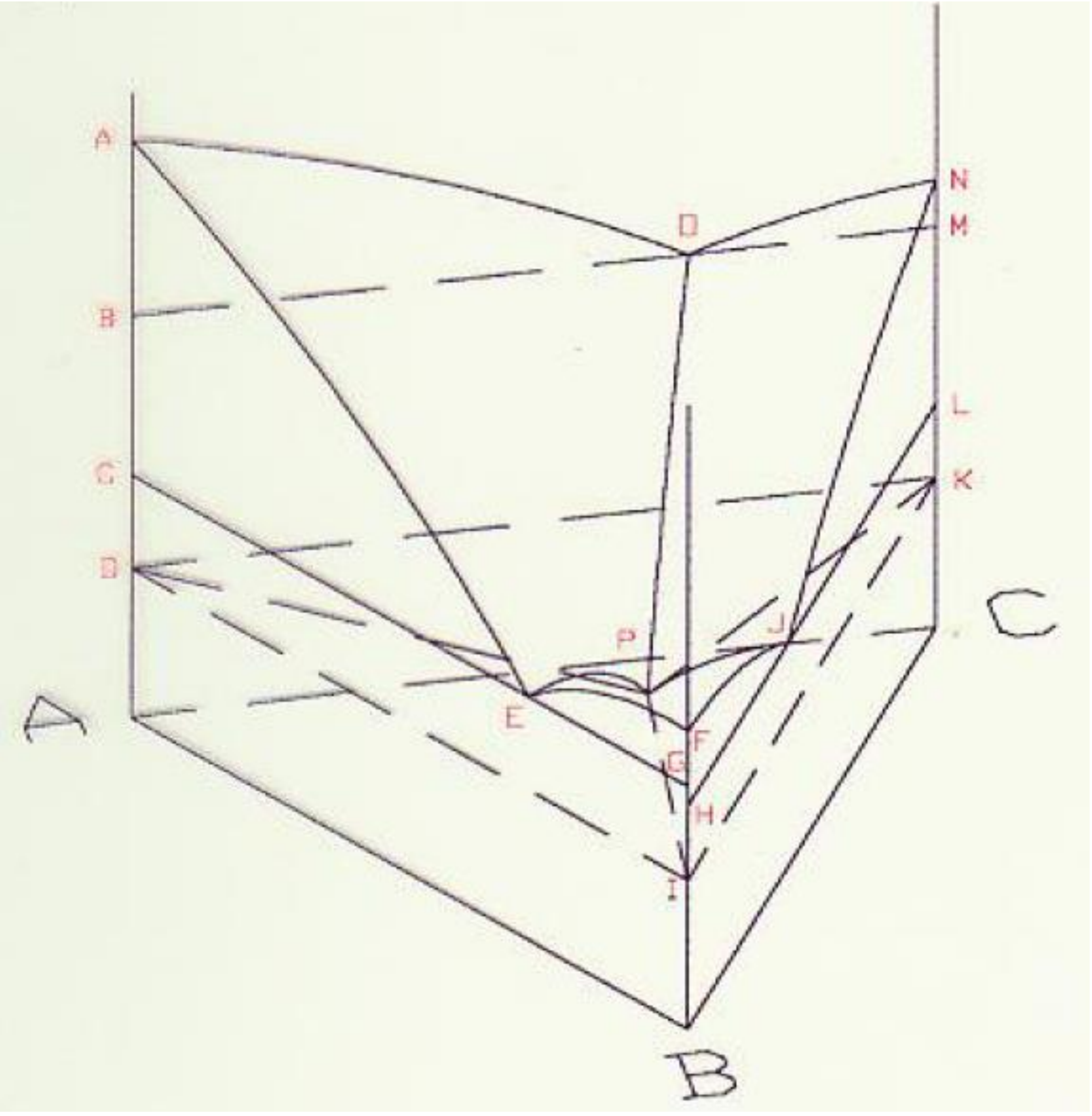

TRI2:
B
L
L+S
X
A
C

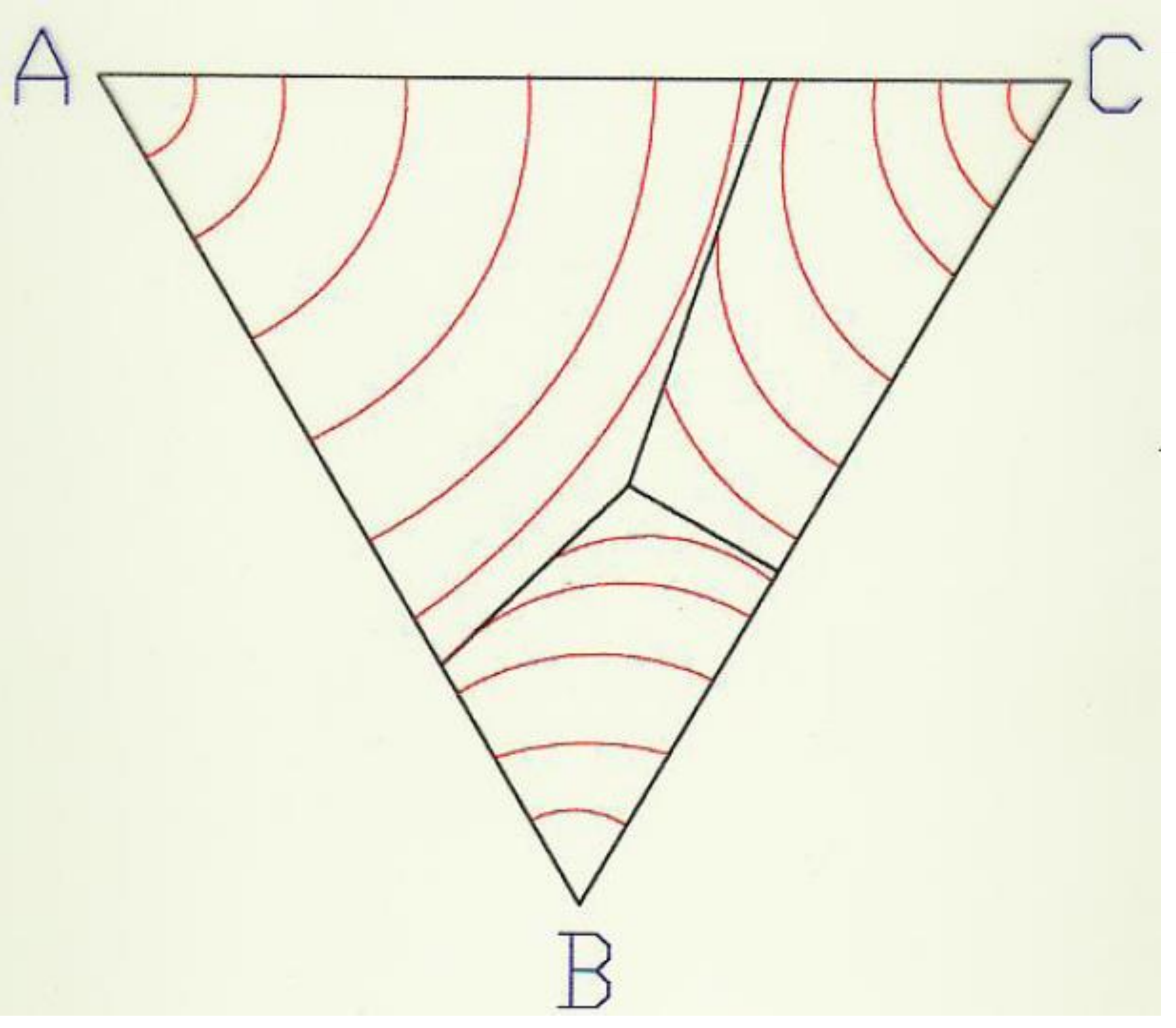

A
B
C

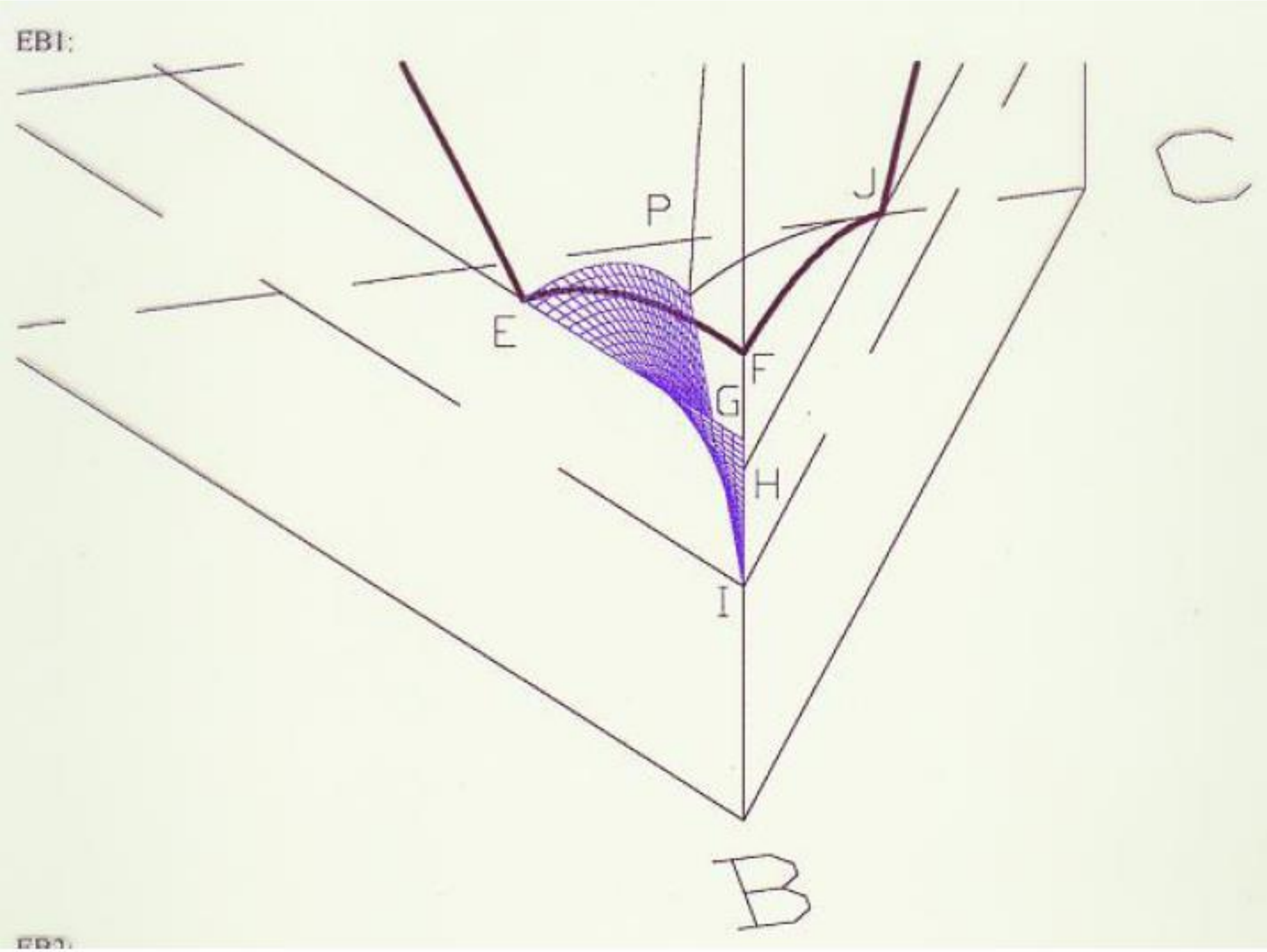

A
B
C

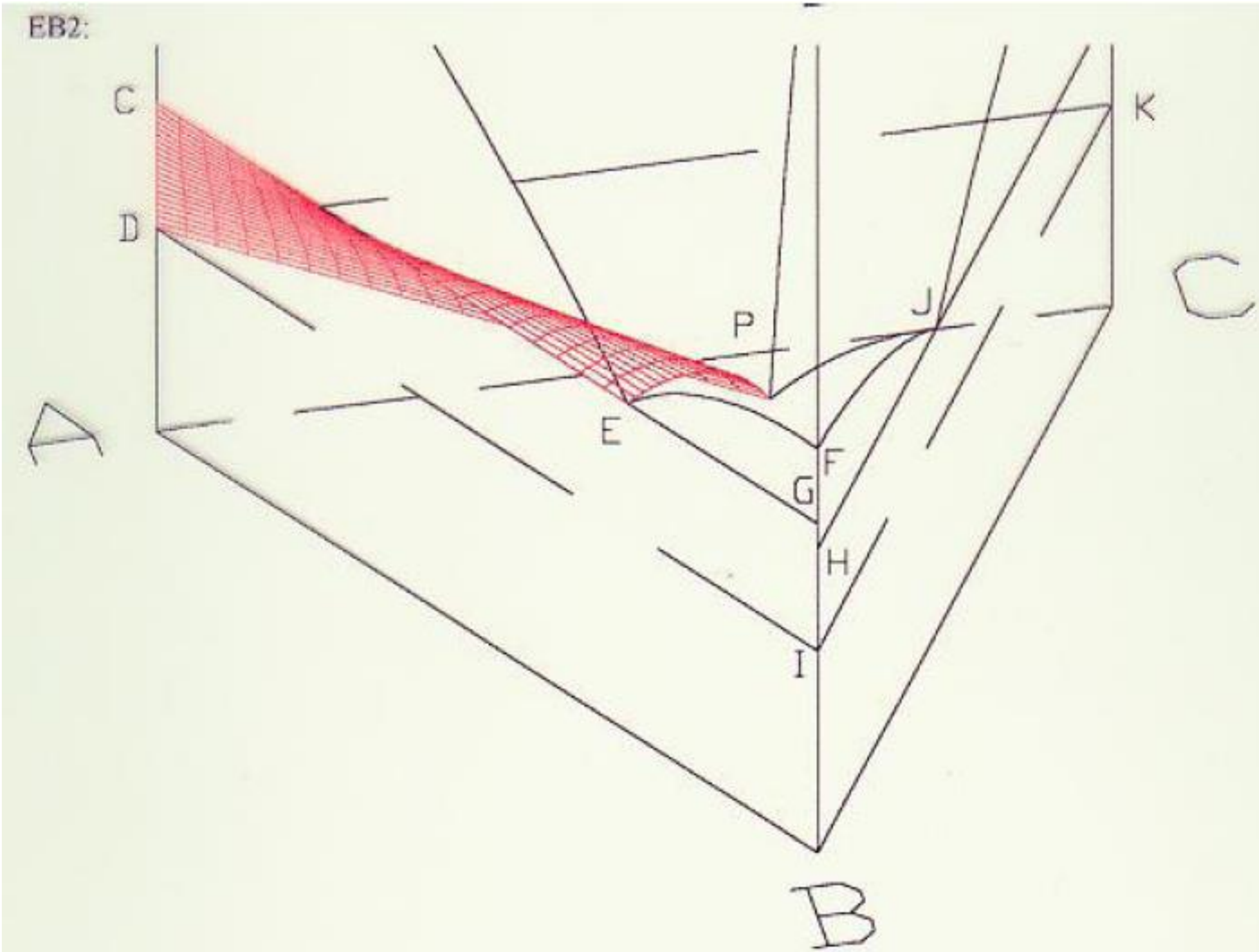

A
B
C

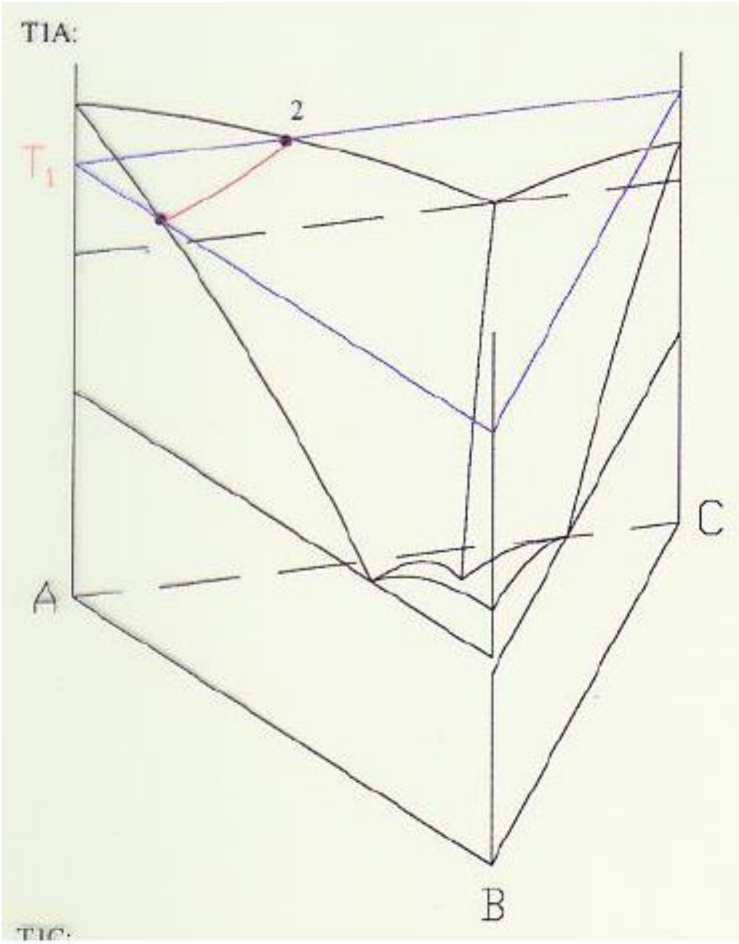

A
B
C

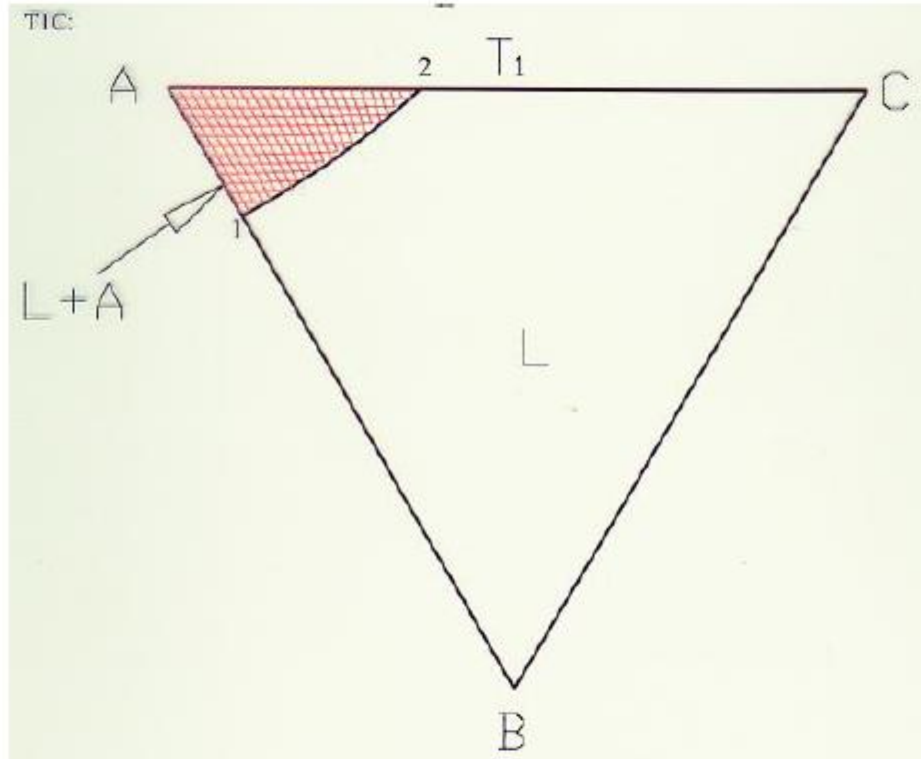

A
N
D
M
B
L
C
K
D
C
J
P
A
E
F
G
H
I
B

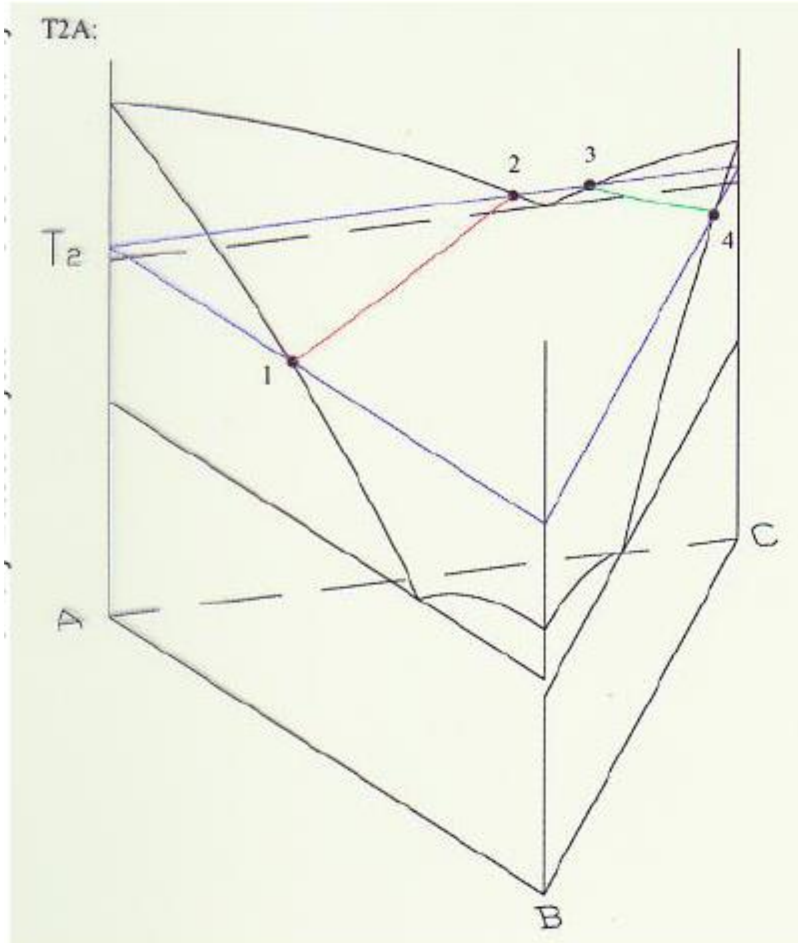

A
C
B

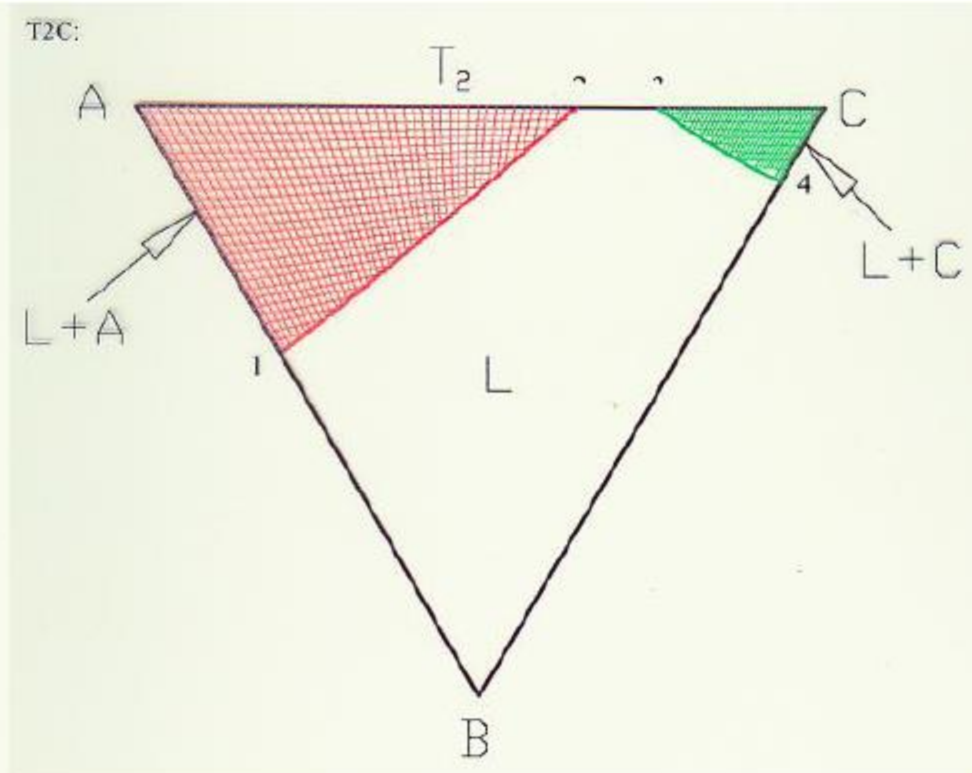

EB1:
P
J
C
E
F
G
H
I
B

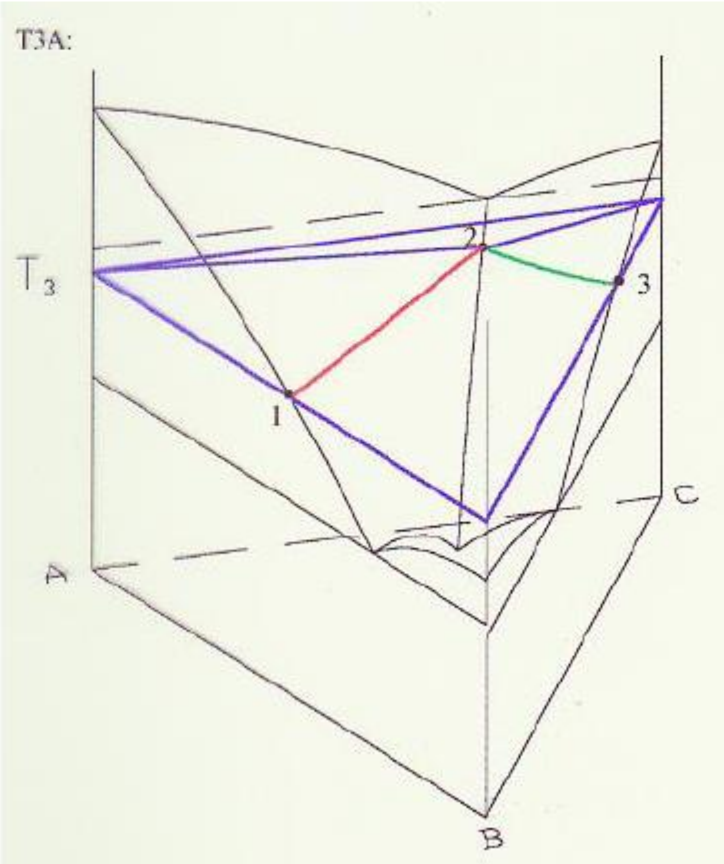

EB2:
C
D
A
E
P
J
K
C
F
G
H
I
B

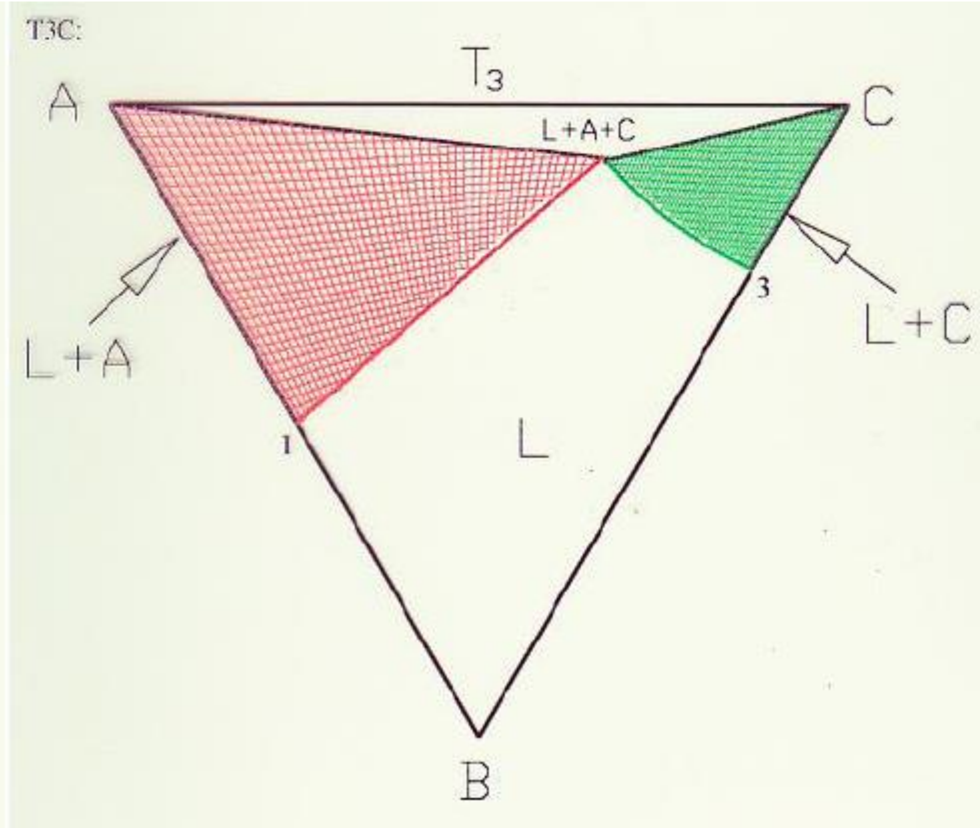

T1A:
2
T1
A
C
B
TIC:

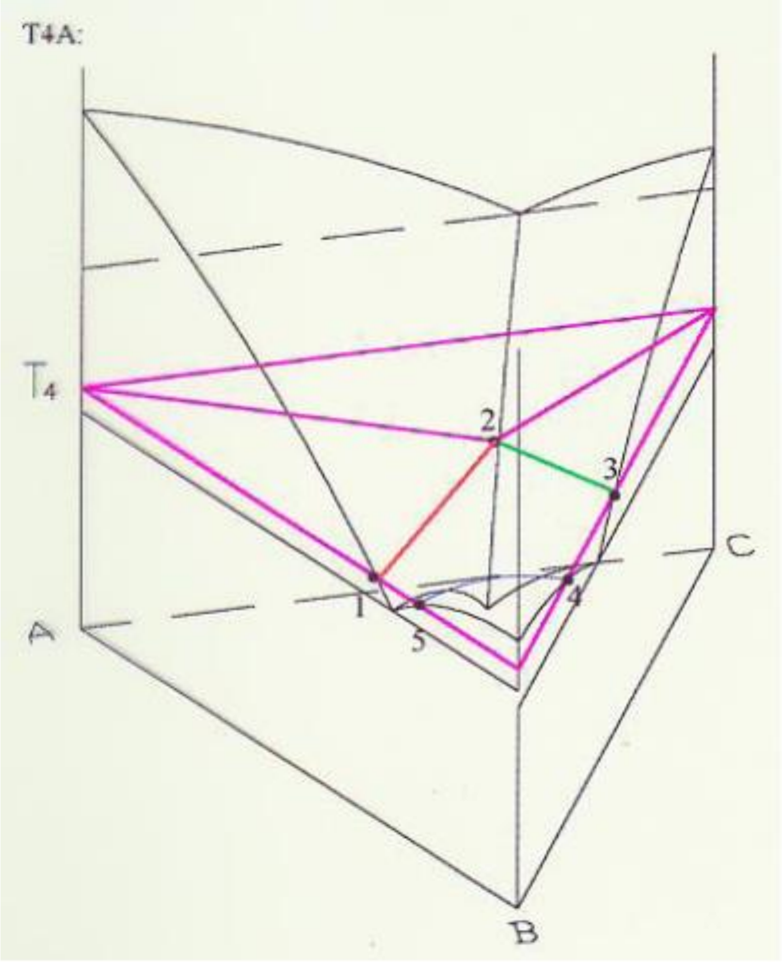

TIC:
A
2
T1
C
1
L+A
L
B


T2A:
T2
A
B
C
1
2
3
4

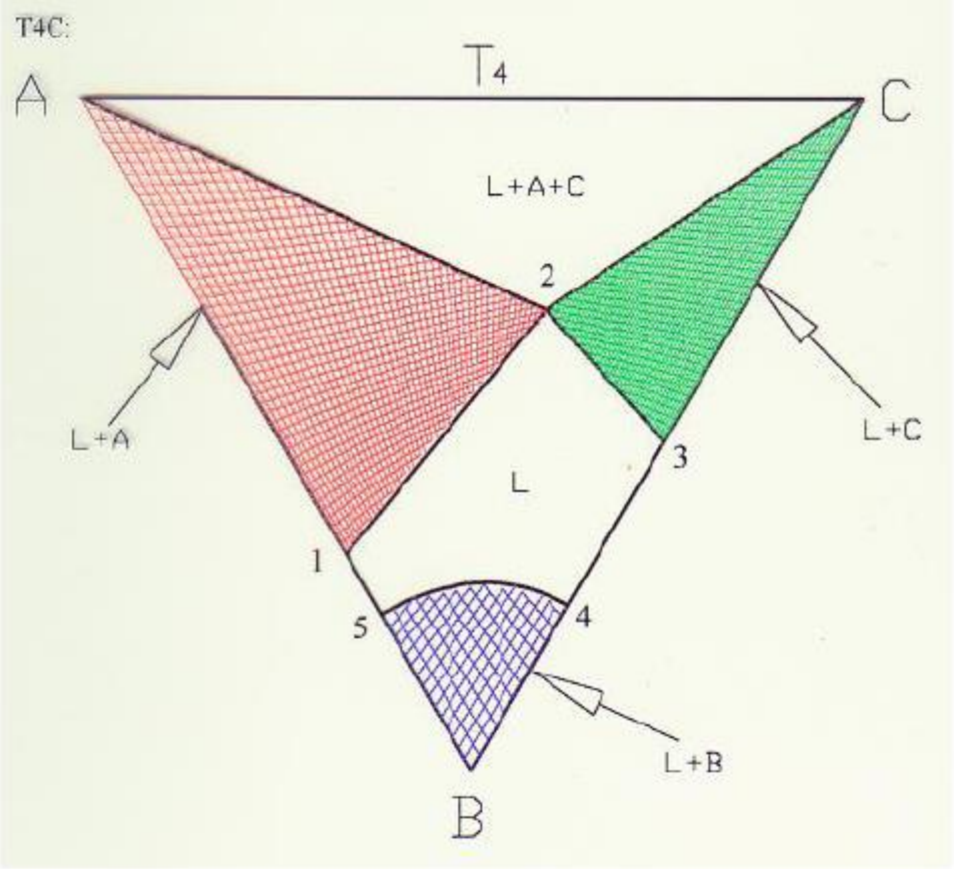

T2C:
T2
A
C
B
L+A
L+C
L
1
4


T3A:
T3
2
3
1
C
A
B

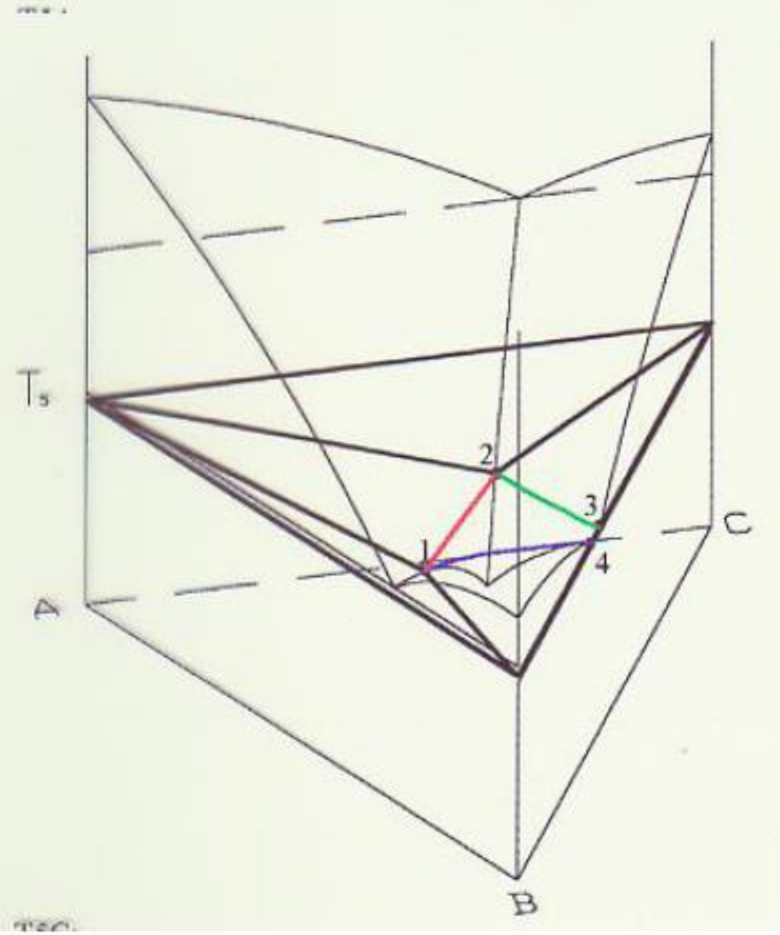

T3C:
T3
A
C
L+A+C
3
L+C
L+A
1
L
B



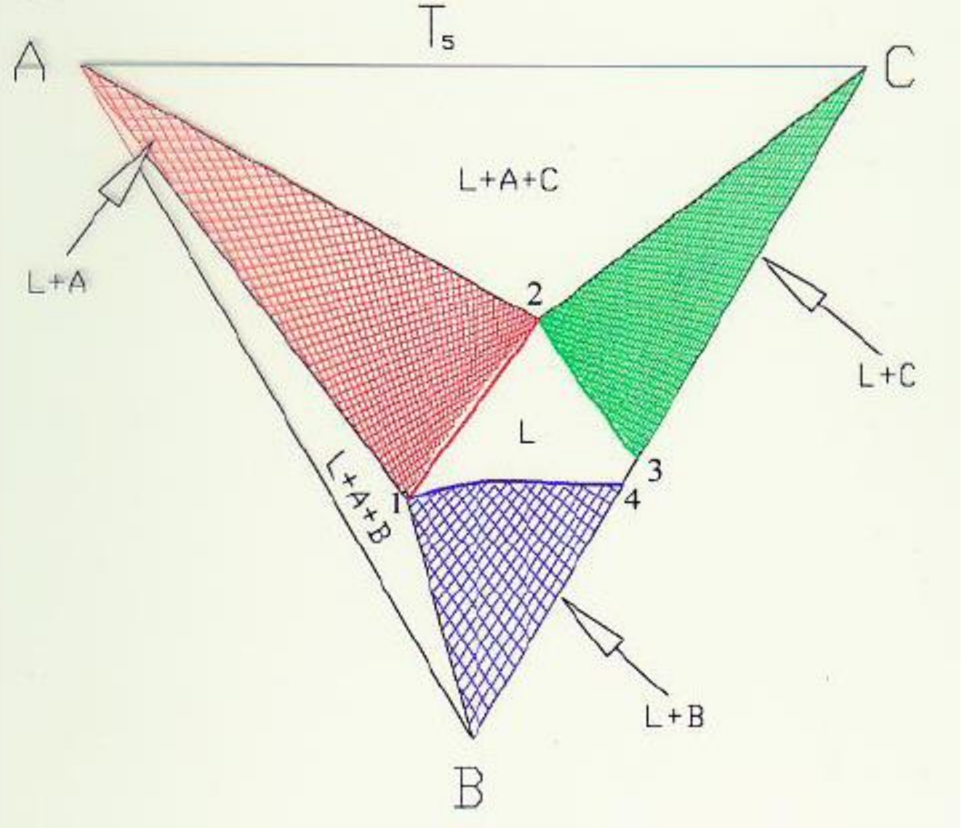
T4A:
T4
2
3
C
1
4
5
A
B

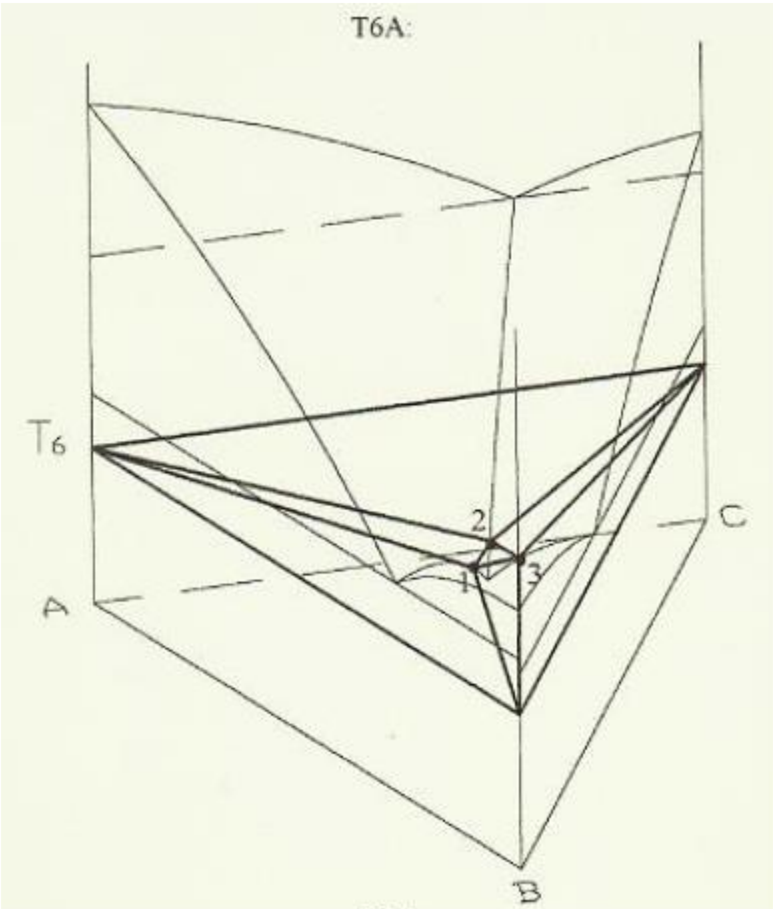


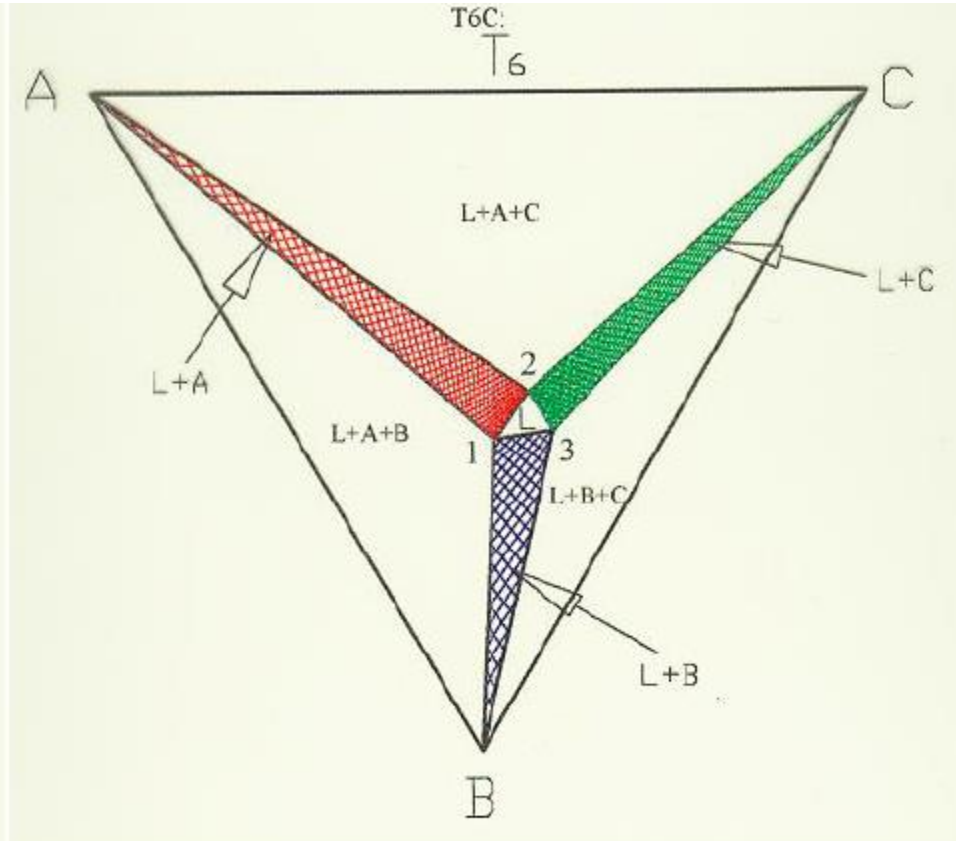
T4C:
T4
A
C
L+A+C
2
L+A
L+C
3
L
1
5
4
L+B
B



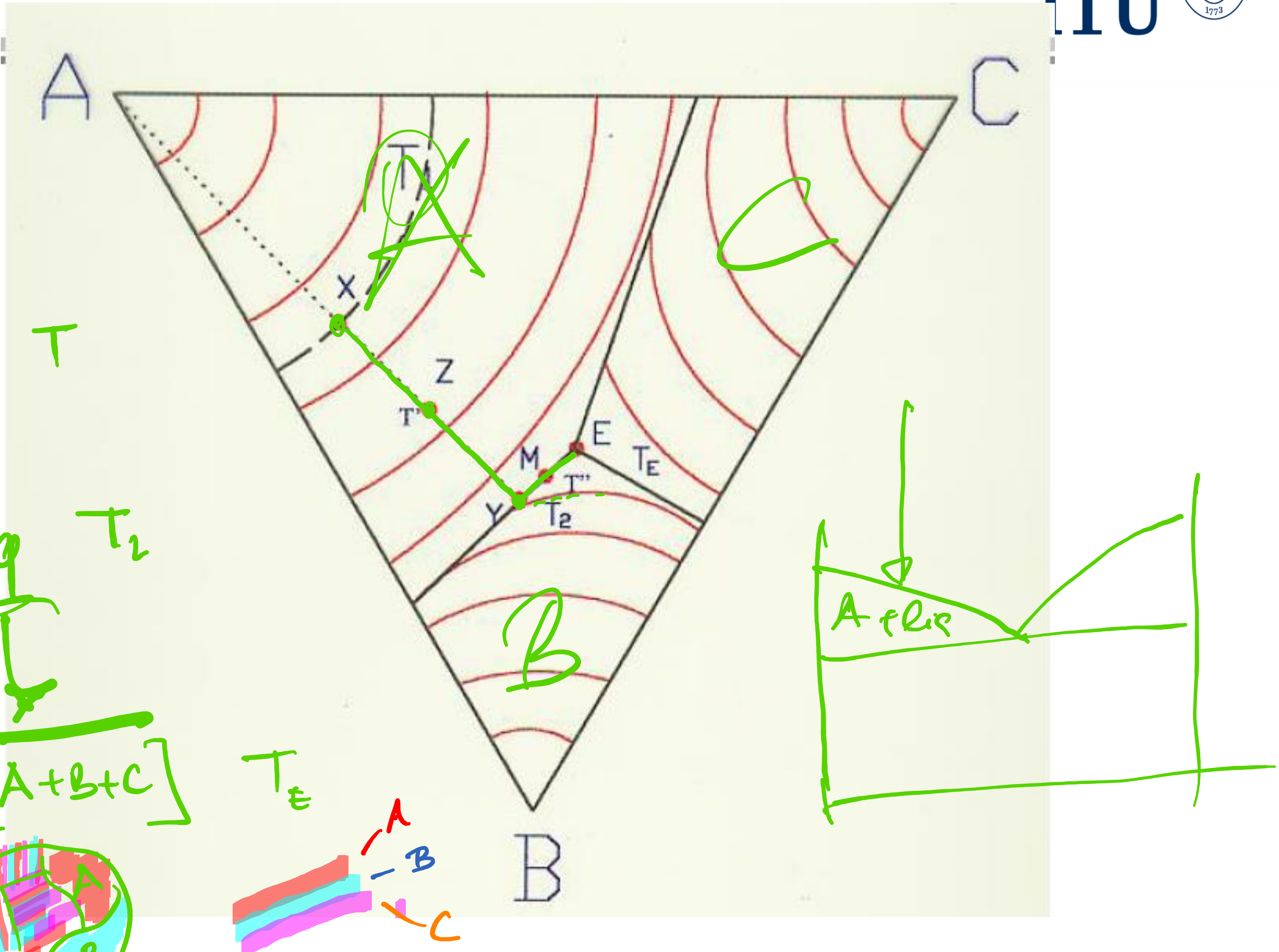
T5C:

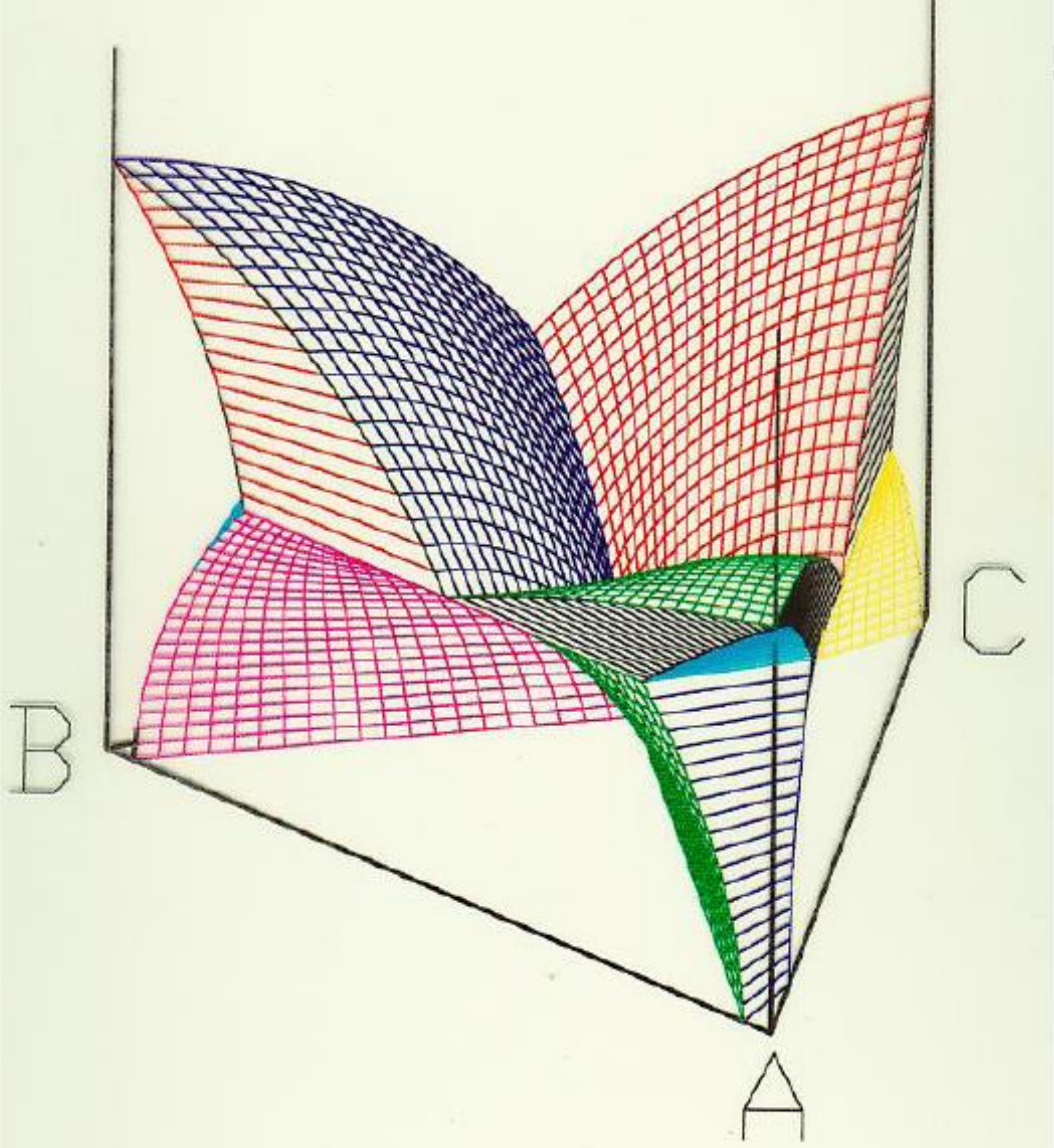



T6A:
T6
A
B
C
1
2
3

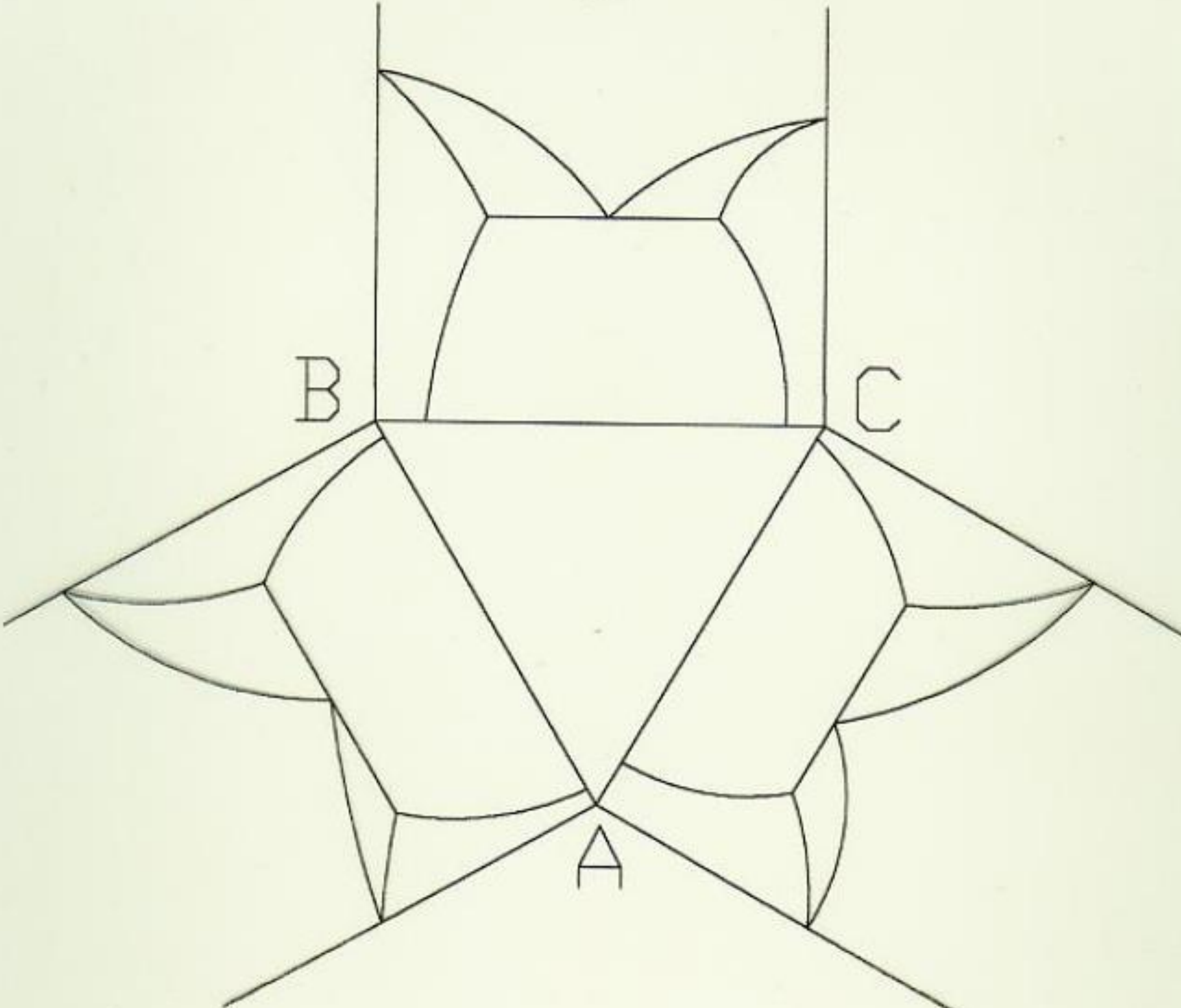

T6C:
T6
A
C
B
L+A+C
L+C
L+A
L+A+B
L+B+C
L+B
L
1
2
3

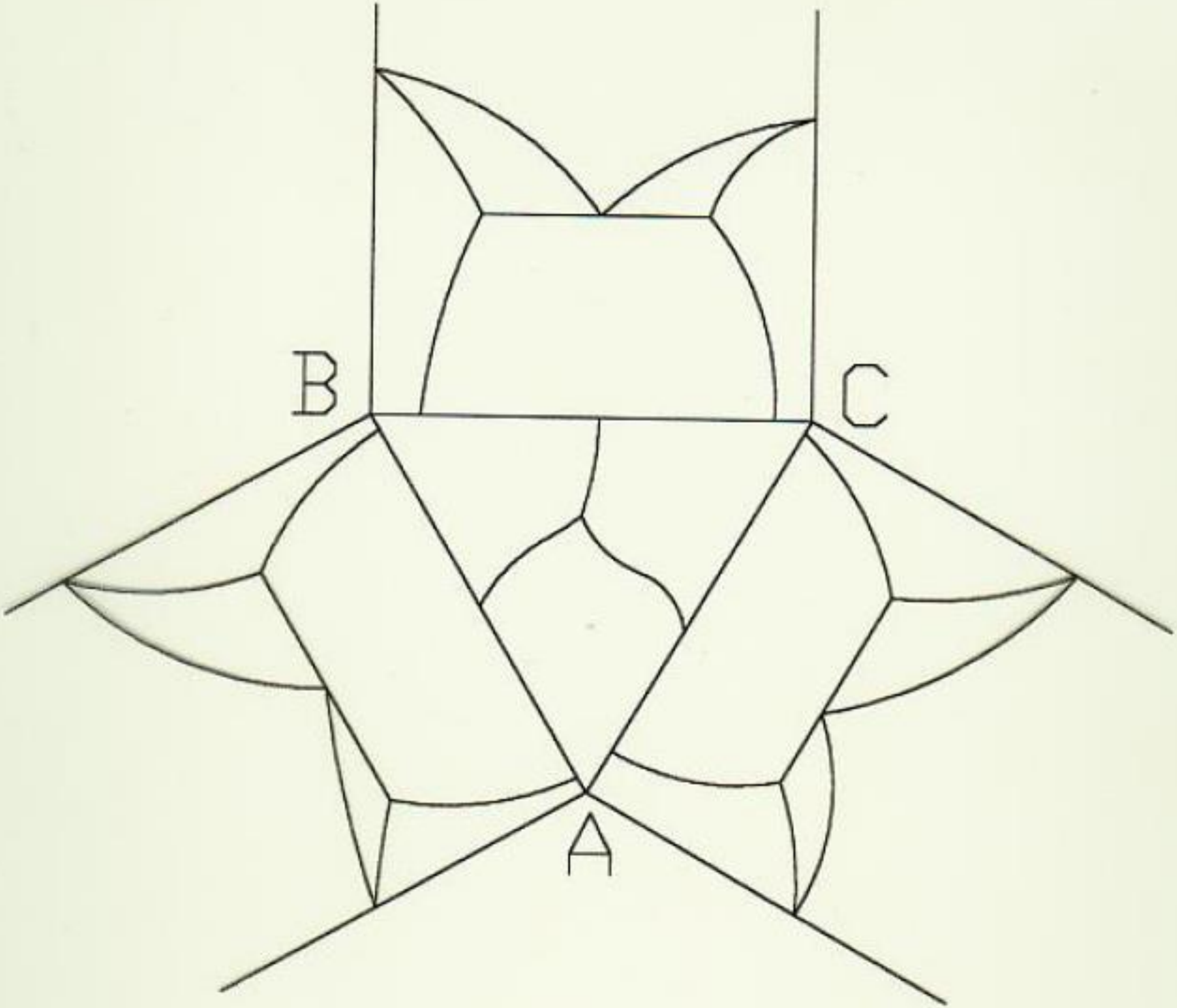
liq
↓
A+liq T
↓
A+B+liq T_2
↓
A+B+[A+B+C] T_E

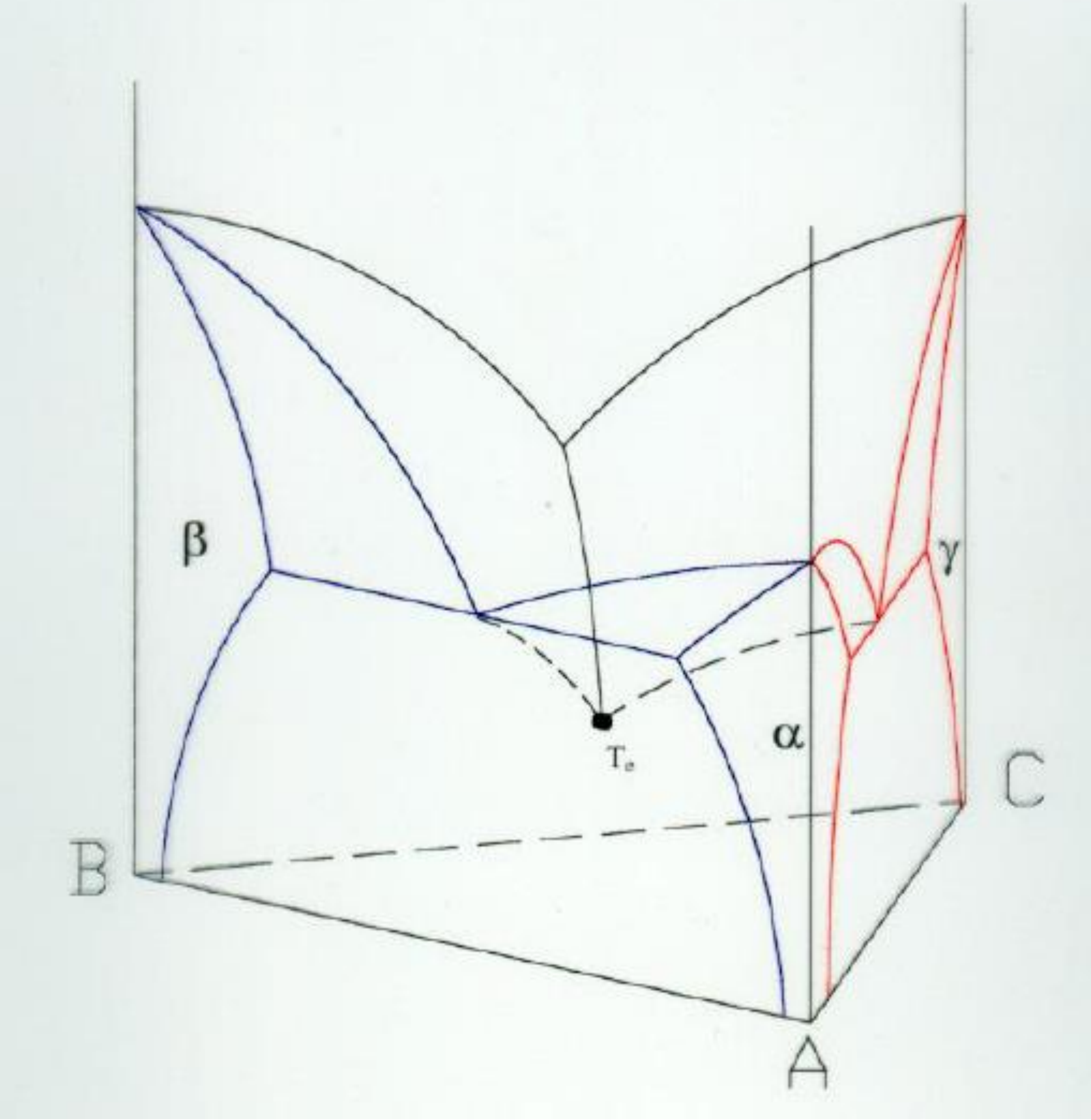


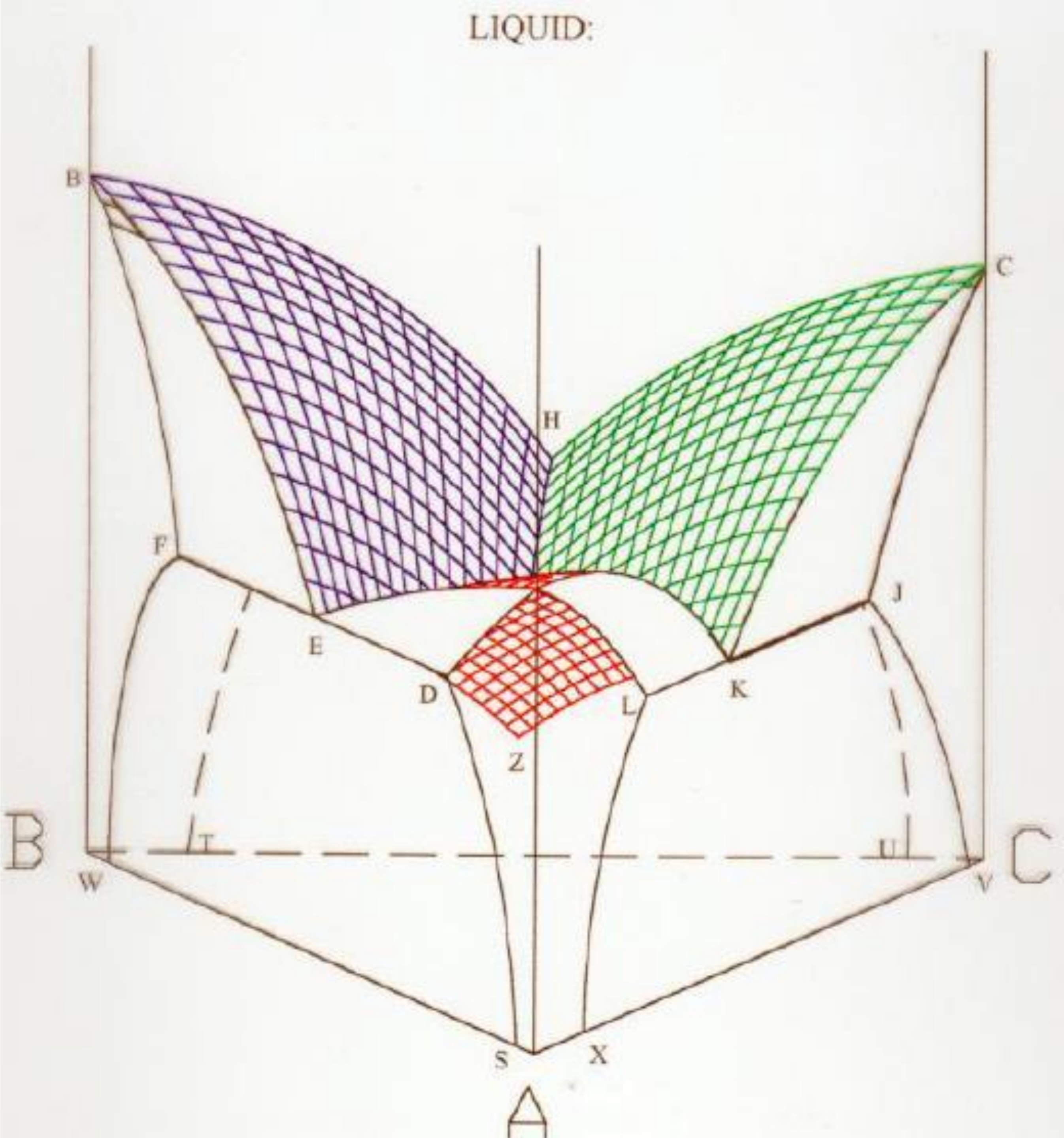

B
C
A

P2:



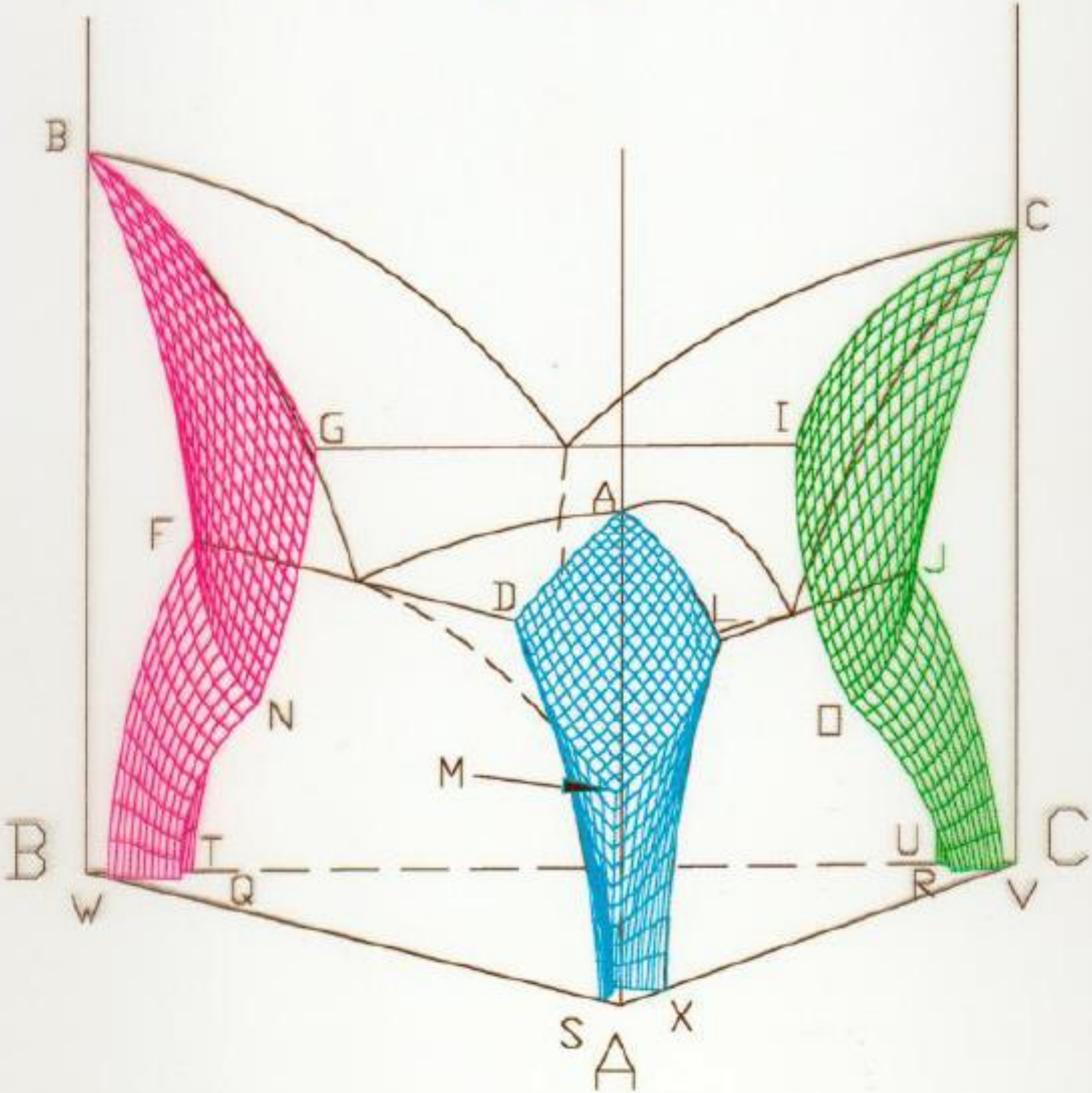

B
C
A

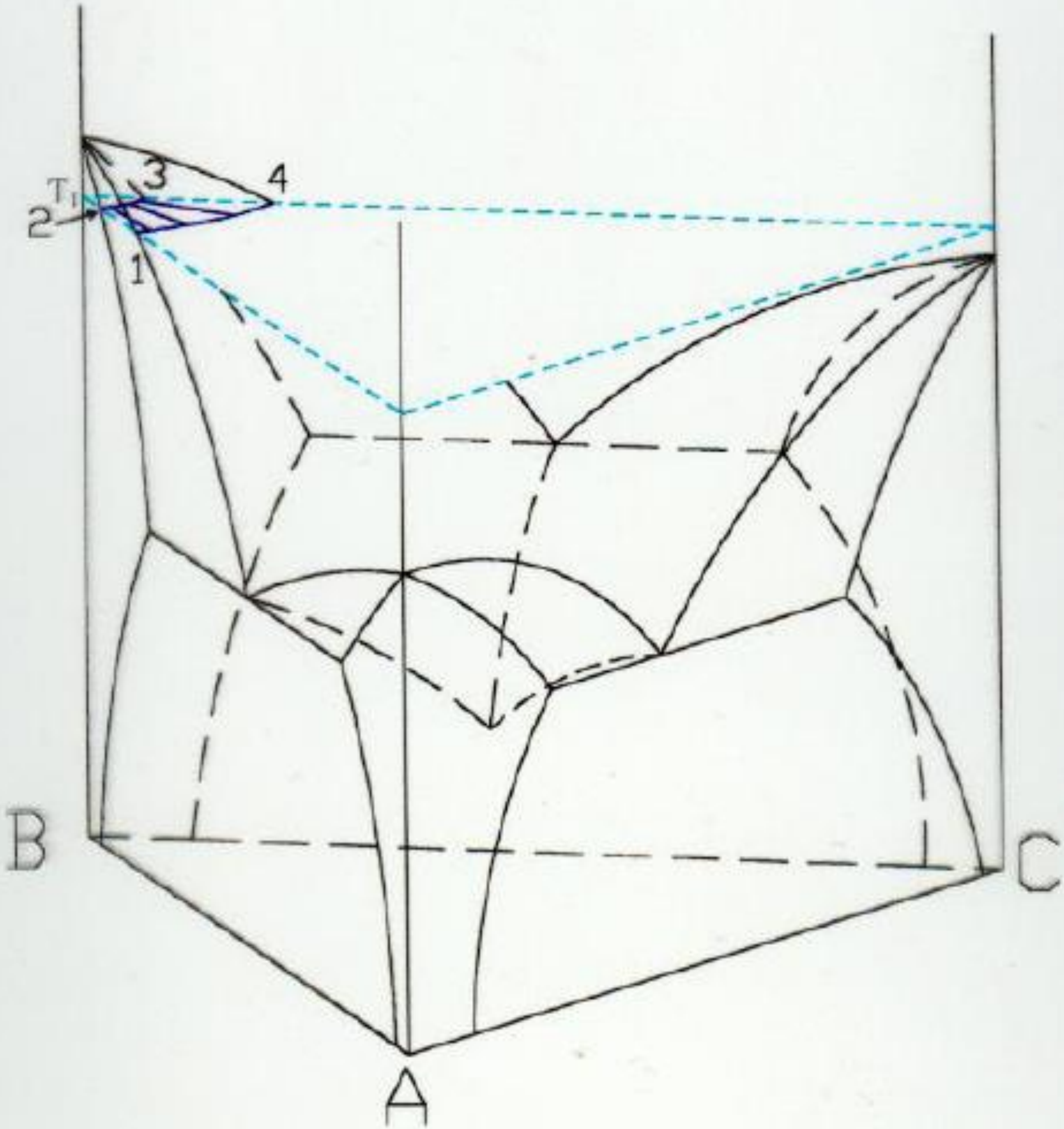

β
γ
α
T_e
C
B
A



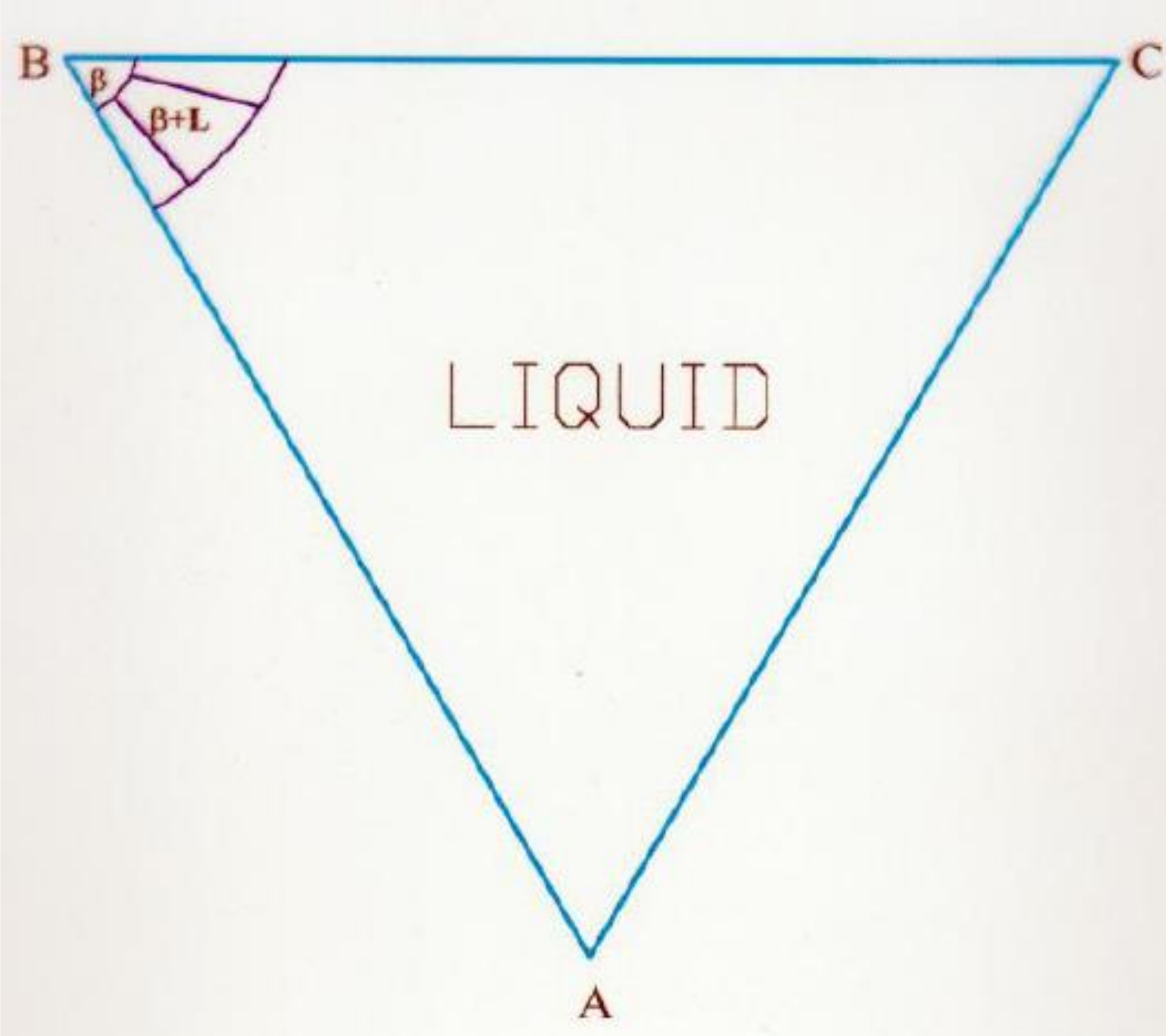
LIQUID:
B
C
H
F
E
D
Z
L
K
J
T
U
B
C
W
V
S
X
A

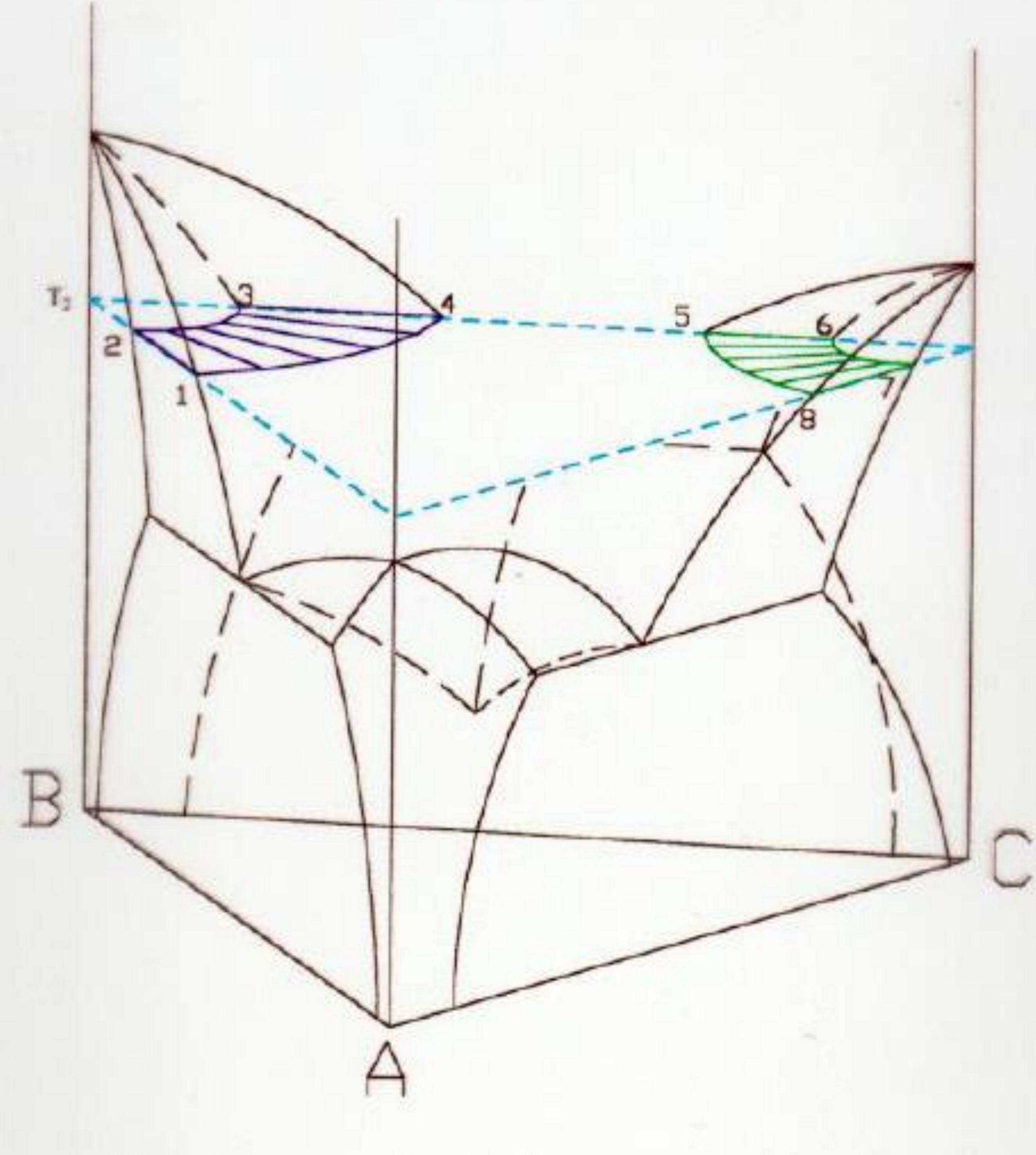
SINGPHSE



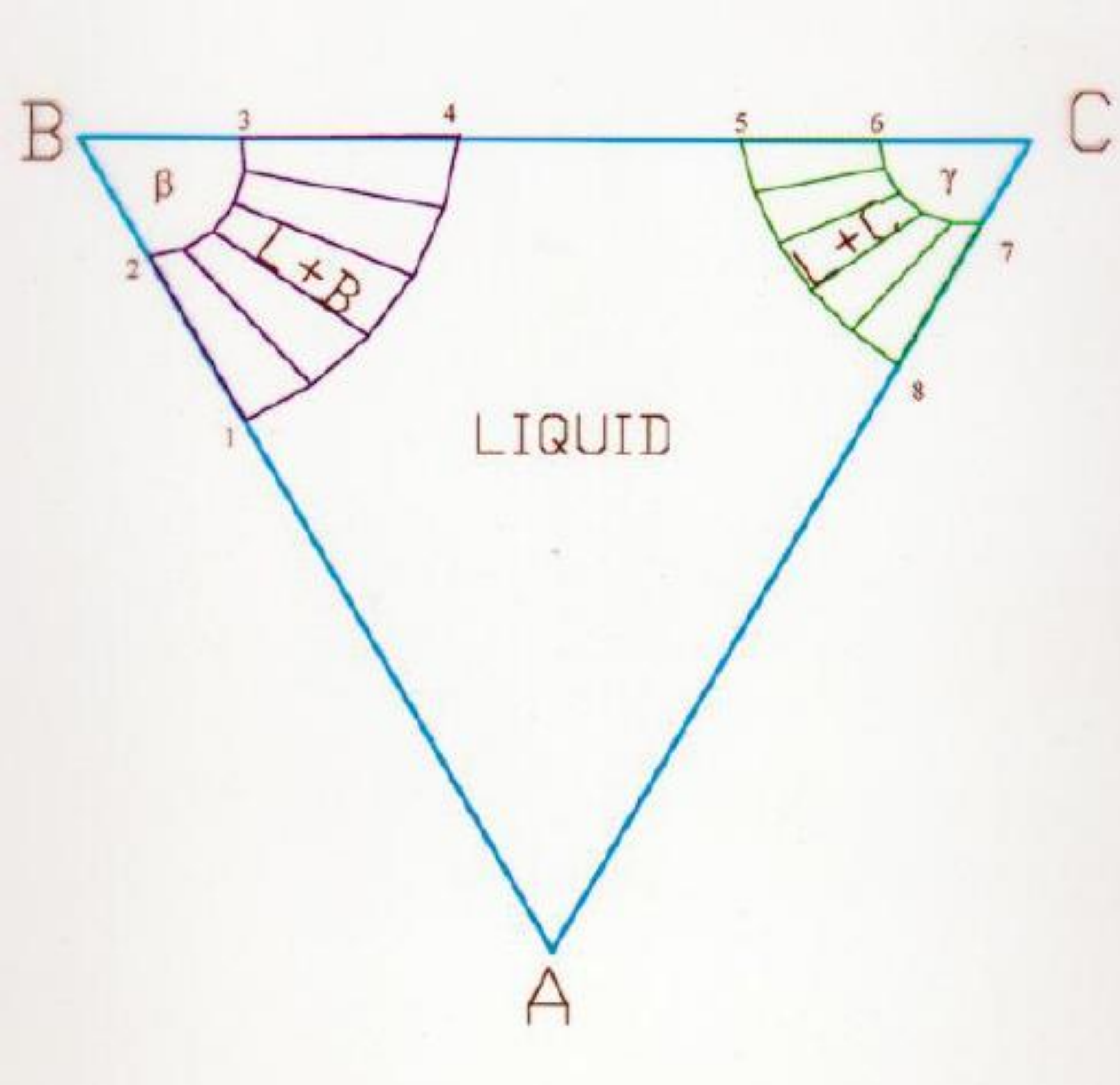


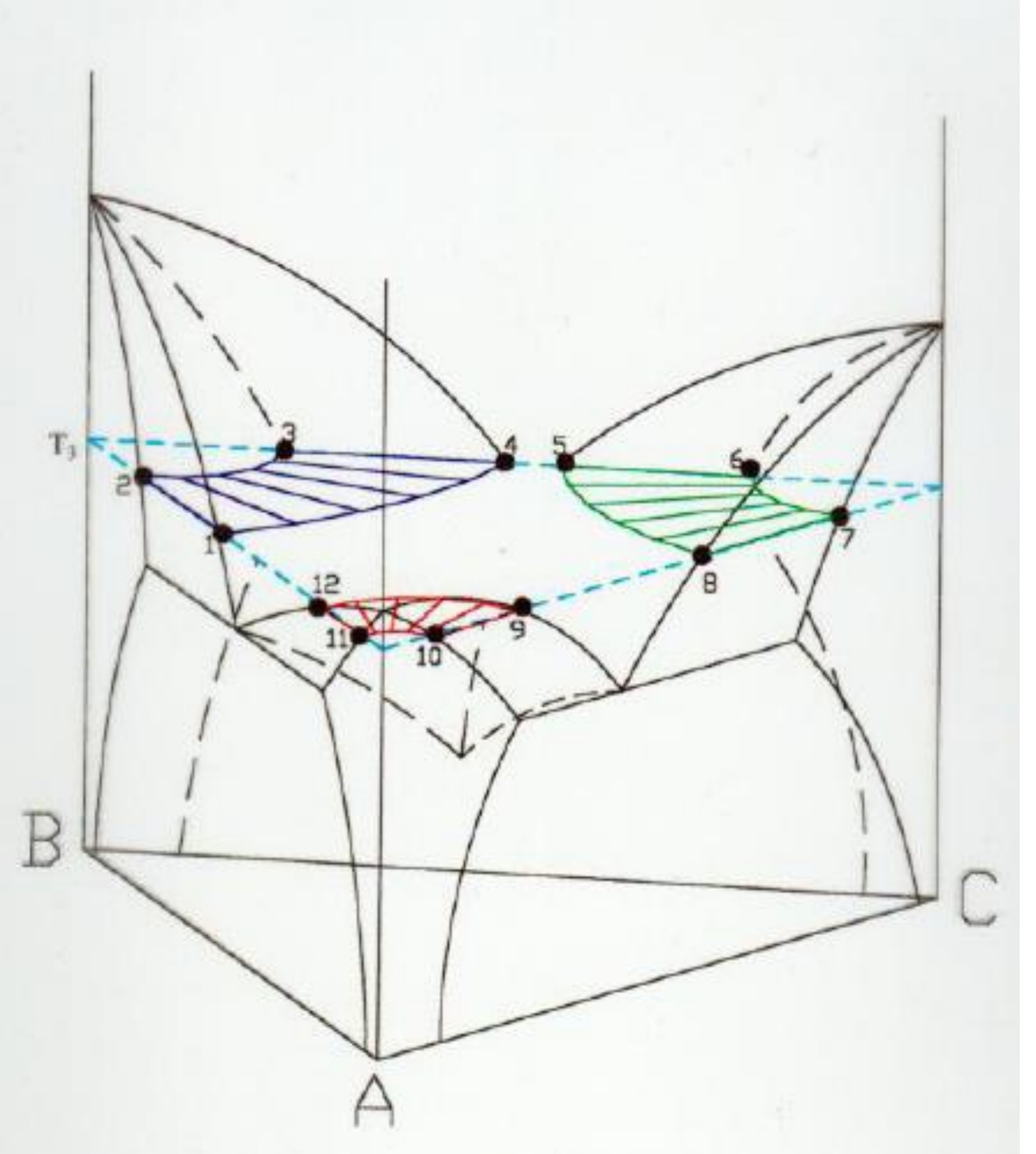
T1
1
2
3
4
B
A
C


B
C
β
β+L
LIQUID
A

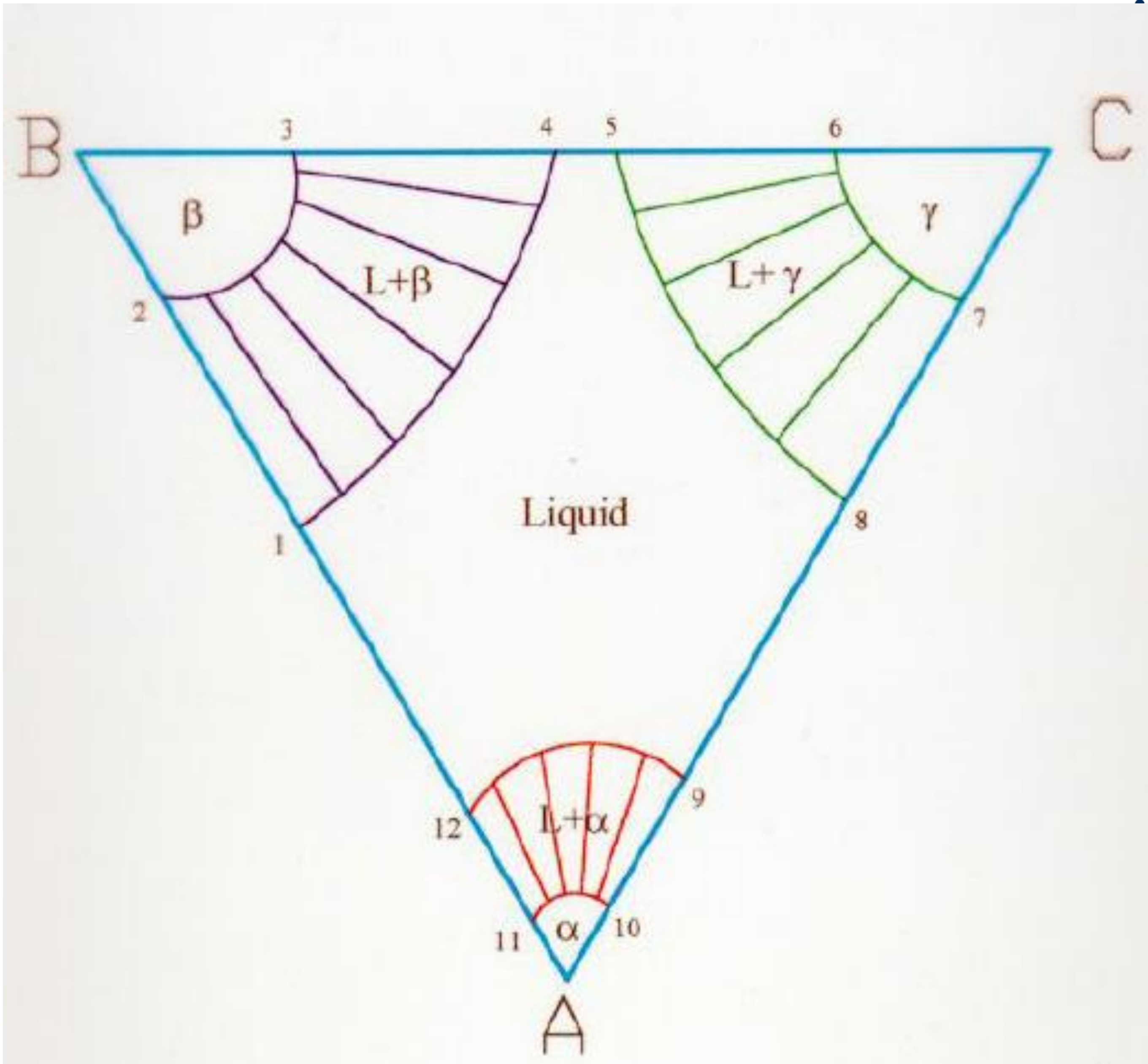


İTÜ

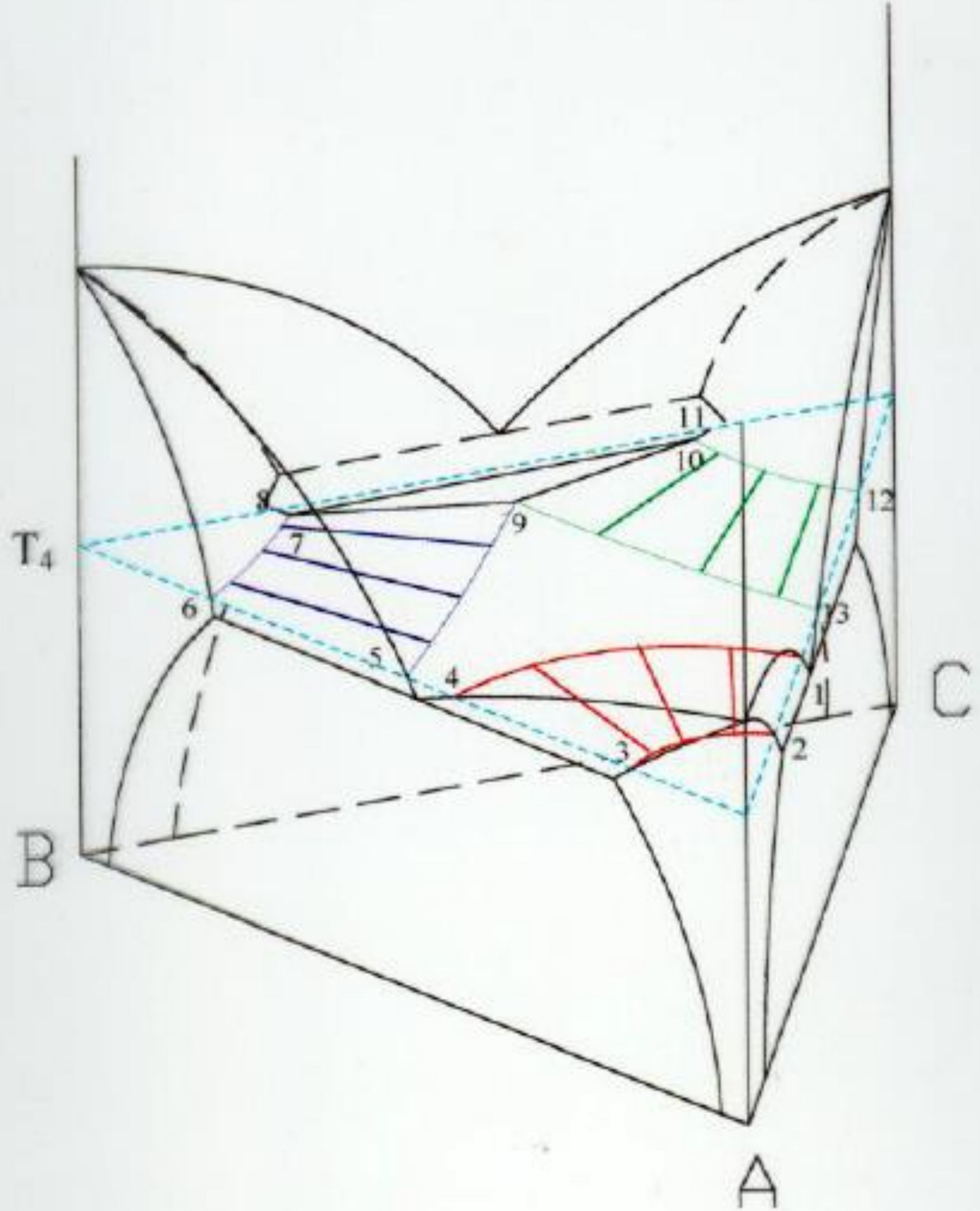

B
3
4
5
6
C
β
γ
L+B
L+C
2
7
8
1
LIQUID
A



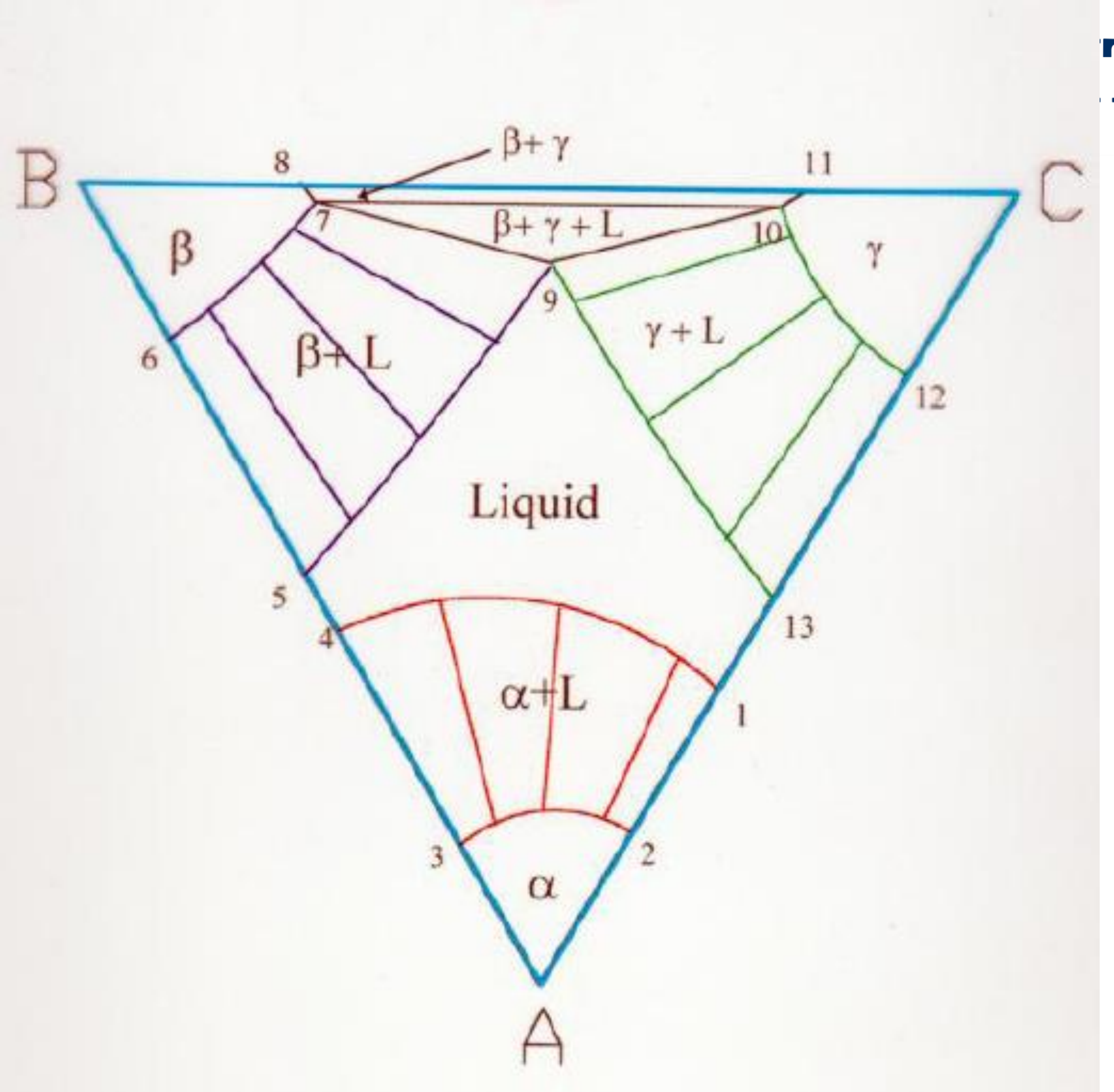
T3
1
2
3
4
5
6
7
8
9
10
11
12
B
C
A

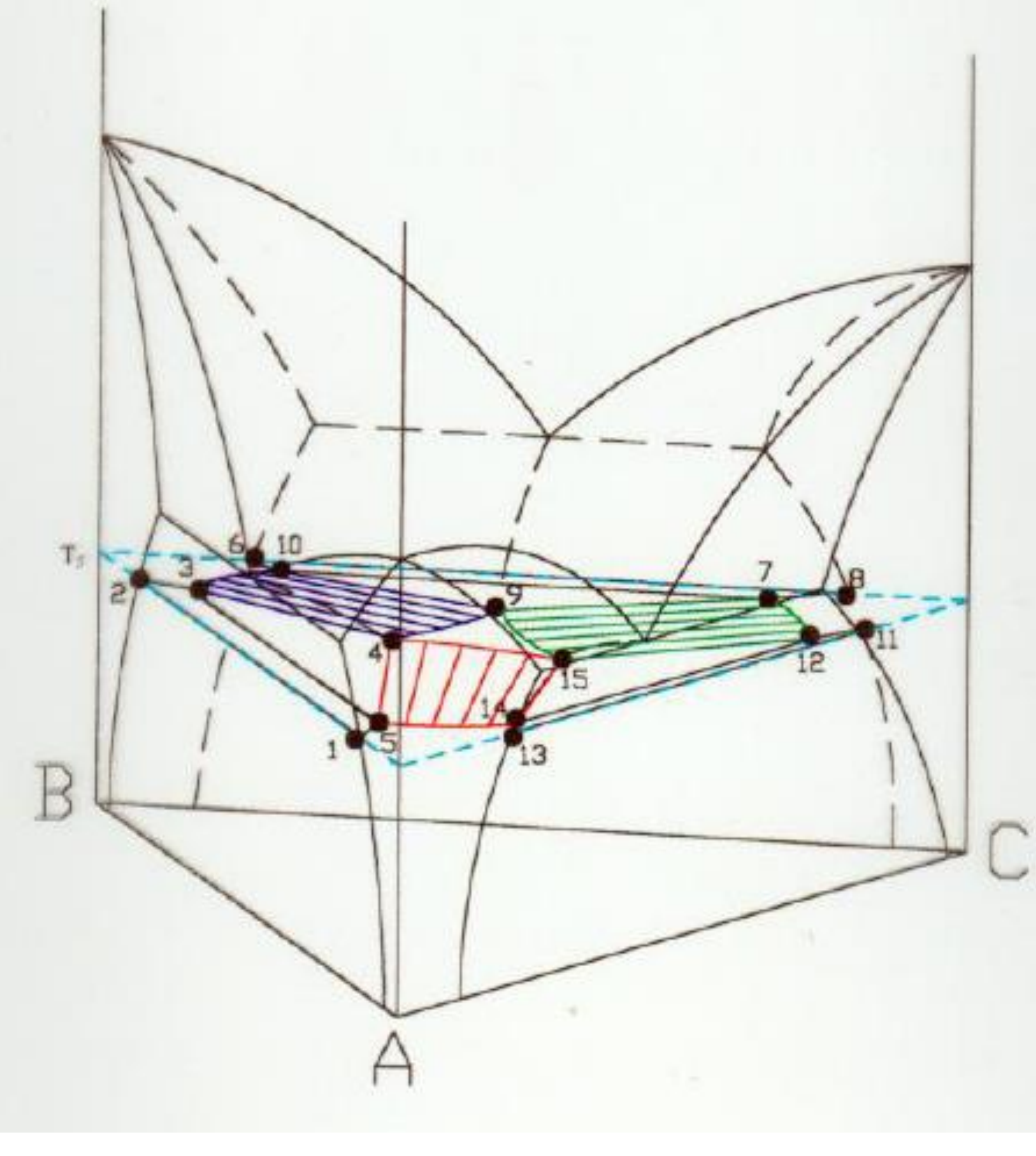


B
C
A
3
4
5
6
β
L+β
L+γ
γ
2
7
Liquid
1
8
L+α
12
9
α
11
10

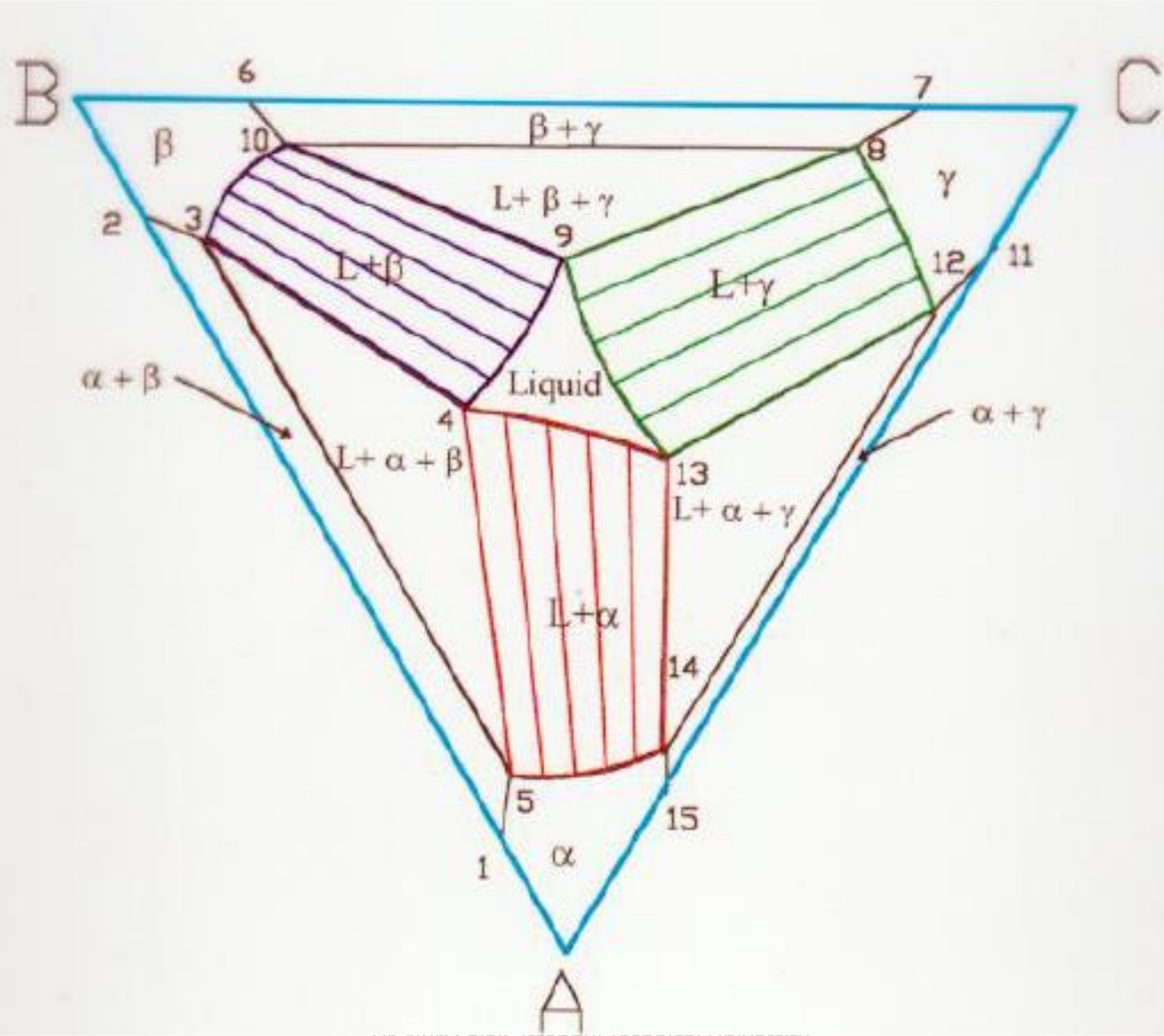


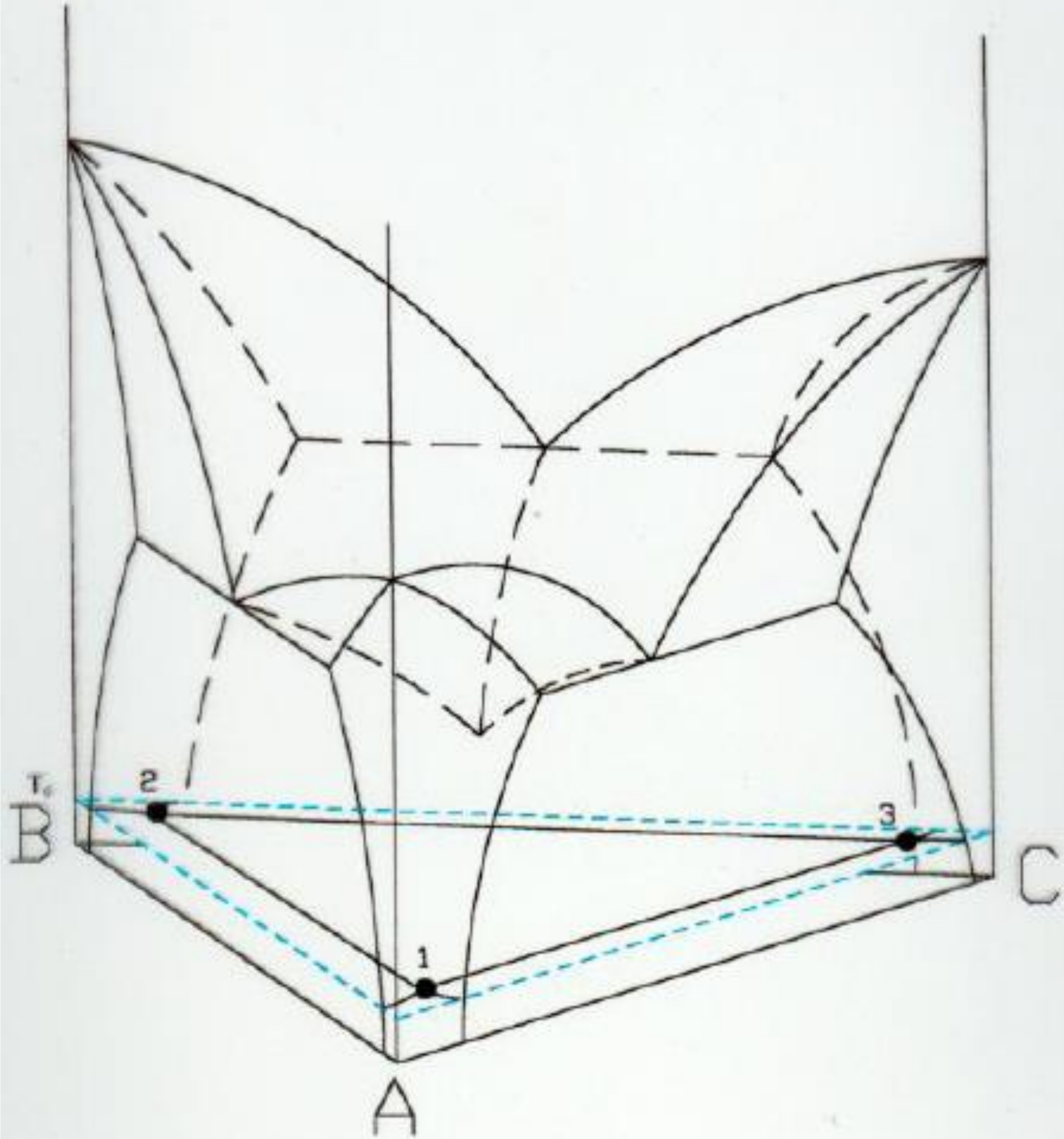
T_4
1
2
3
4
5
6
7
8
9
10
11
12
13
A
B
C


β+ γ
8
11
B
C
7
β+ γ + L
10
β
γ
9
γ + L
6
β+ L
12
Liquid
5
13
4
α+L
1
3
2
α
A

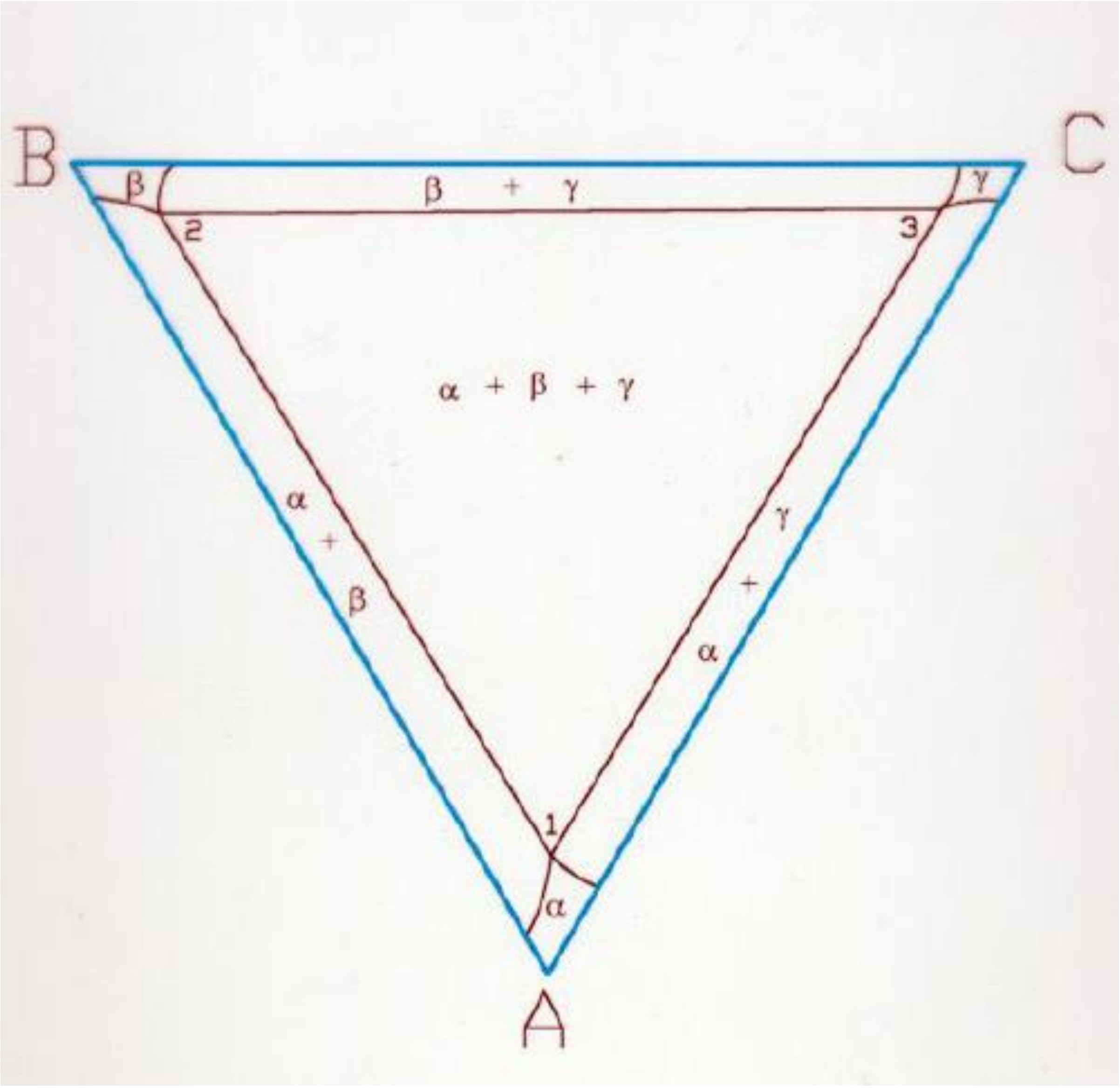


T
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
B
A
C


B
C
A
6
7
β + γ
10
8
β
γ
L+ β + γ
2
3
9
L+β
12
11
L+γ
α + β
Liquid
α + γ
4
L+ α + β
13
L+ α + γ
L+α
14
5
15
1
α

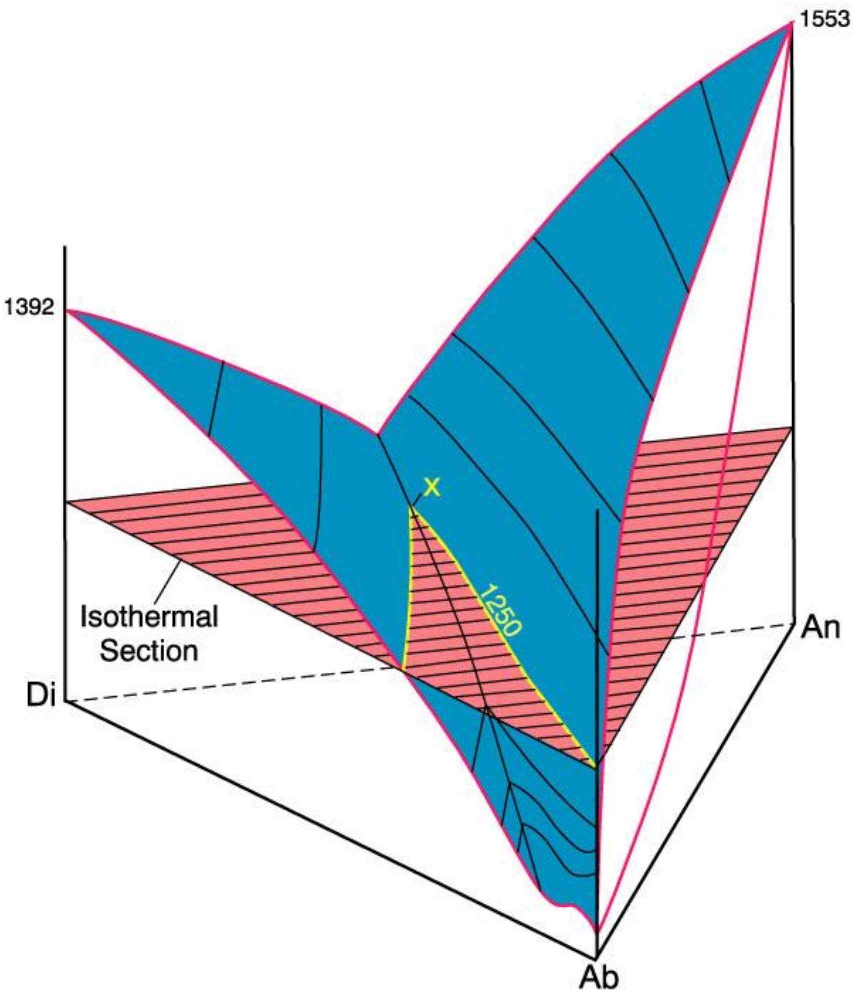


B
C
A
1
2
3



B
C
β
β + γ
γ
2
3
α + β + γ
α
+
β
γ
+
α
1
α
A

Oblique View



Isothermal Section

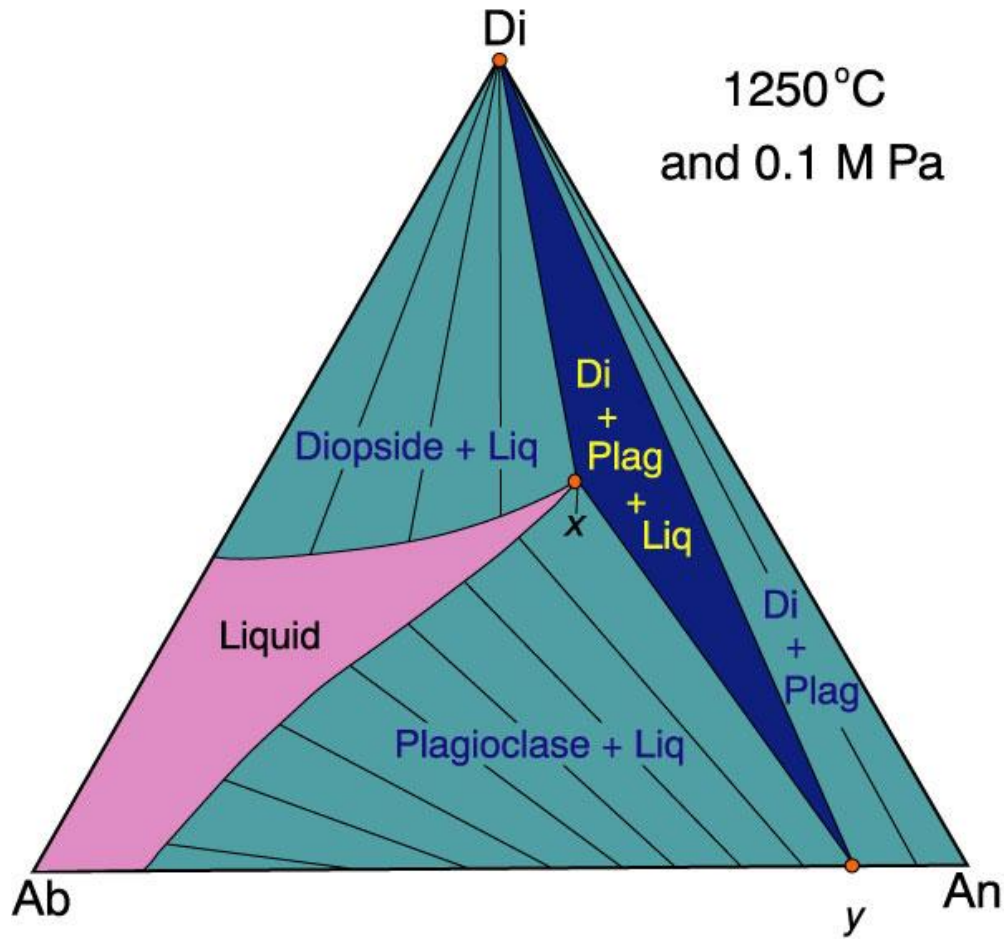
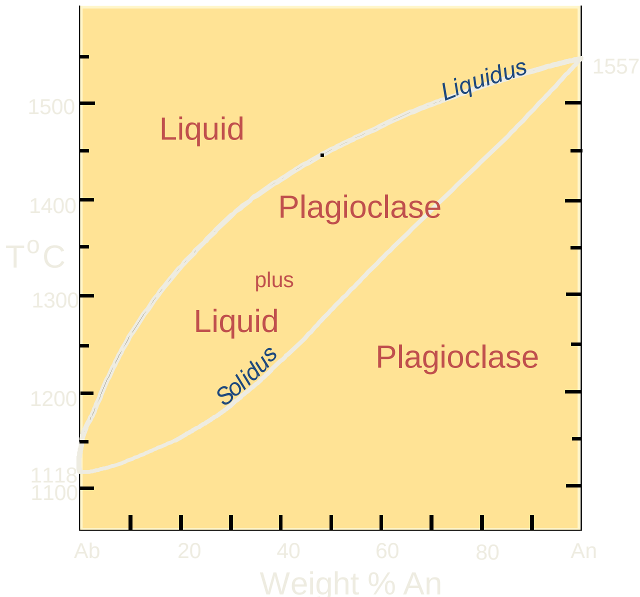
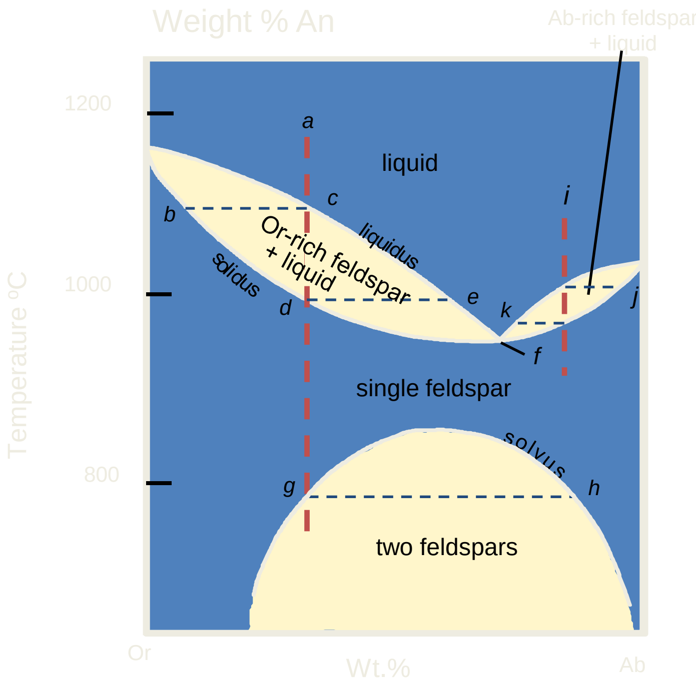


Figure 7.8. Oblique view illustrating an isothermal section through the diopside-albite-anorthite system. Figure 7.9. Isothermal section at 1250ºC (and 0.1 MPa) in the system Di-An-Ab. Both from Morse (1994), Basalts and Phase Diagrams. Krieger Publishers.

Ternary Feldspars





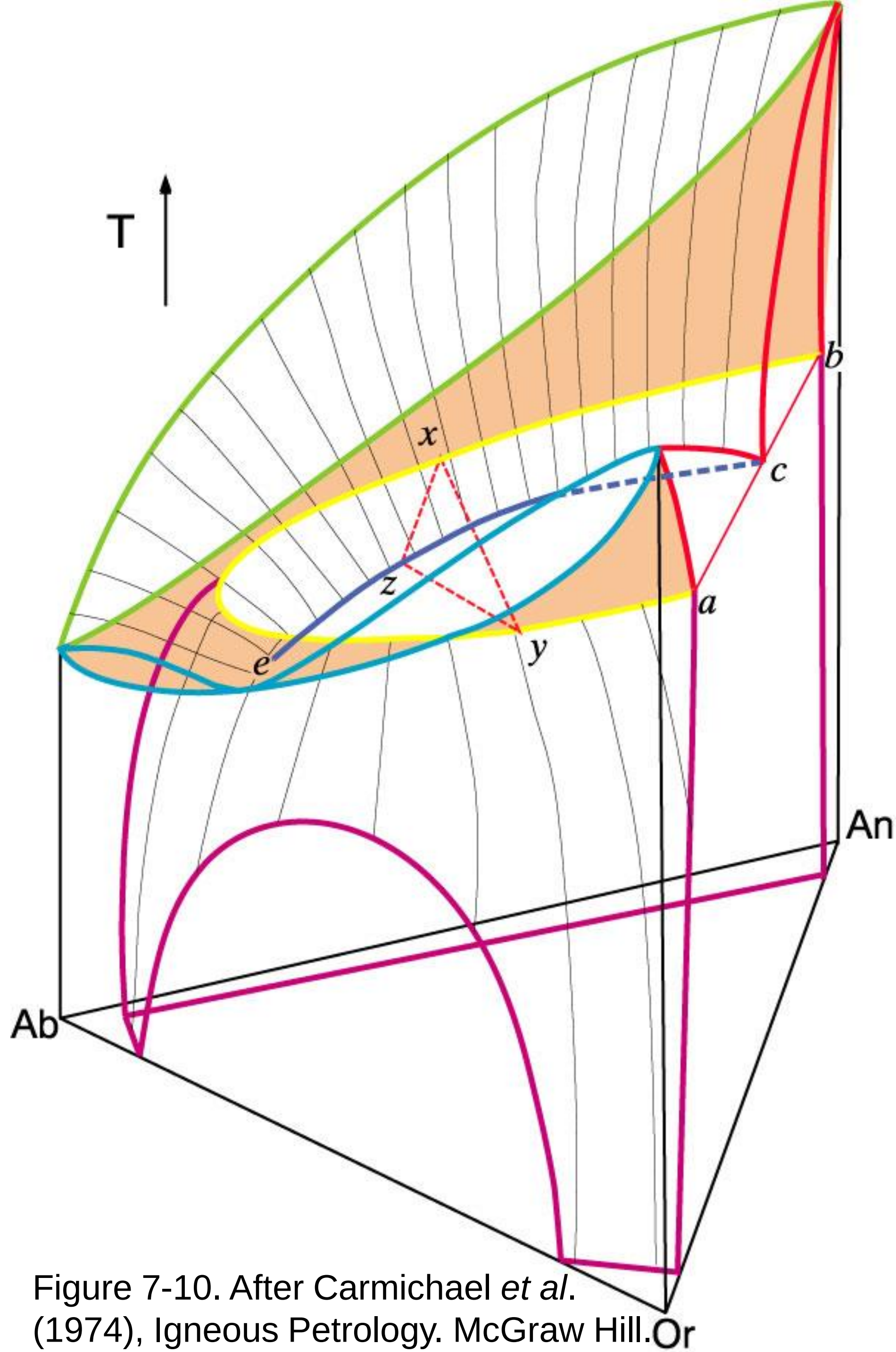
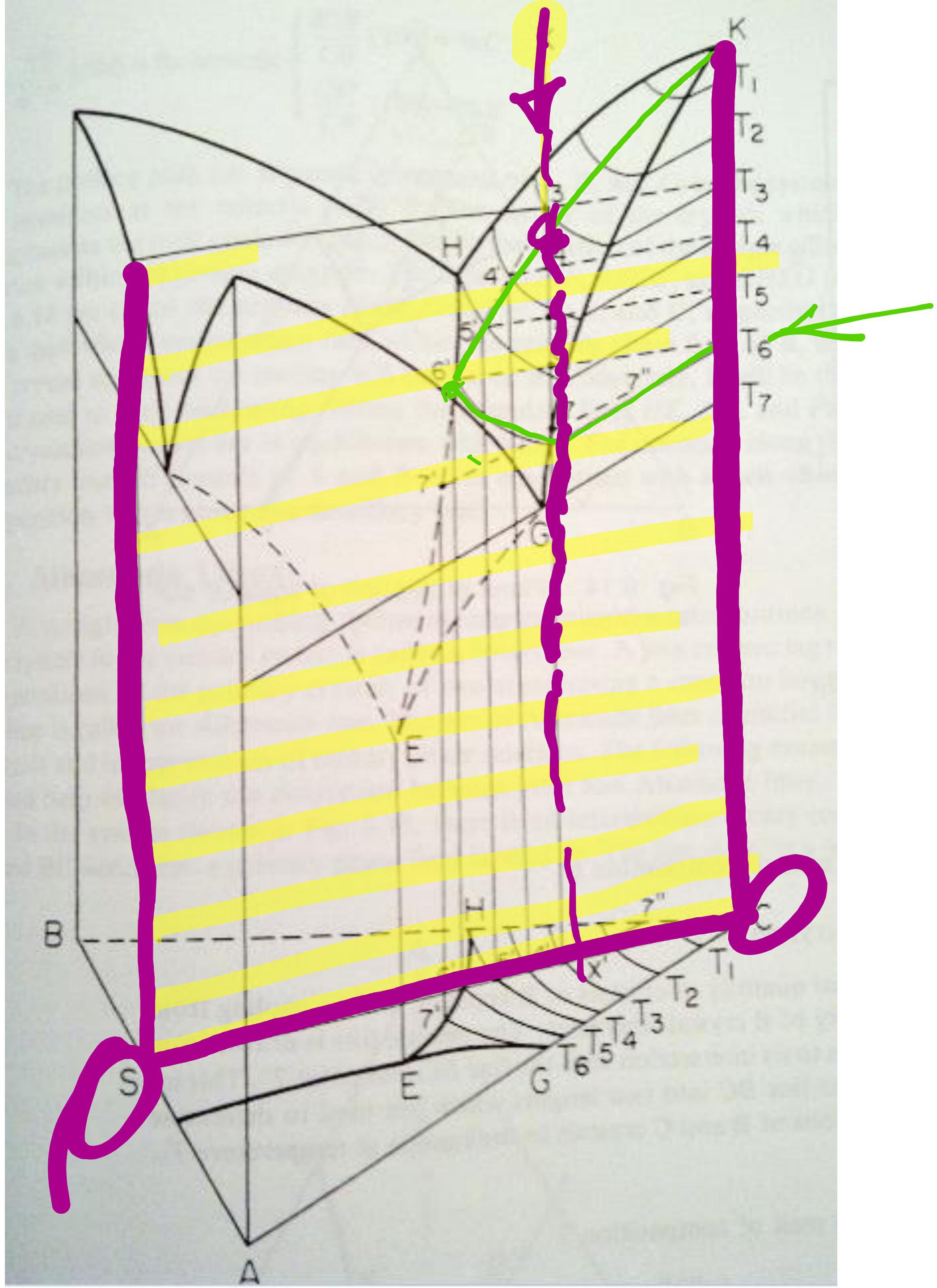
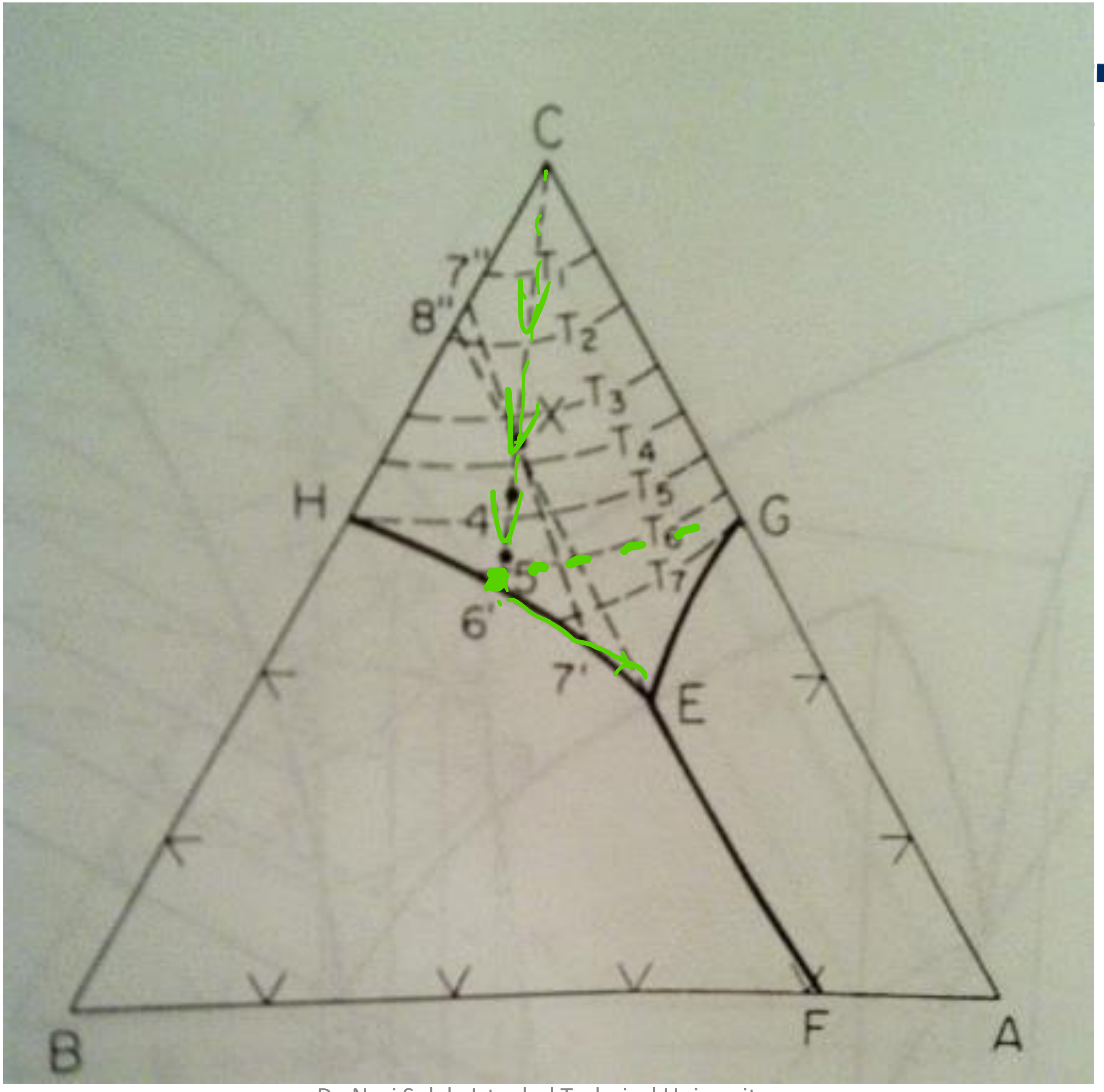
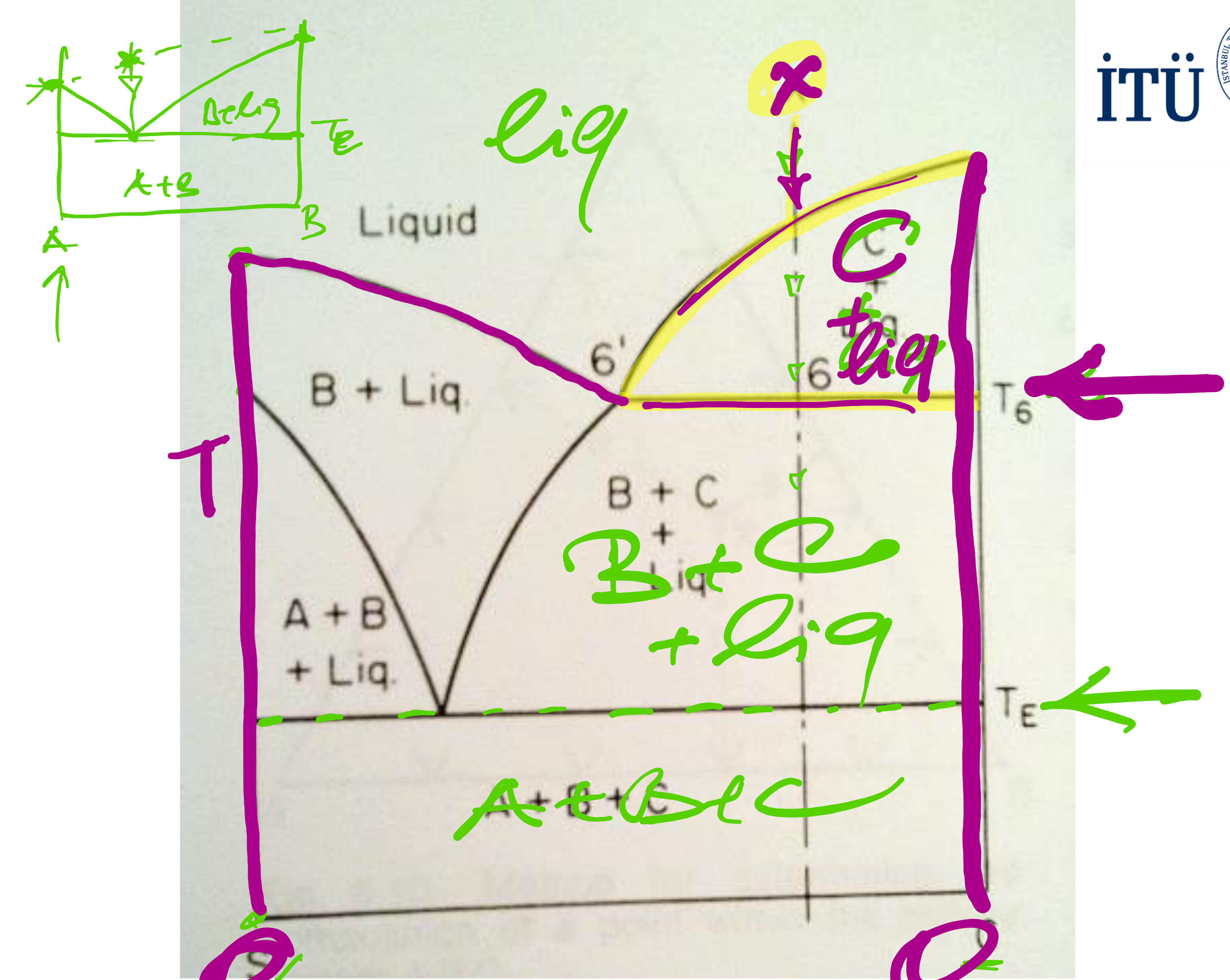


Figure 7-10. After Carmichael *et al*. (1974), Igneous Petrology. McGraw Hill.

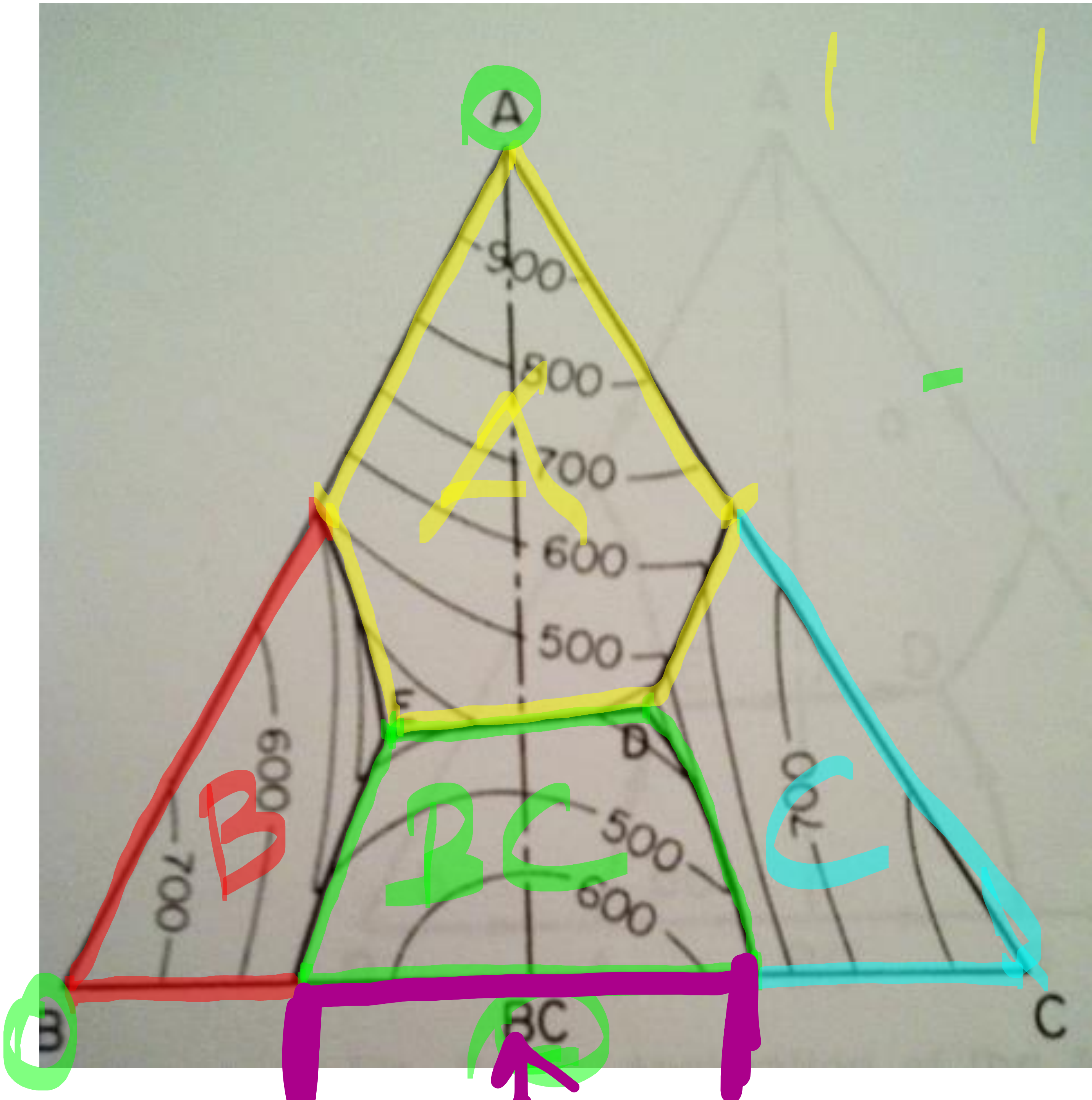


İTÜ


C
7''
8''
T_1
T_2
T_3
X
T_4
T_5
T_6
T_7
H
G
4
5
6'
7'
E
B
F
A

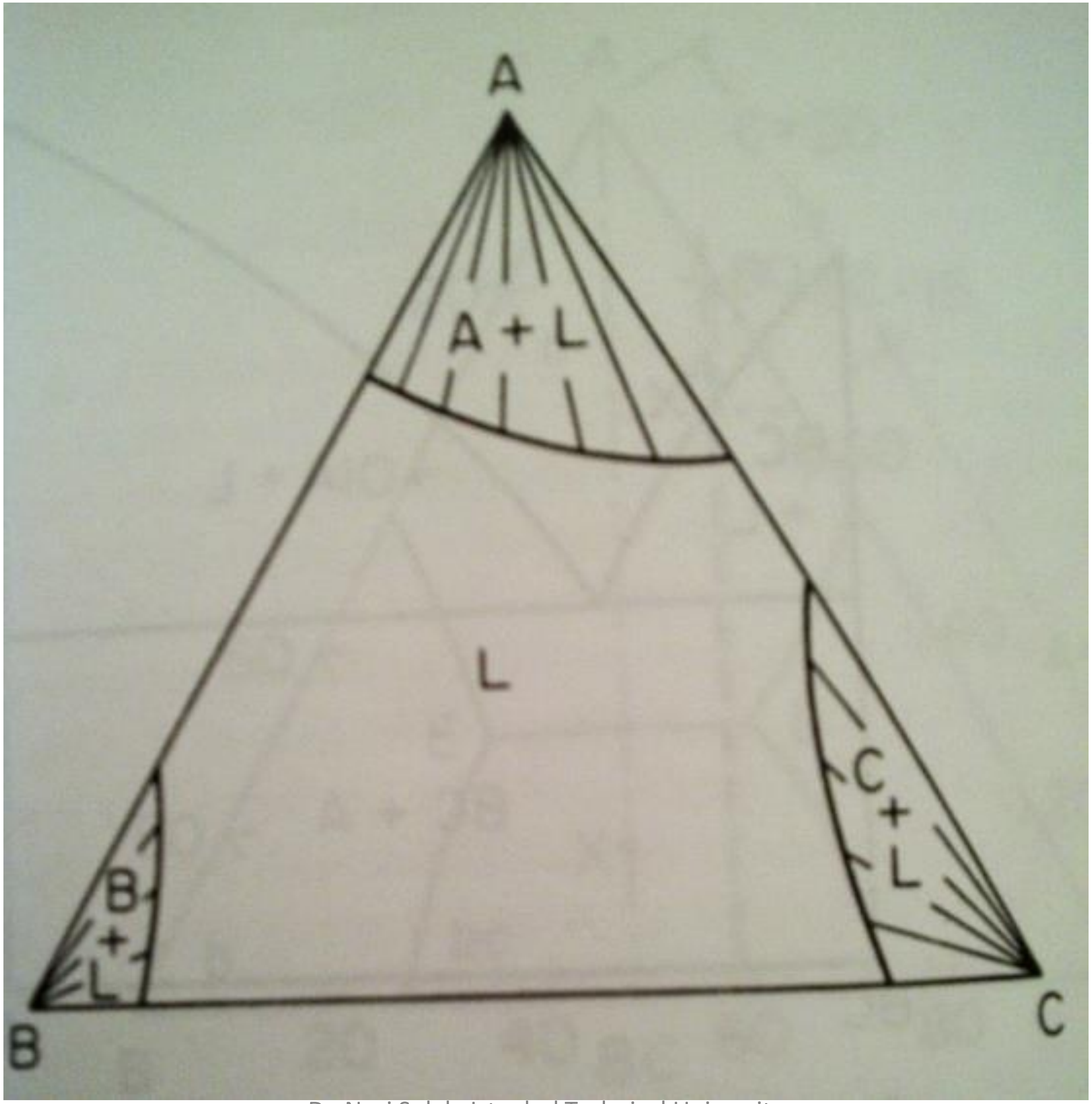


Liquid
liq
B + Liq.
6'
6
C + Liq
T6
B + C + Liq
A + B + Liq.
TE
A + B + C
B+C+liq
A+B+C
A+B
B+liq
TE
A
B
T

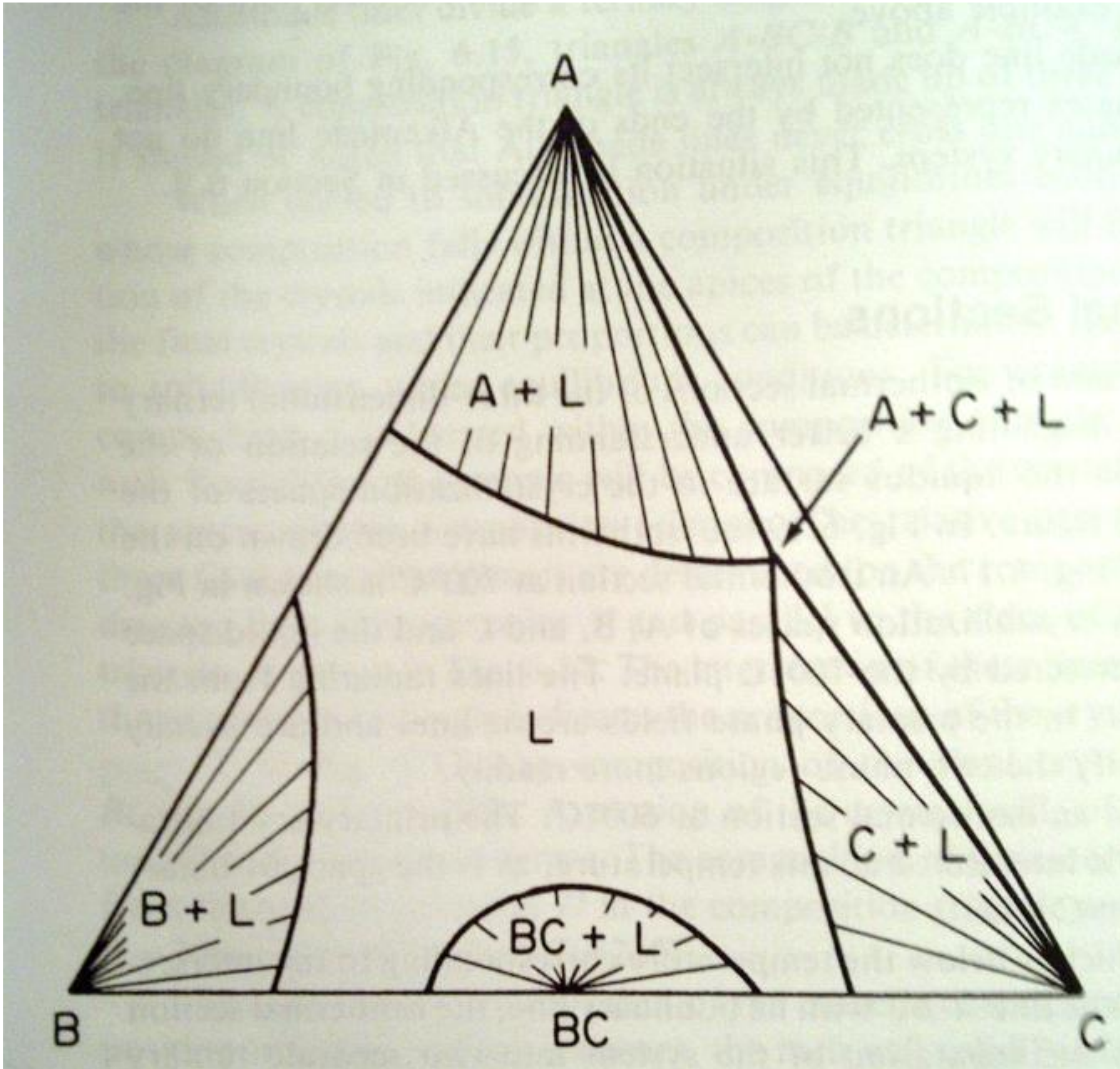


A
900
800
700
600
500
E
D
600
700
500
600
700
B
BC
C
A
B
BC
C

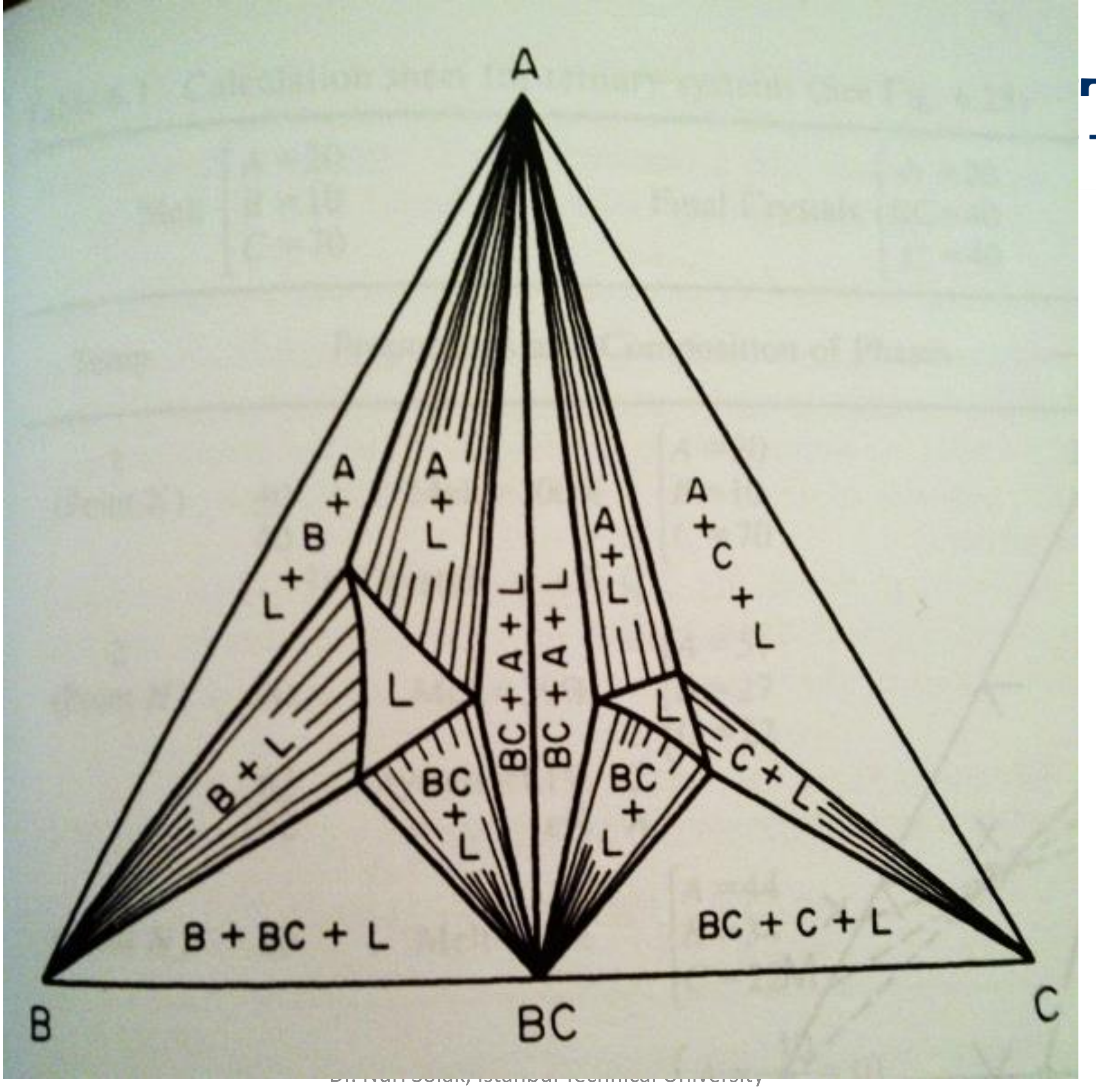
700 C

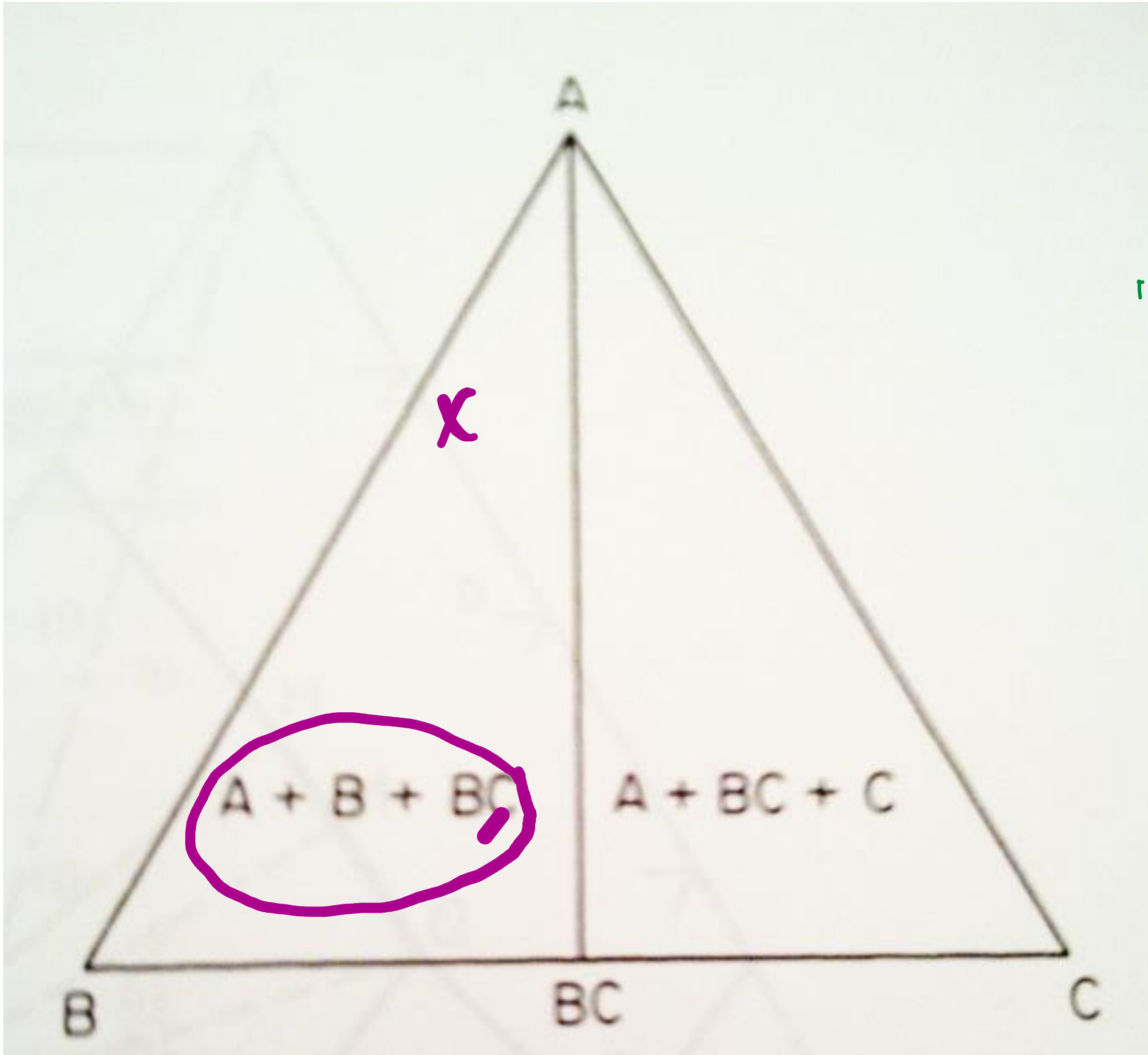


600 C



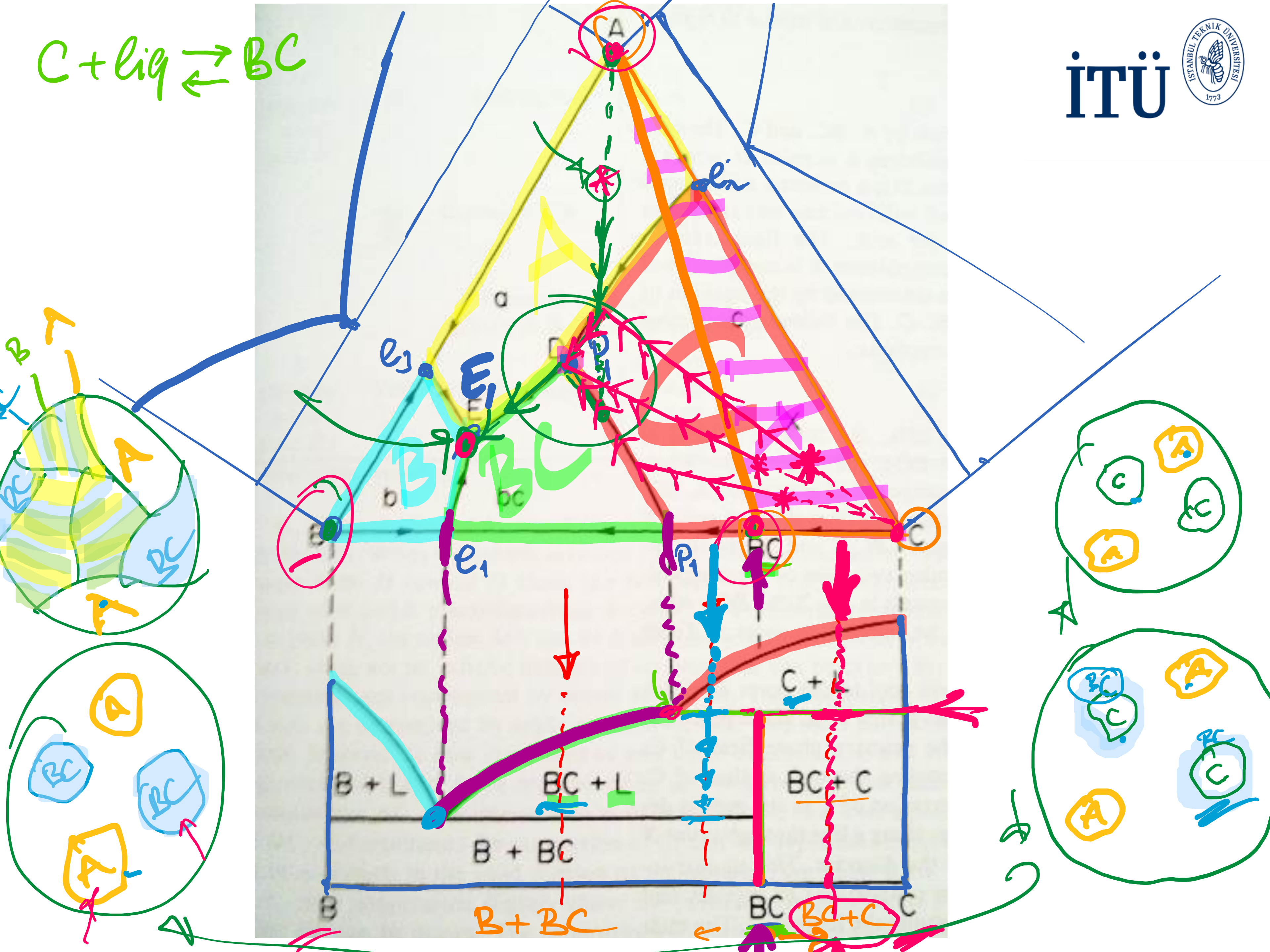
400 C

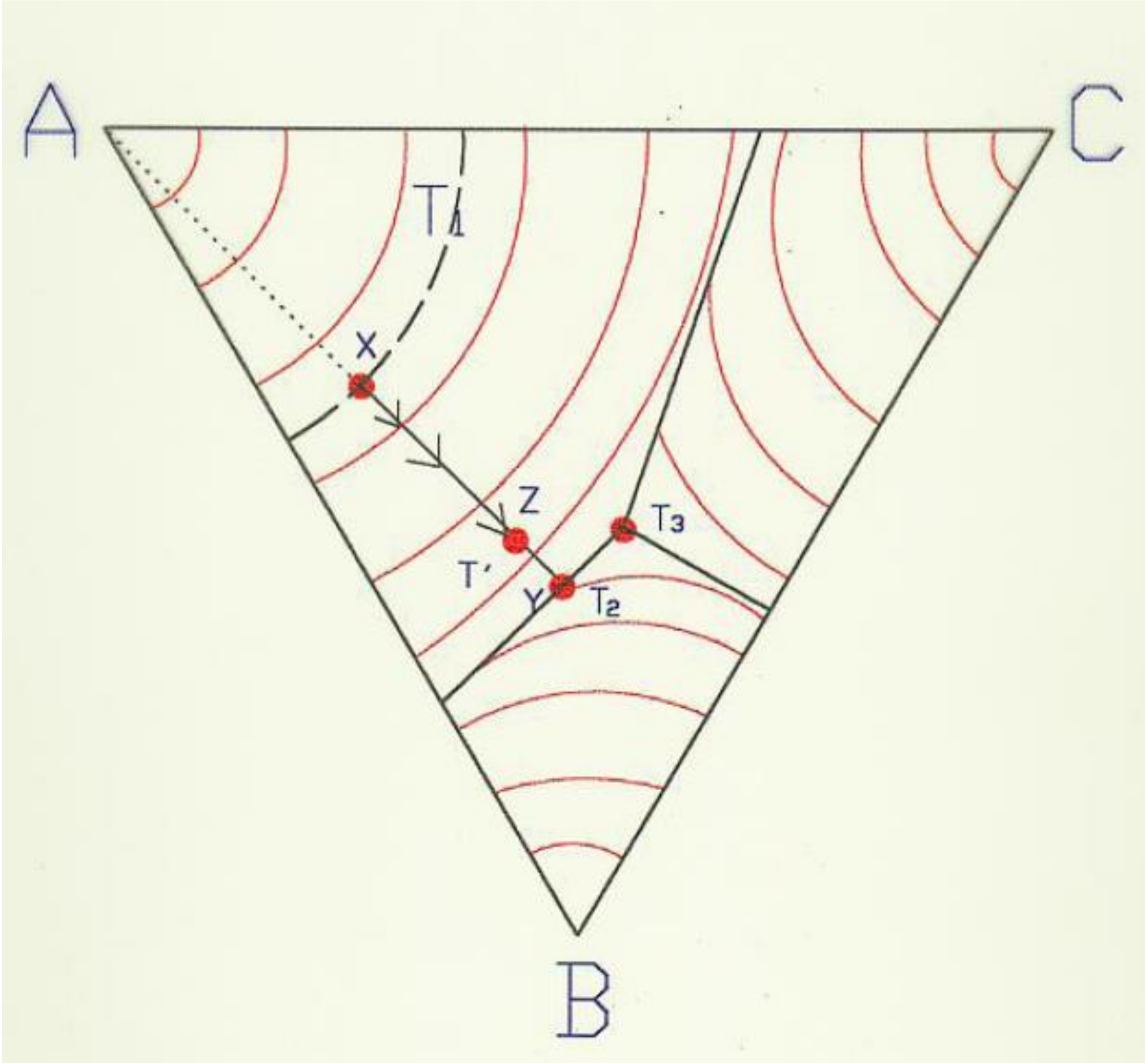


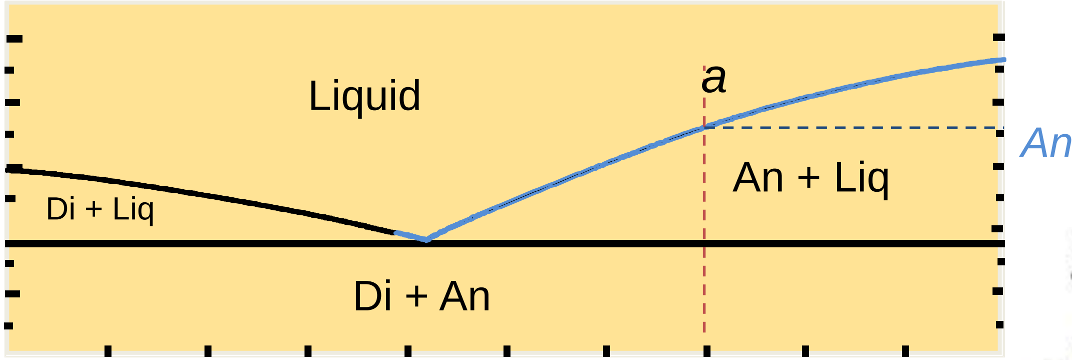


300 C

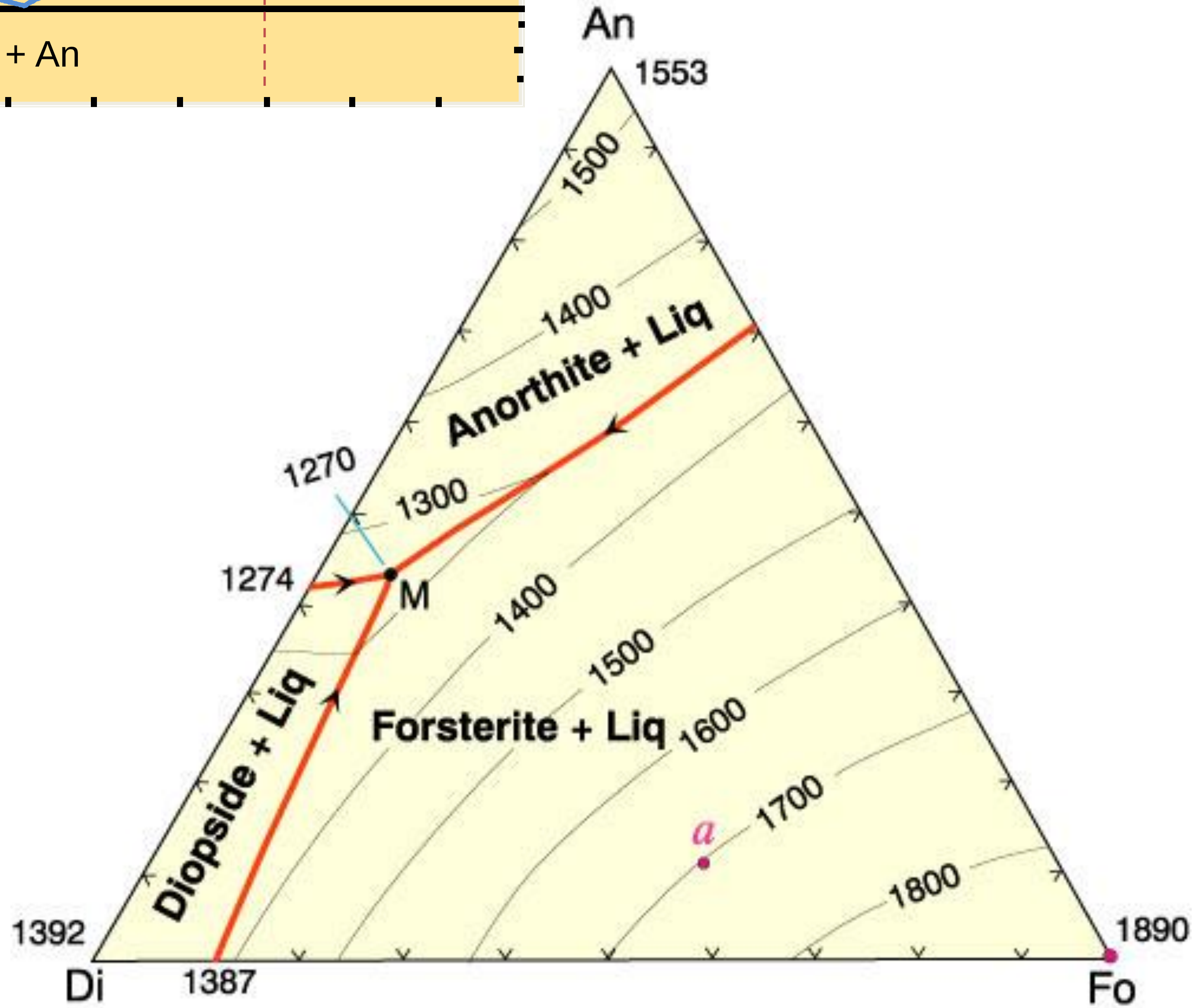
$C + liq \rightleftarrows BC$



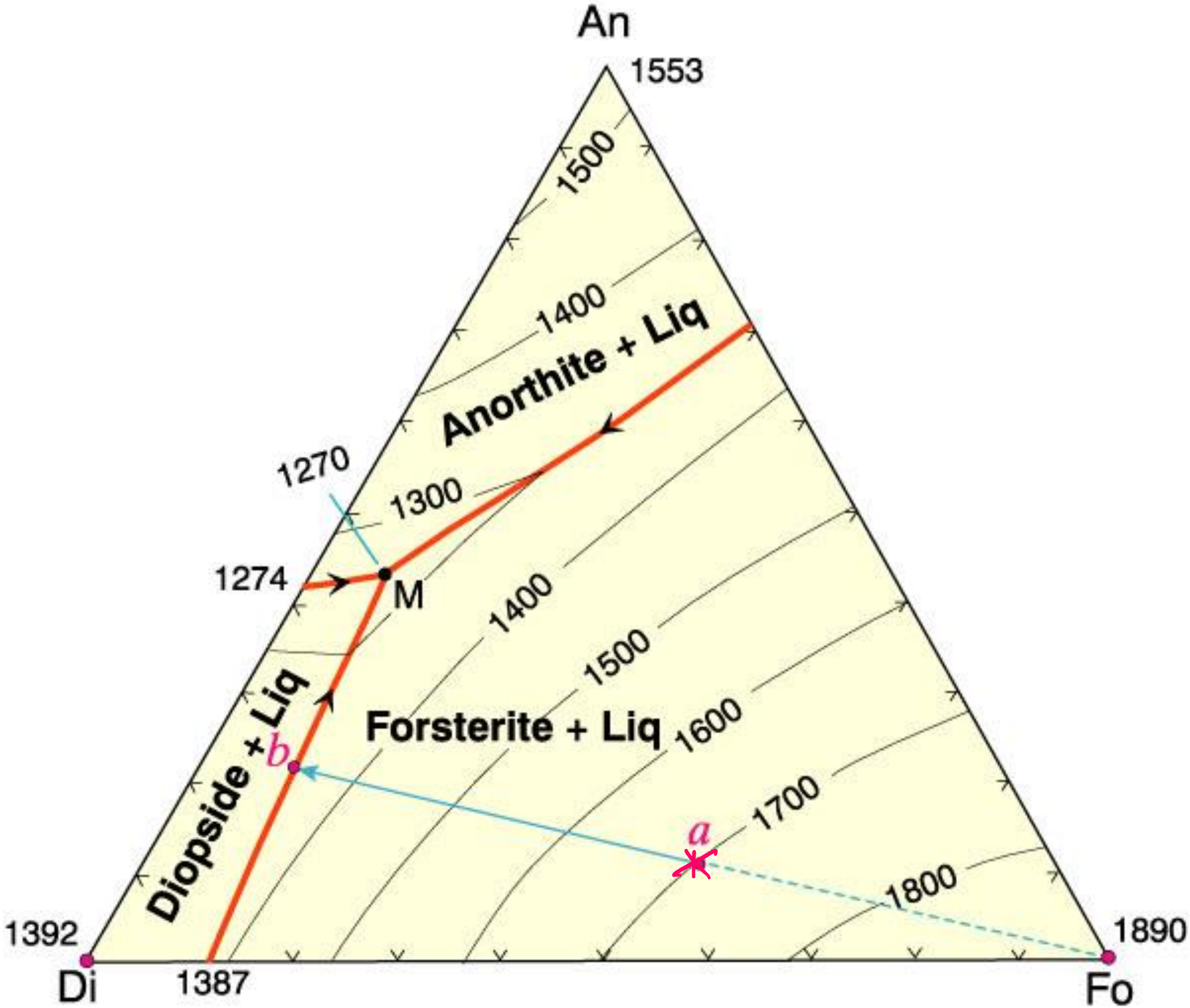

A
C
B
T1
X
Z
T3
T'
Y
T2



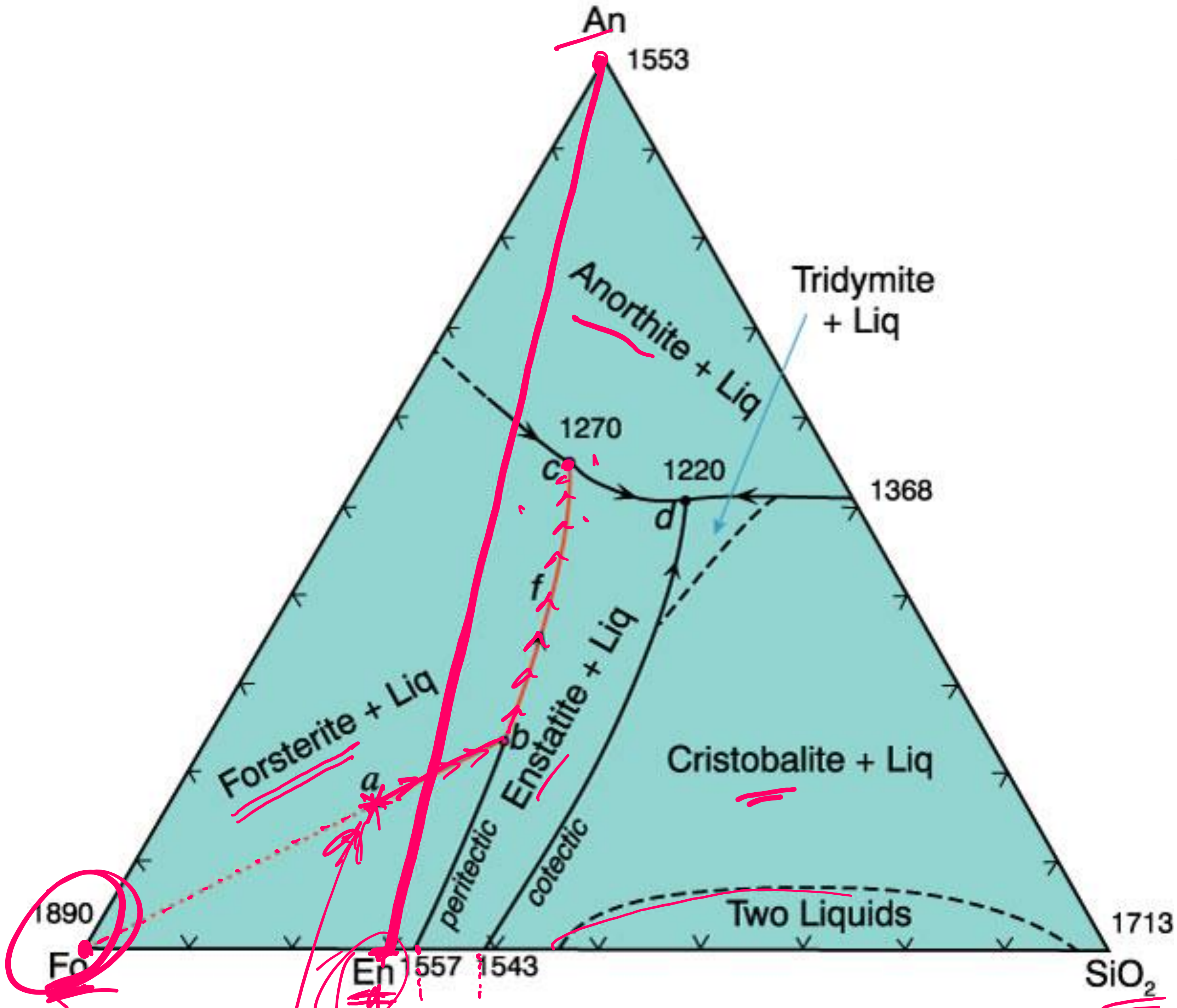
Liquid
a
An
An + Liq
Di + Liq
Di + An



An
1553
1500
1400
Anorthite + Liq
1270
1300
1274
M
1400
1500
Forsterite + Liq
1600
Diopside + Liq
1700
a
1800
1392
1890
Di
1387
Fo



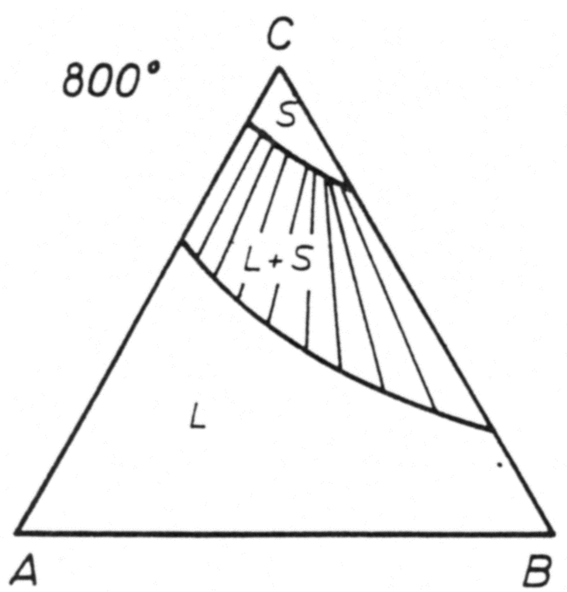
An
1553
1500
1400
Anorthite + Liq
1270
1300
1274
M
1400
1500
Diopside + Liq
Forsterite + Liq
1600
b
1700
a
1800
1392
1890
Di
1387
Fo


An
1553
Anorthite + Liq
Tridymite
+ Liq
1270
c
1220
d
1368
f
Forsterite + Liq
Enstatite + Liq
a
b
Cristobalite + Liq
peritectic
cotectic
Two Liquids
1890
Fo
En
1557
1543
1713
SiO2

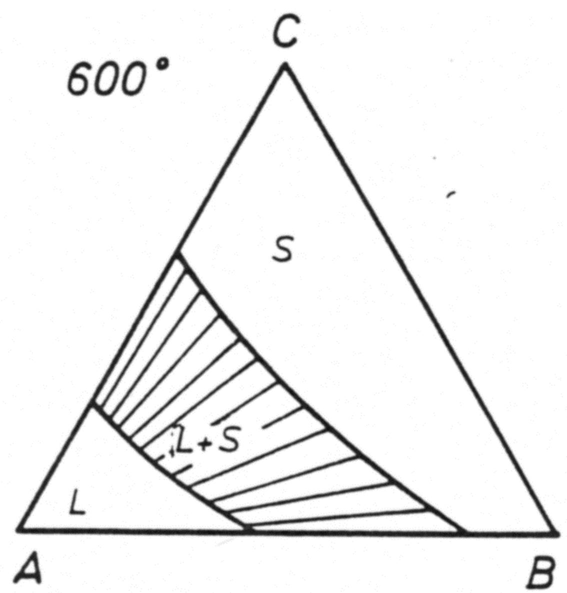
Solidification Profile

Isothermal Sections

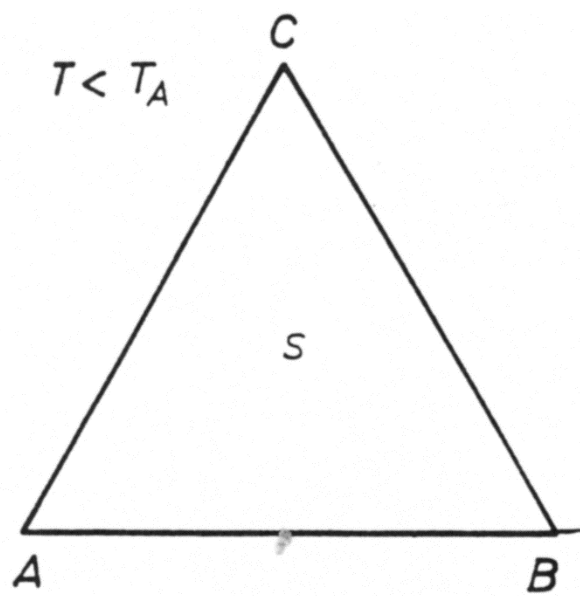
$T_A < T_B < T < T_C$



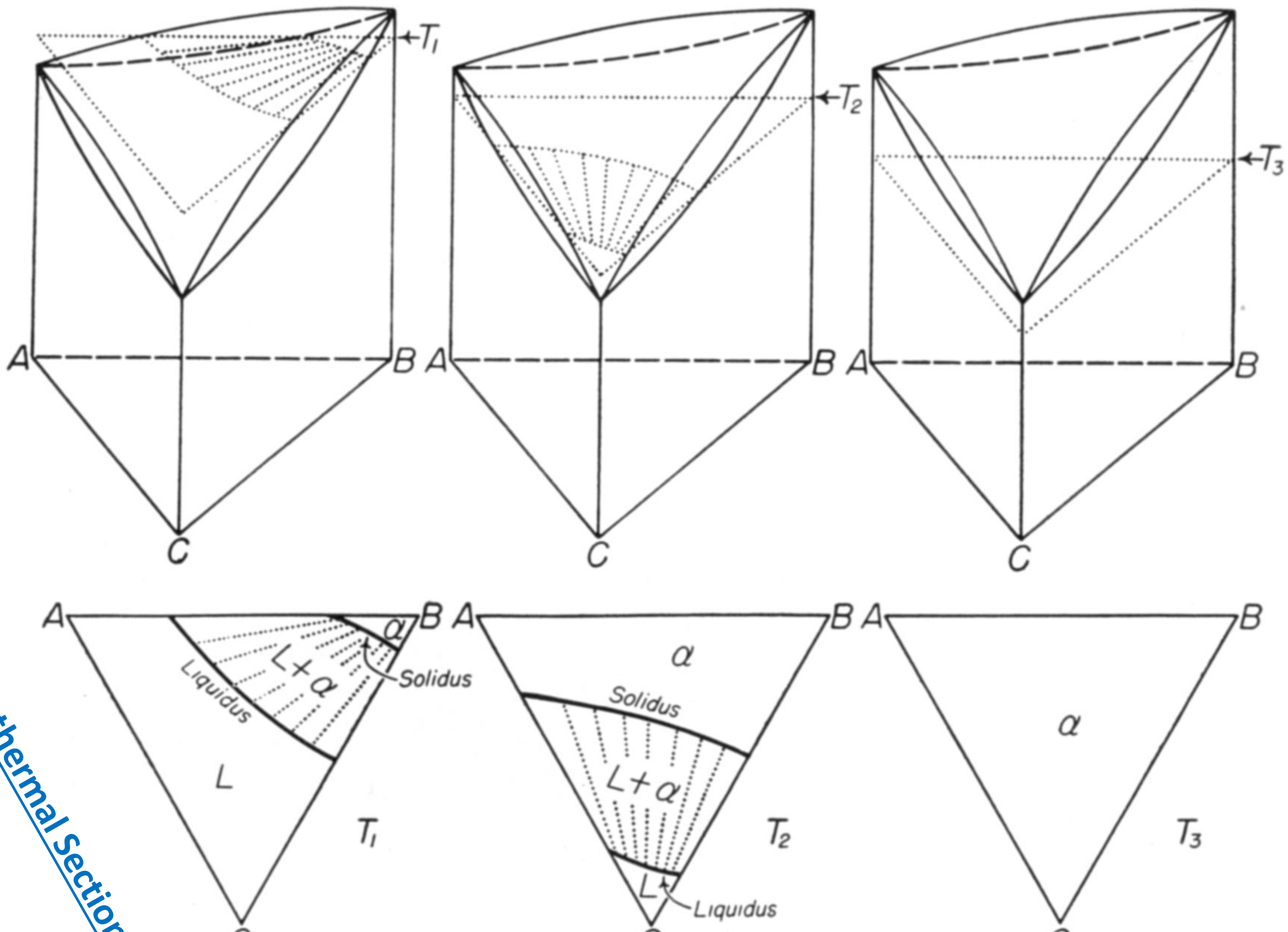
$T_A < T < T_B < T_C$



$T < T_A < T_B < T_C$

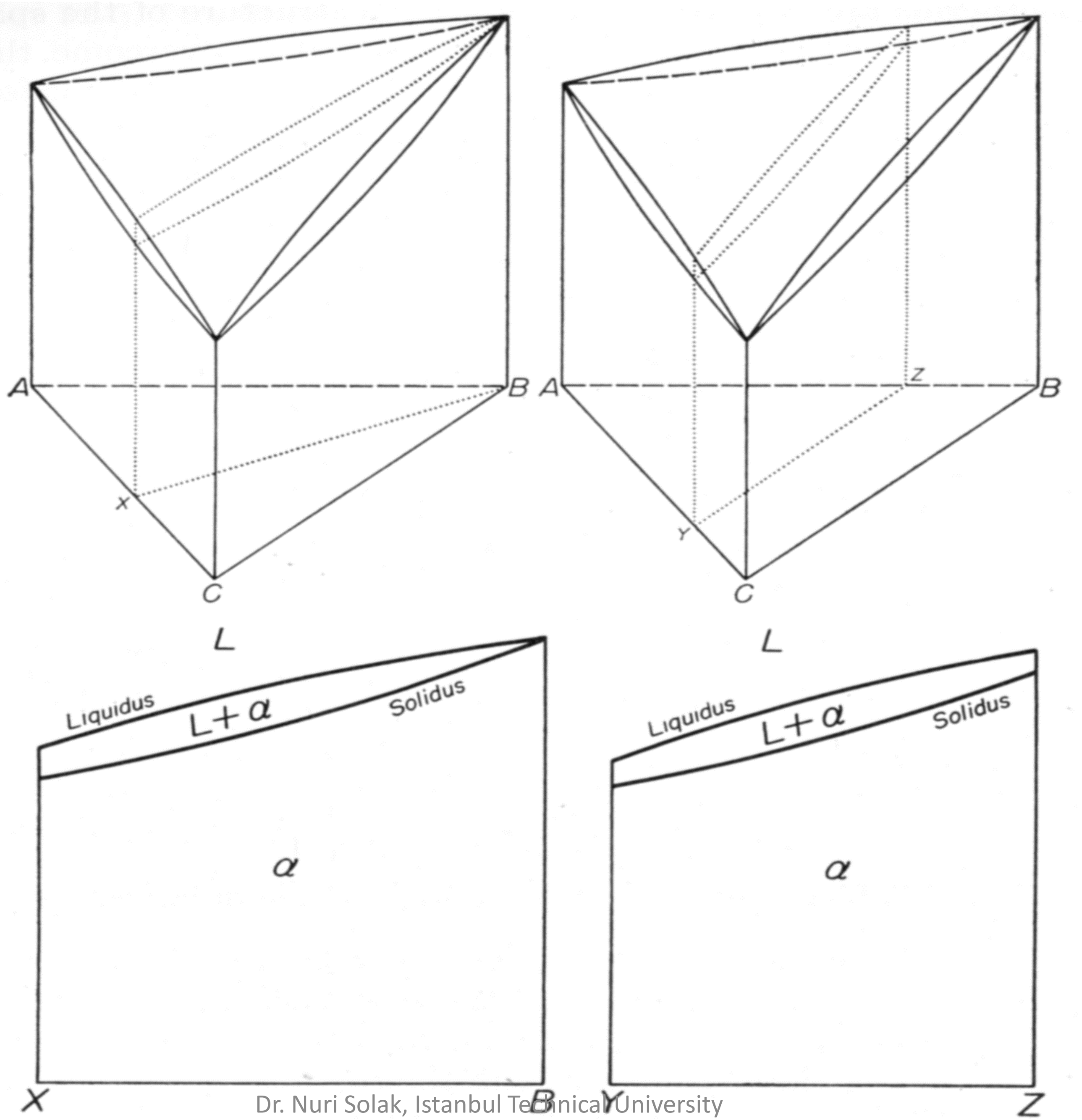


Isothermal Sections



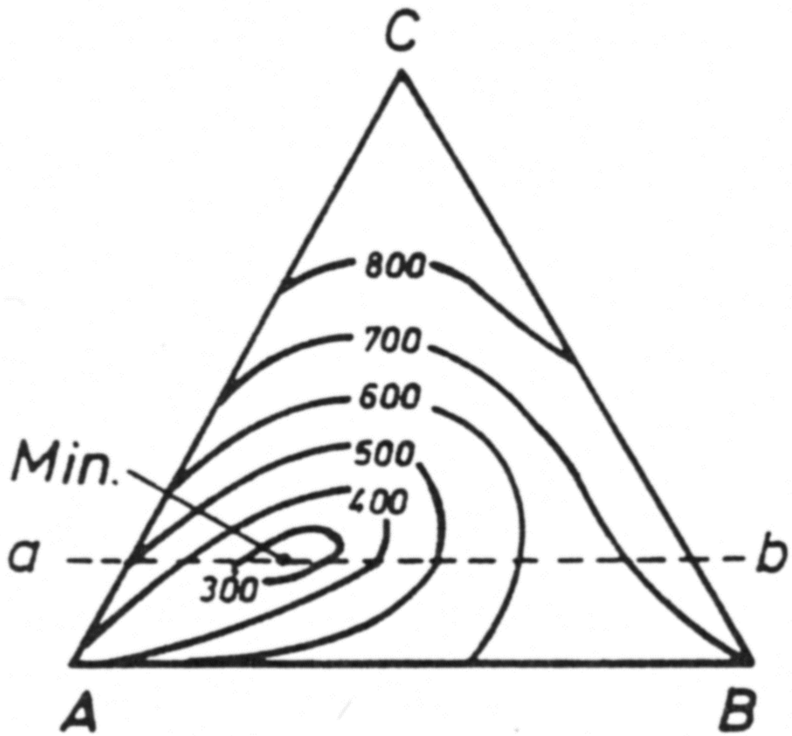
Isopleth

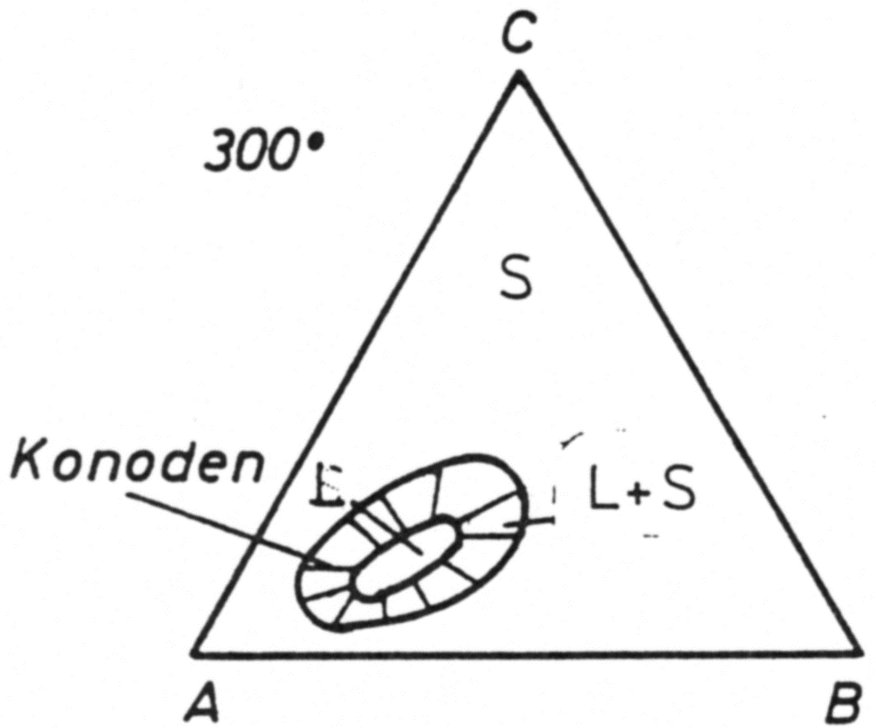
Isopleths



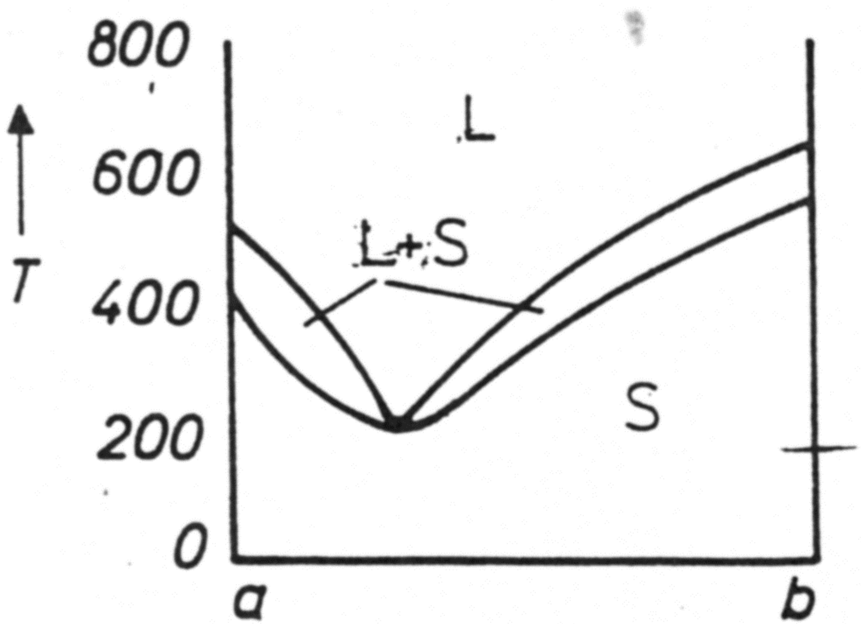
Isothermal Section-with minima

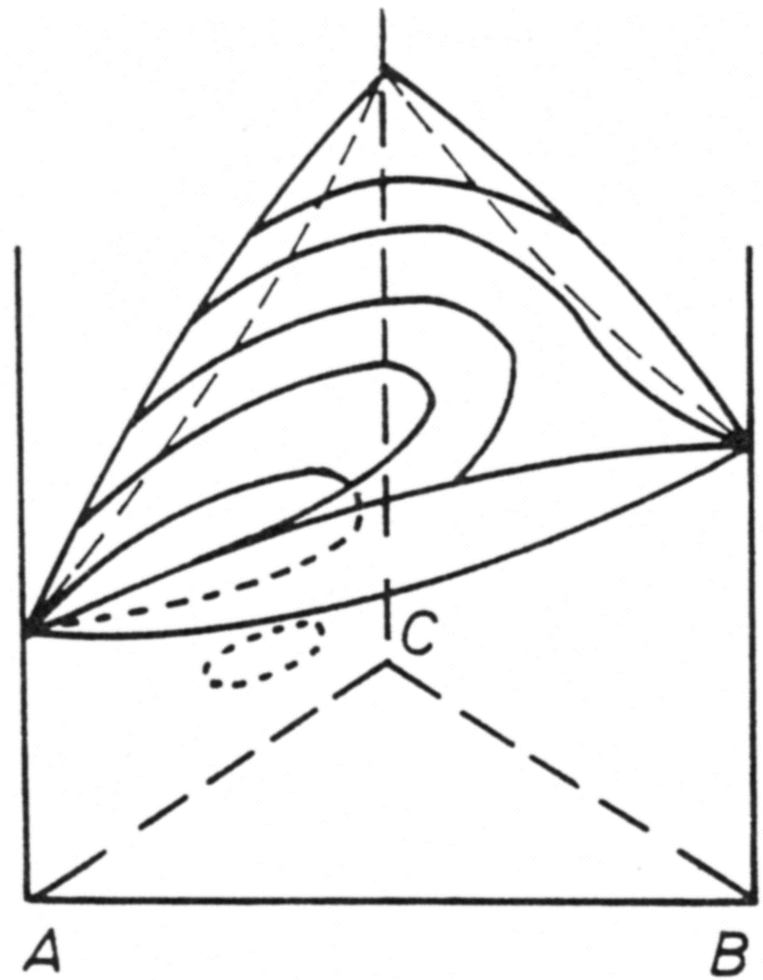
$T_{min} < \color{blue}{T} < T_A < T_B < T_C$



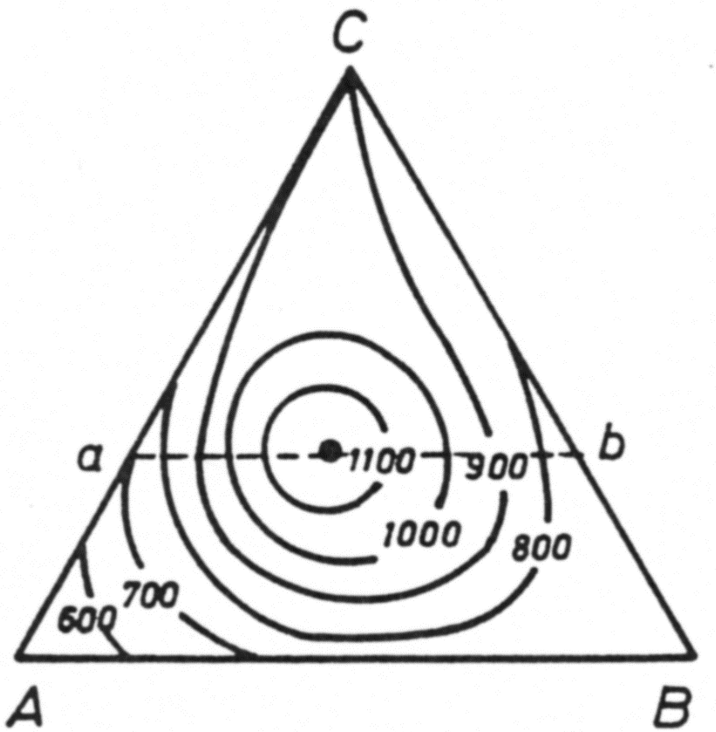


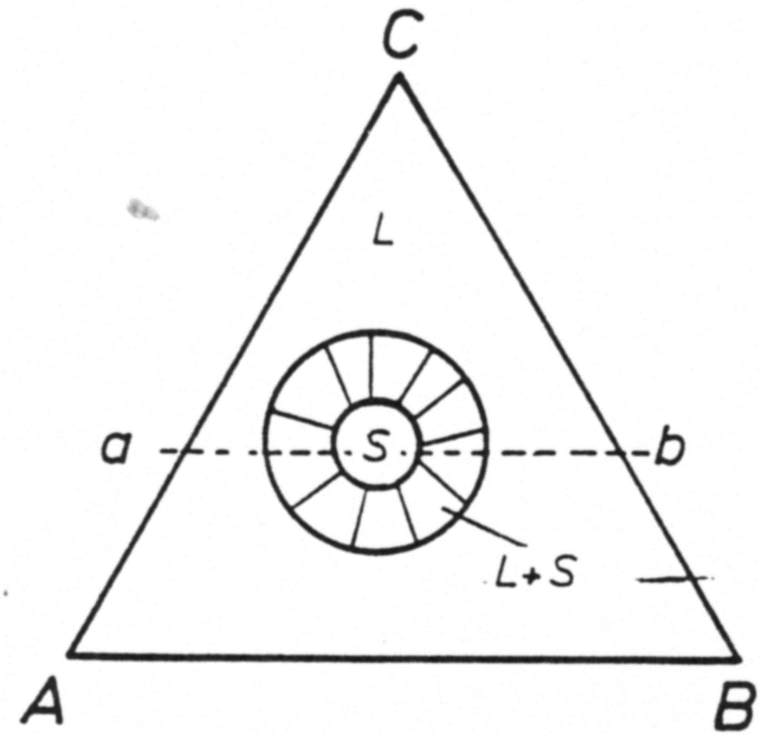
Isothermal Section-with minima



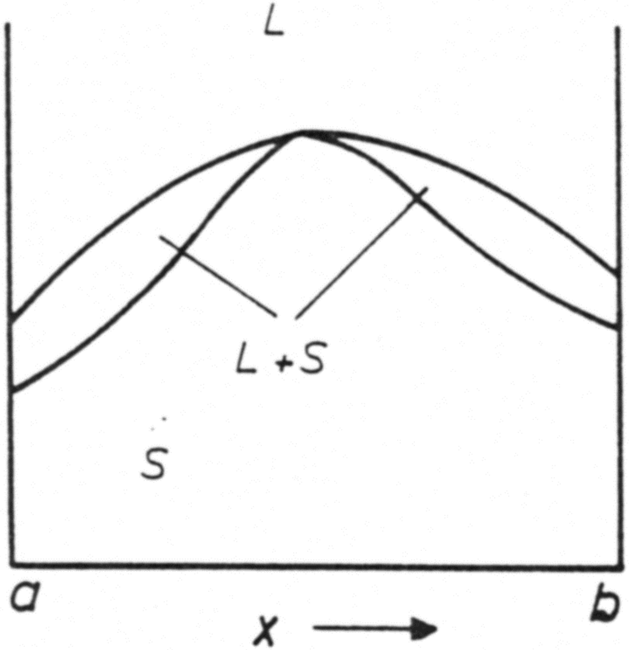


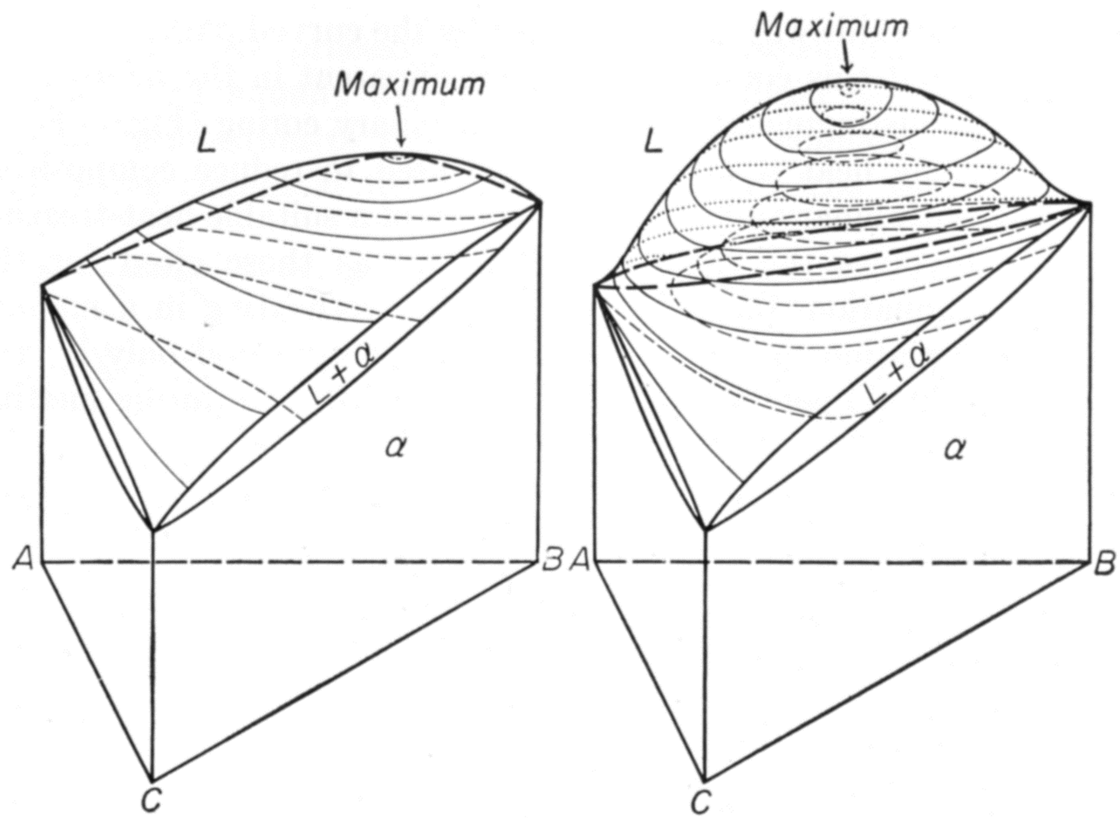
Isothermal Section-with maxima



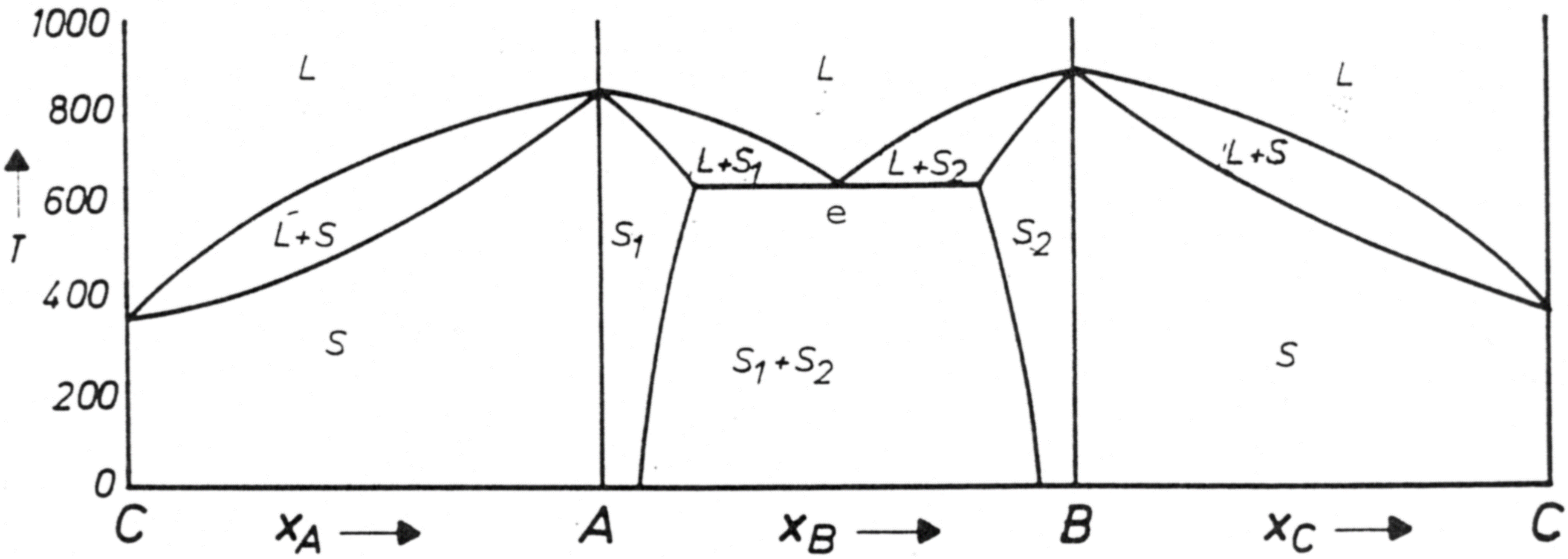


Isothermal Section-with maxima

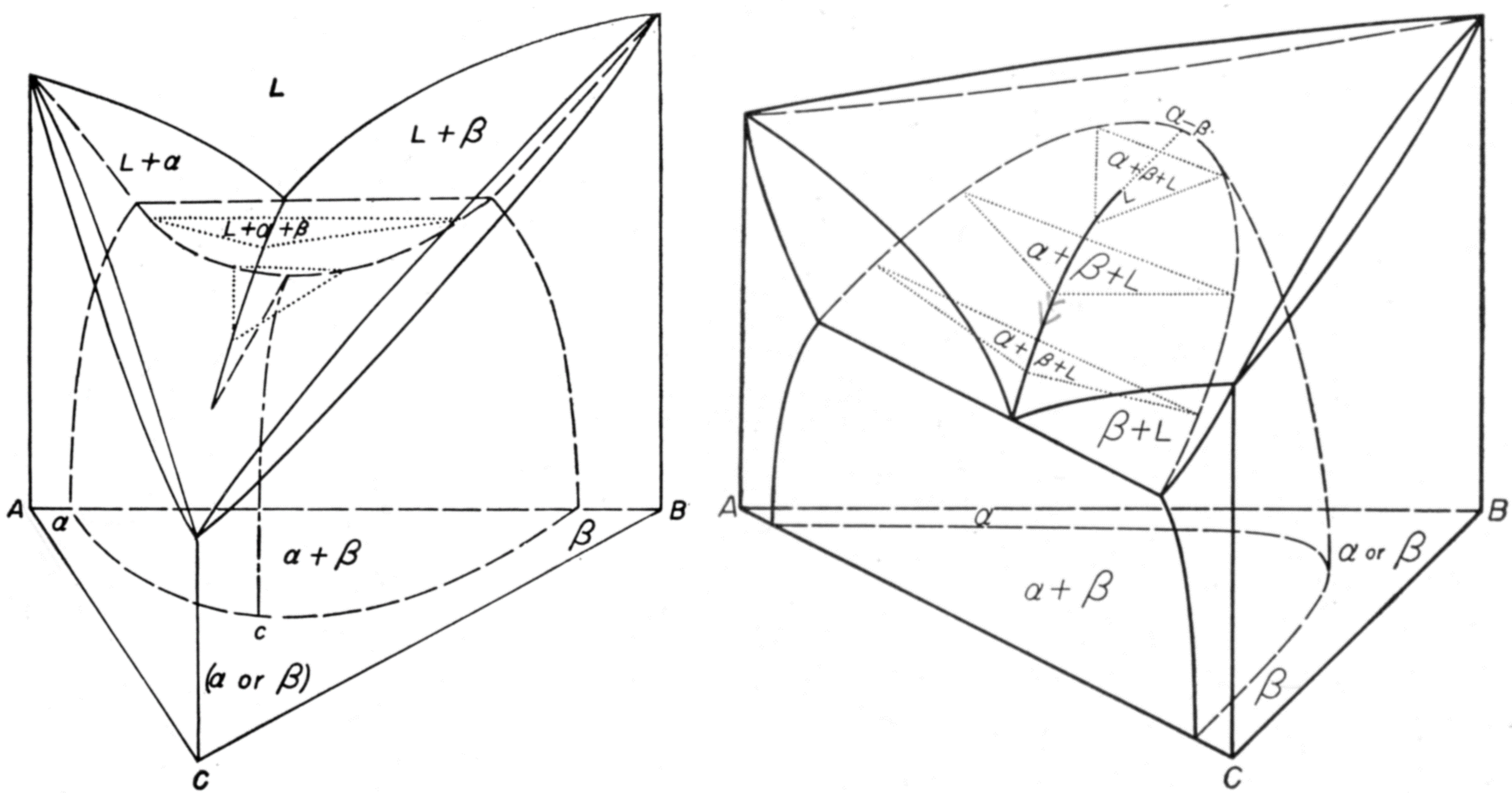


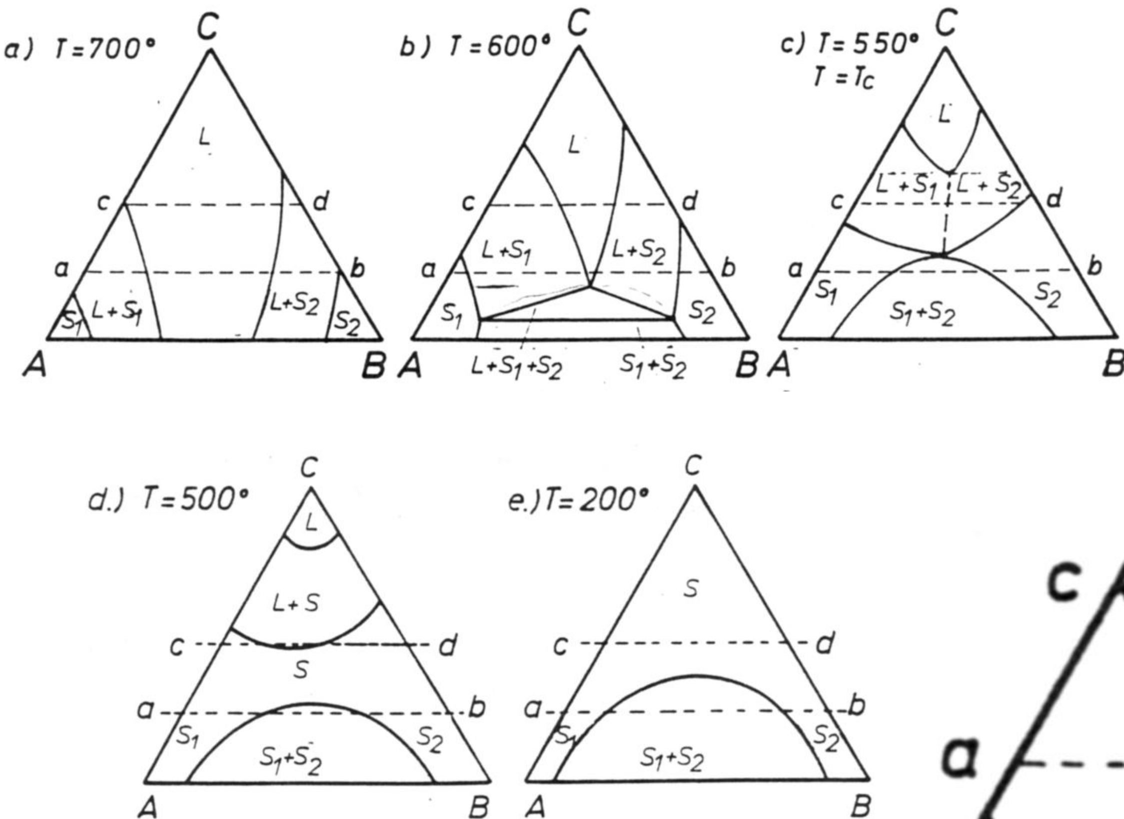


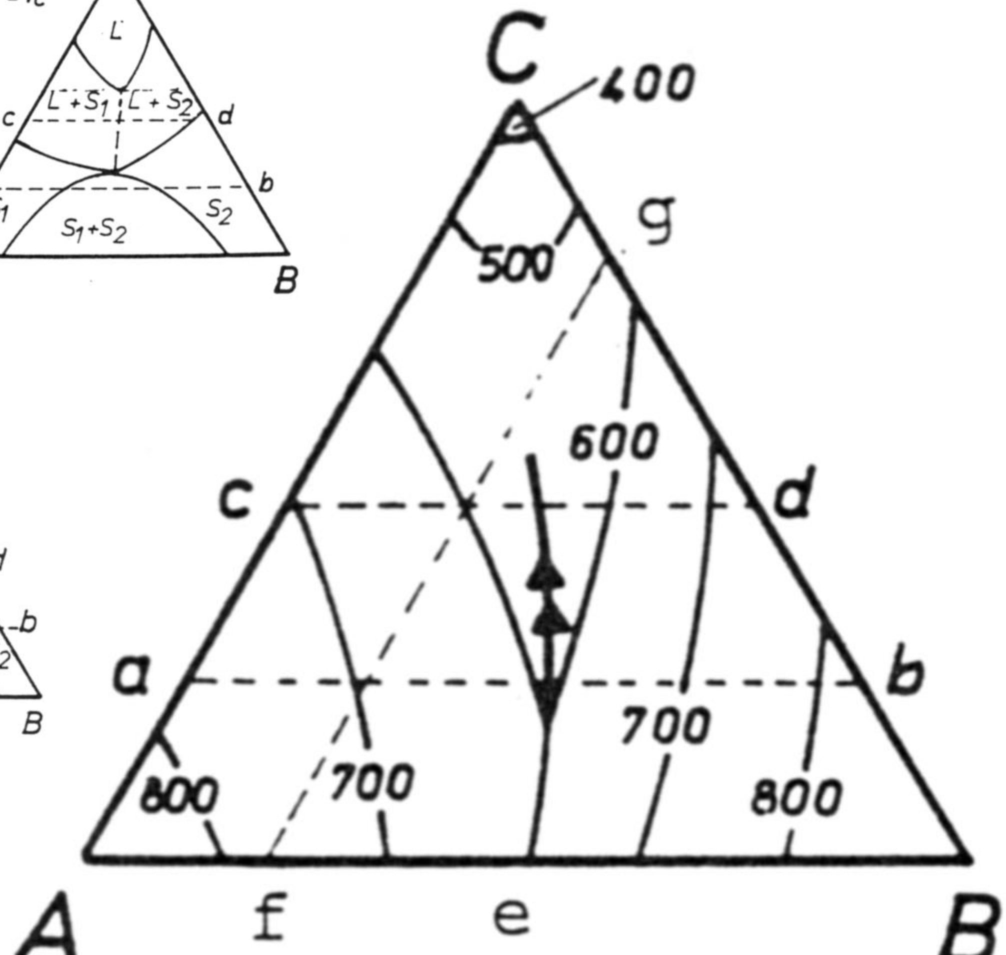
Ternary with a partial solubility



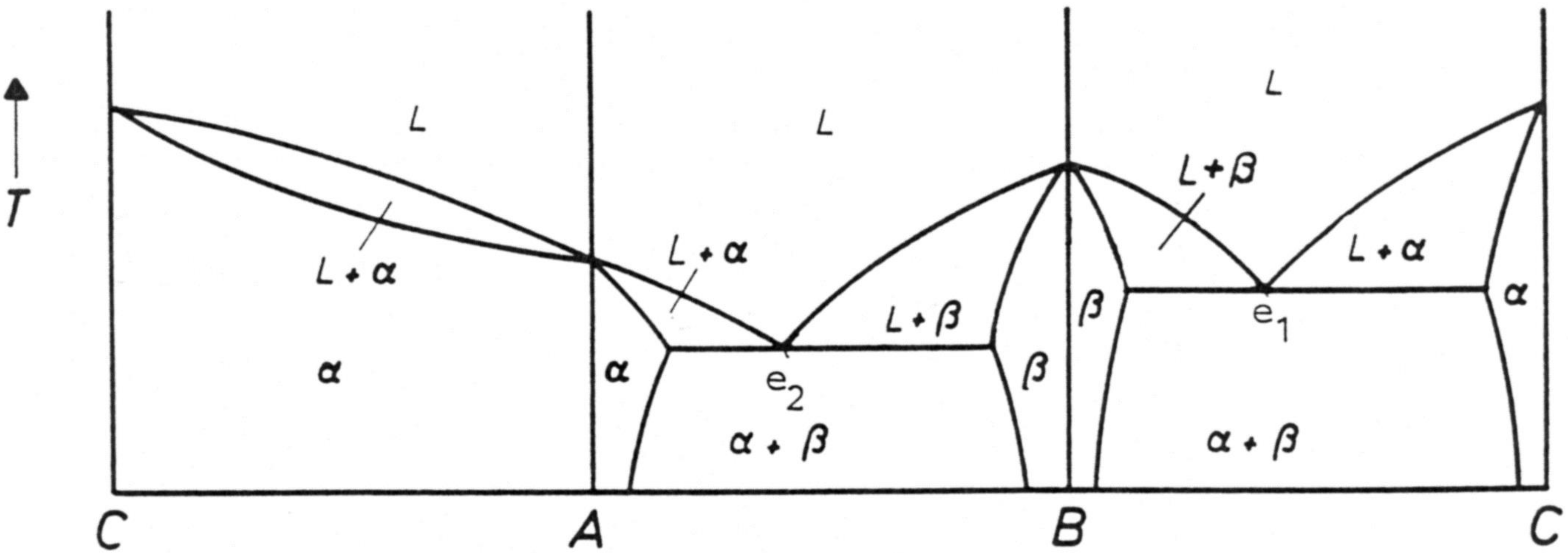
Ternary with partial solubility

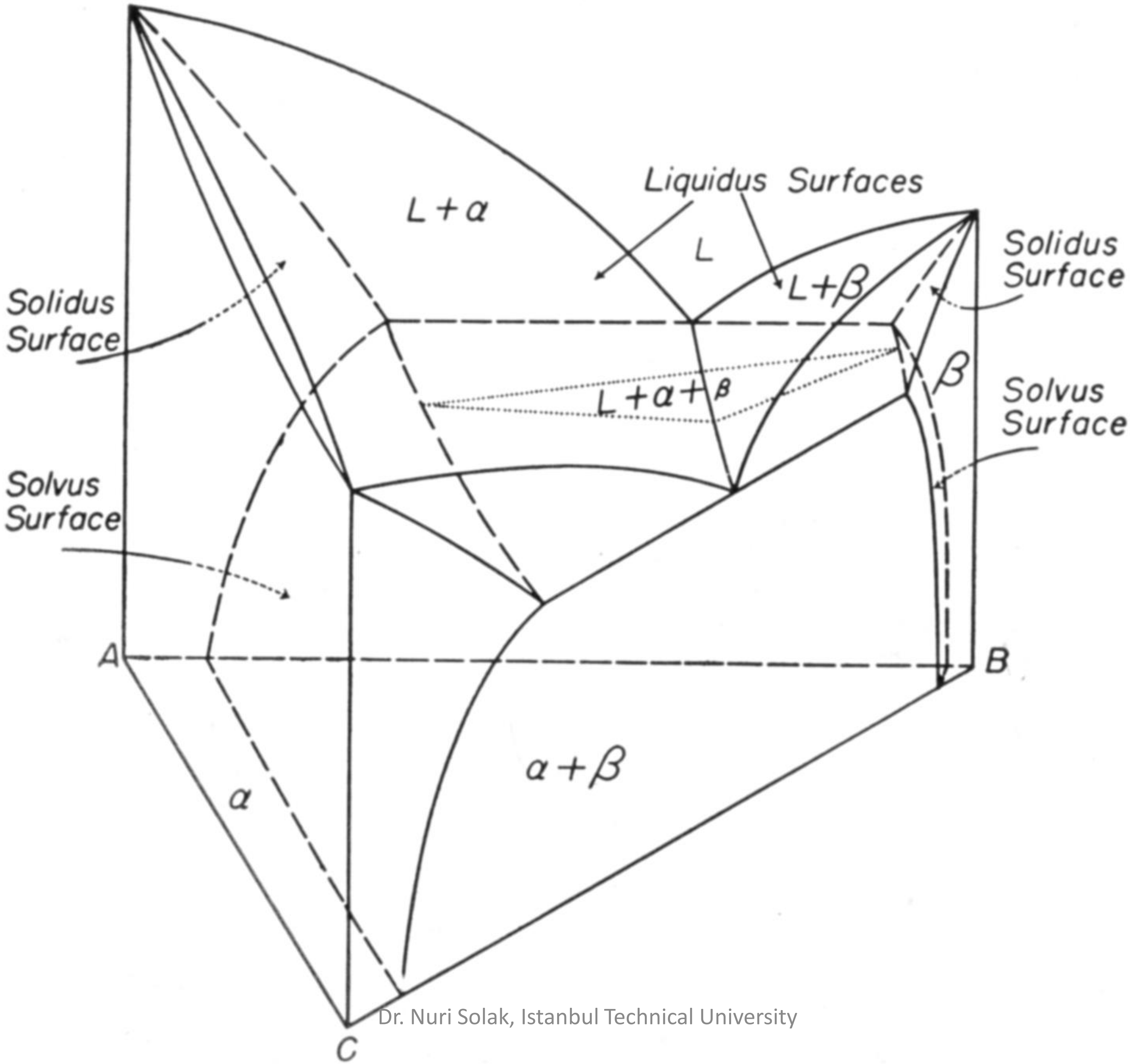



a) T=700°
b) T=600°
c) T=550°
T=Tc
d.) T=500°
e.) T=200°
C
A
B
a
b
c
d
L
L+S1
L+S2
S1
S2
L+S1+S2
S1+S2
L+S
S

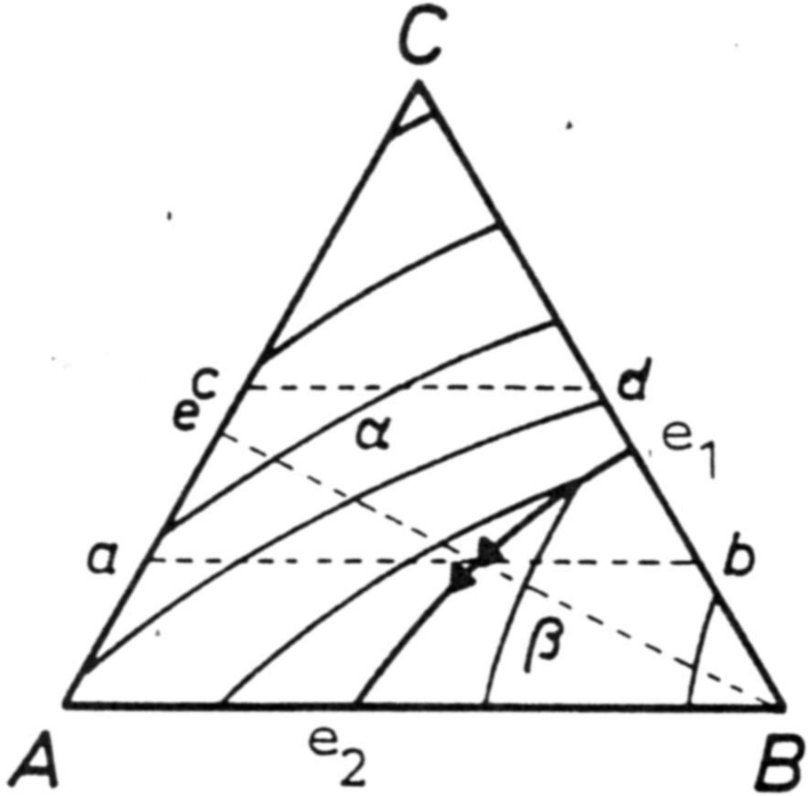

C
400
500
600
700
800
g
c
d
a
b
A
f
e
B

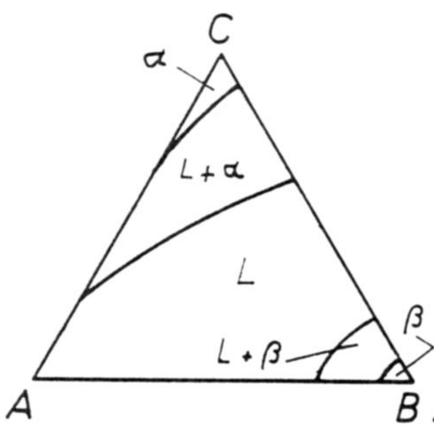
Ternary with partial solubilities



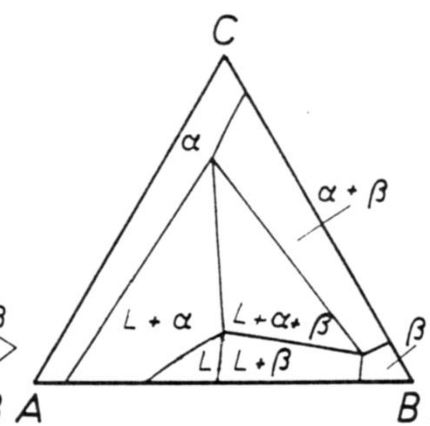


L + α
Liquidus Surfaces
L
L+β
Solidus Surface
Solidus Surface
L+α+β
β
Solvus Surface
Solvus Surface
A
B
α
α+β
C

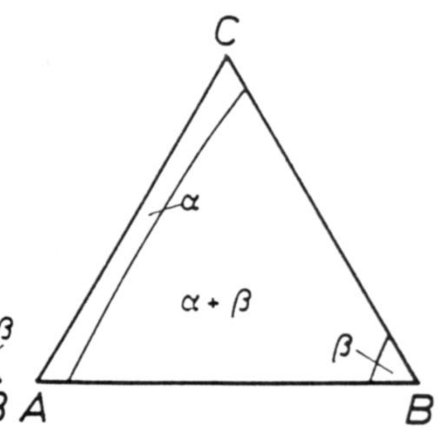




$T > Te_1$

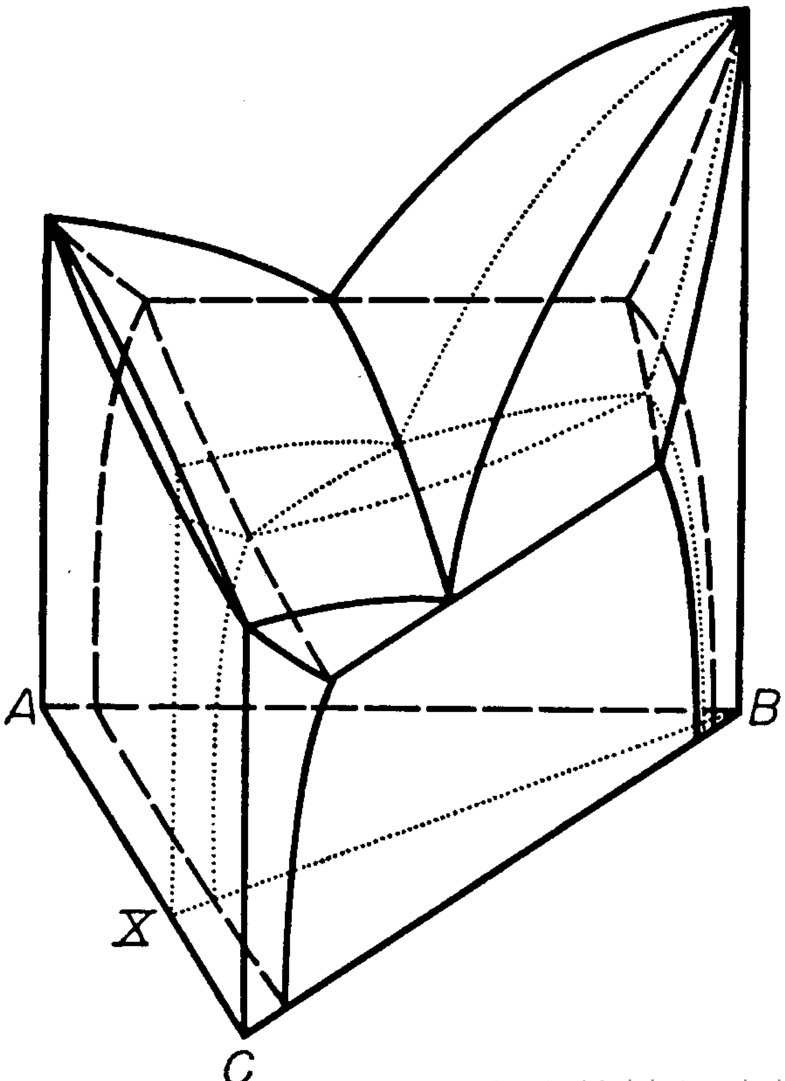


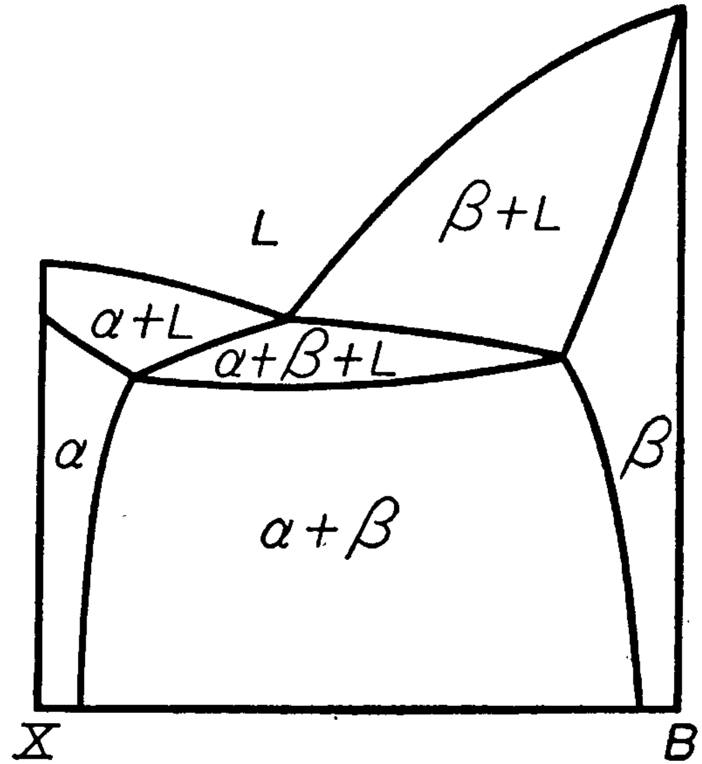
$Te_1 > T > Te_2$



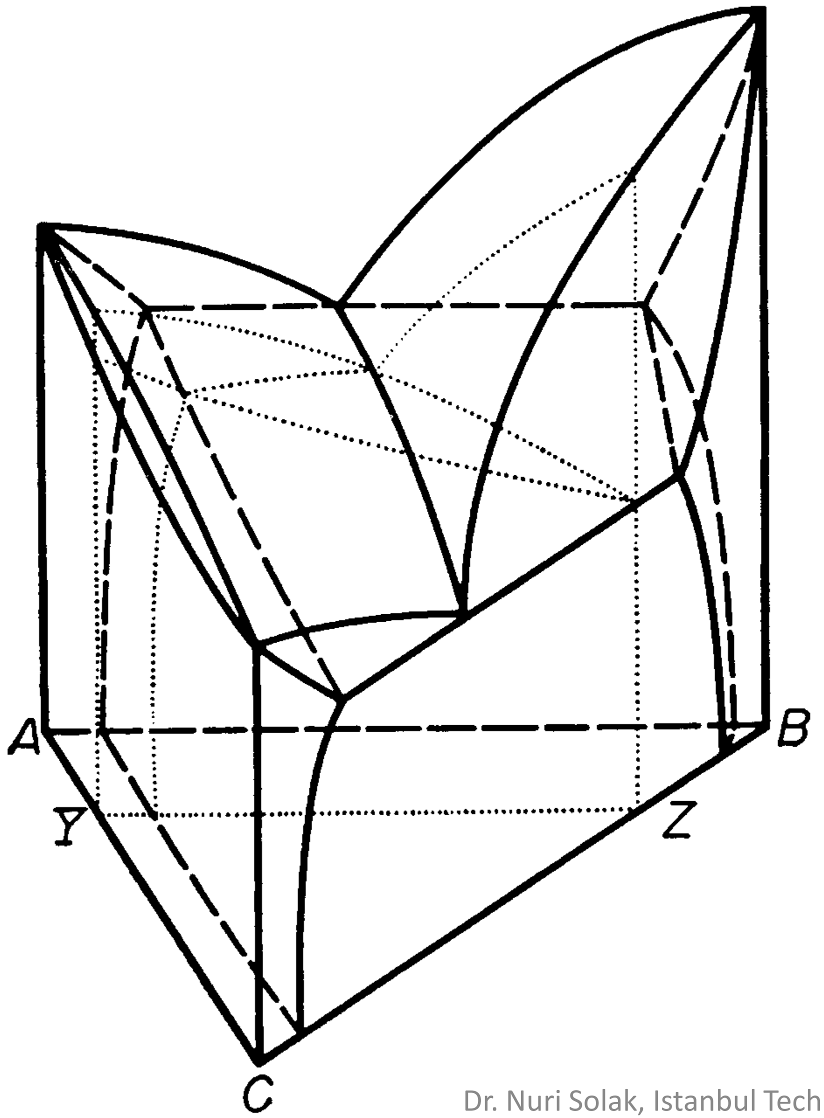
$T < Te_2$

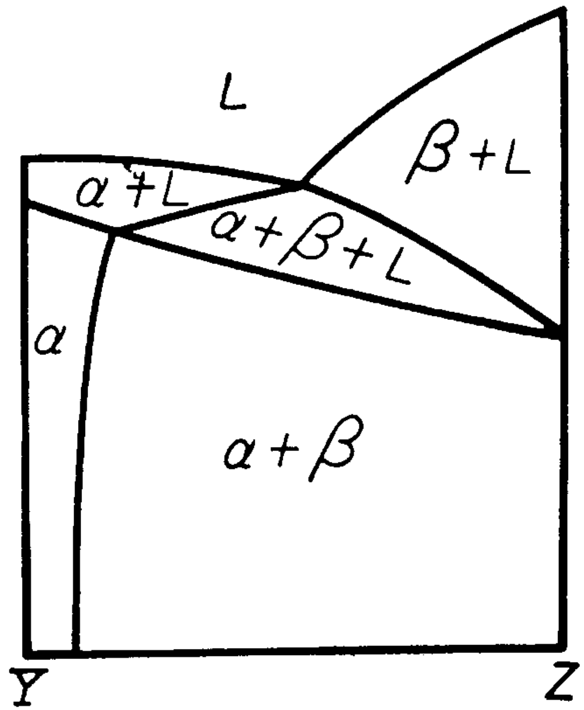
An Isopleth



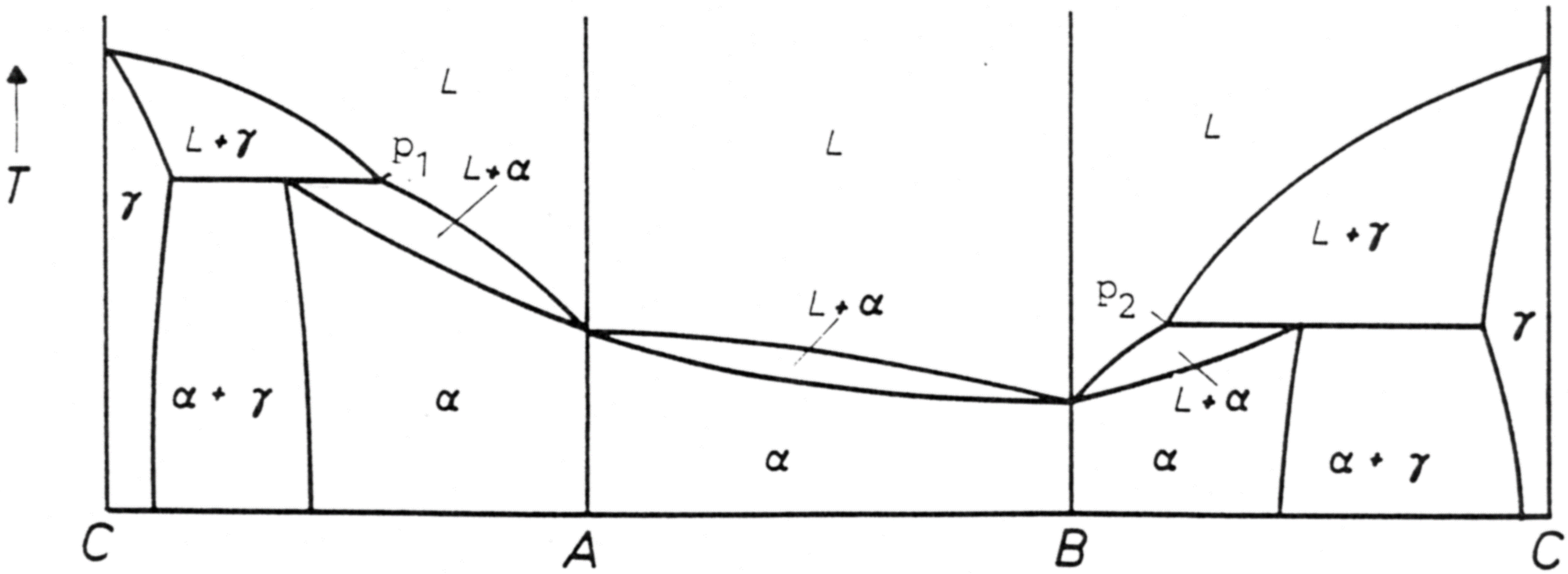


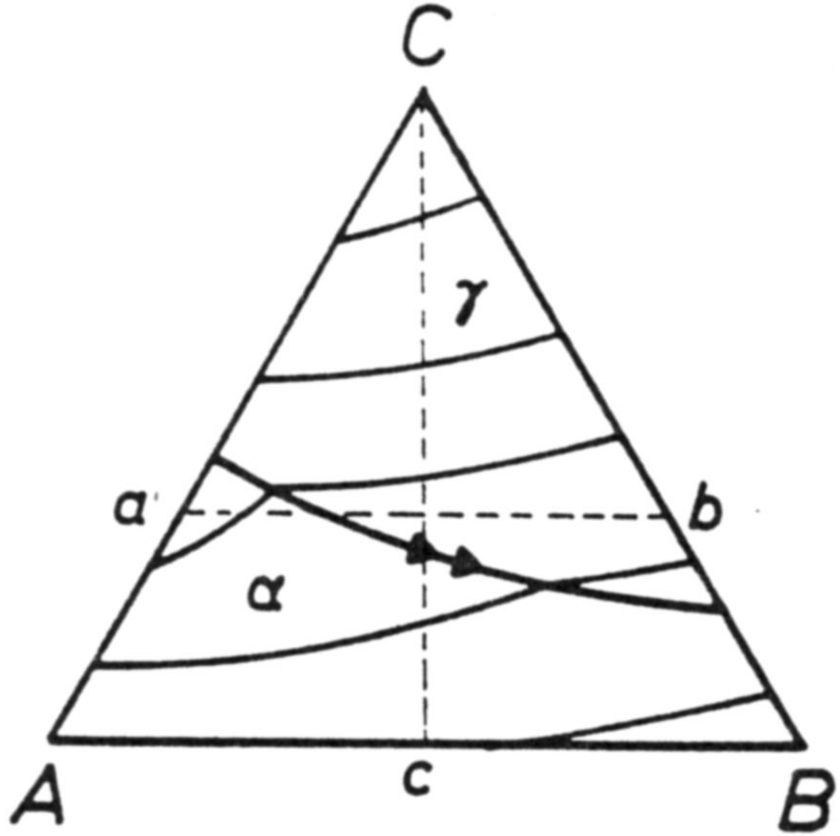
Another Isopleth

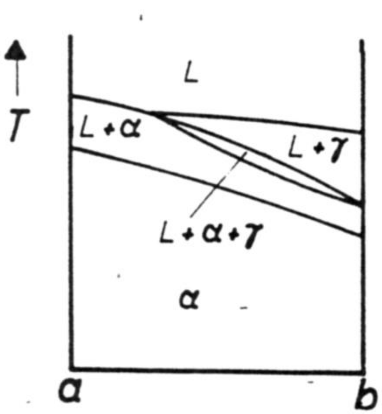


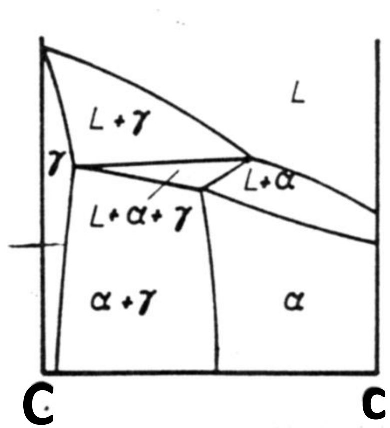


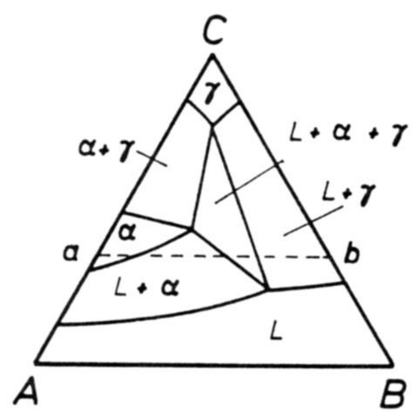
Ternary with Peritectic Reactions

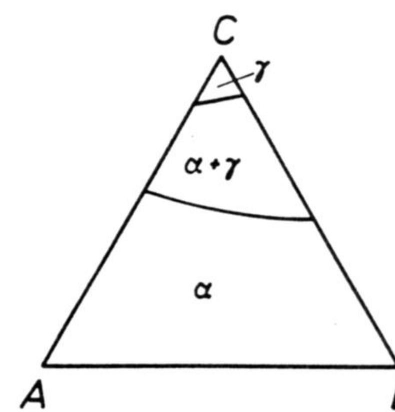








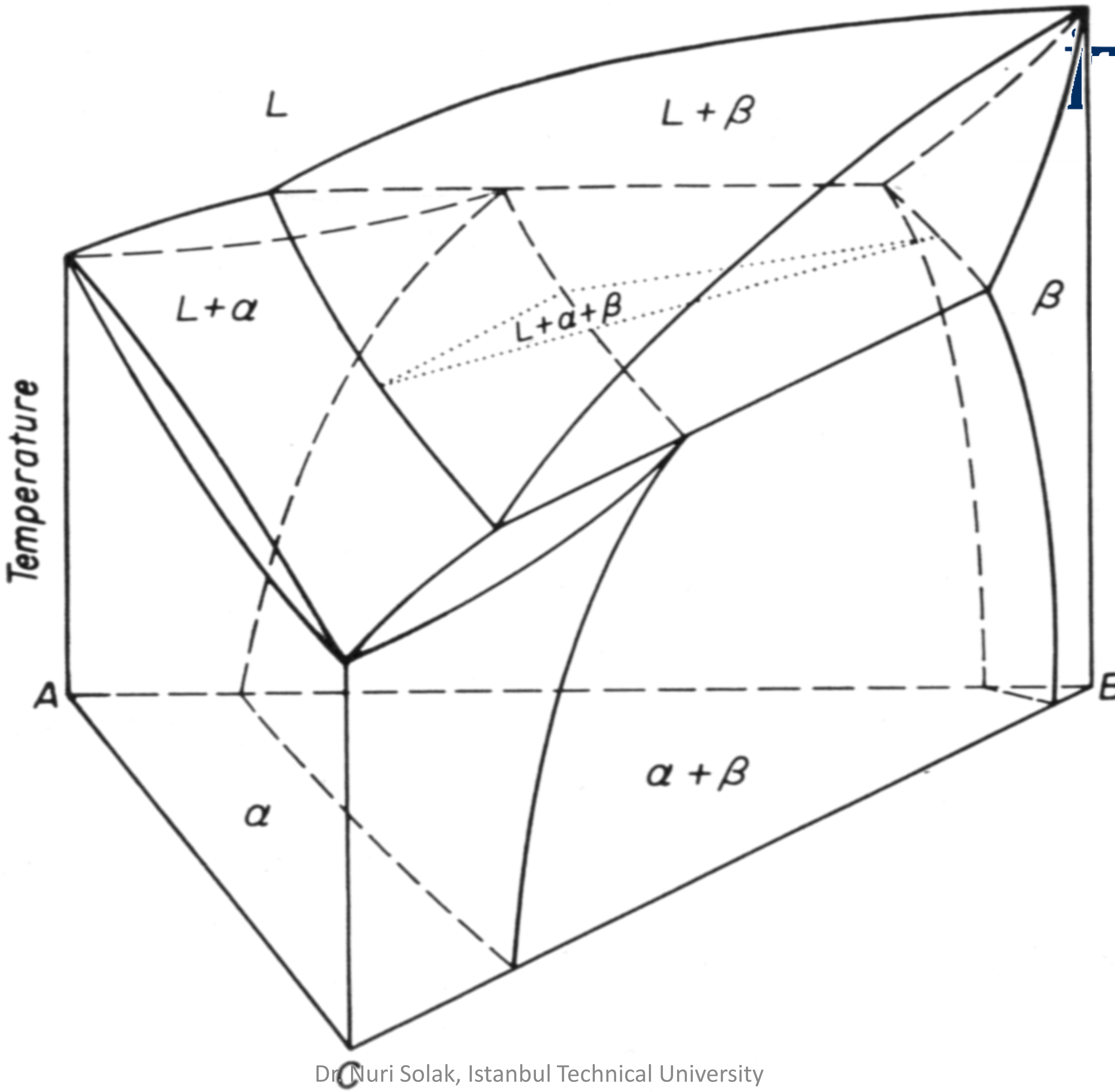




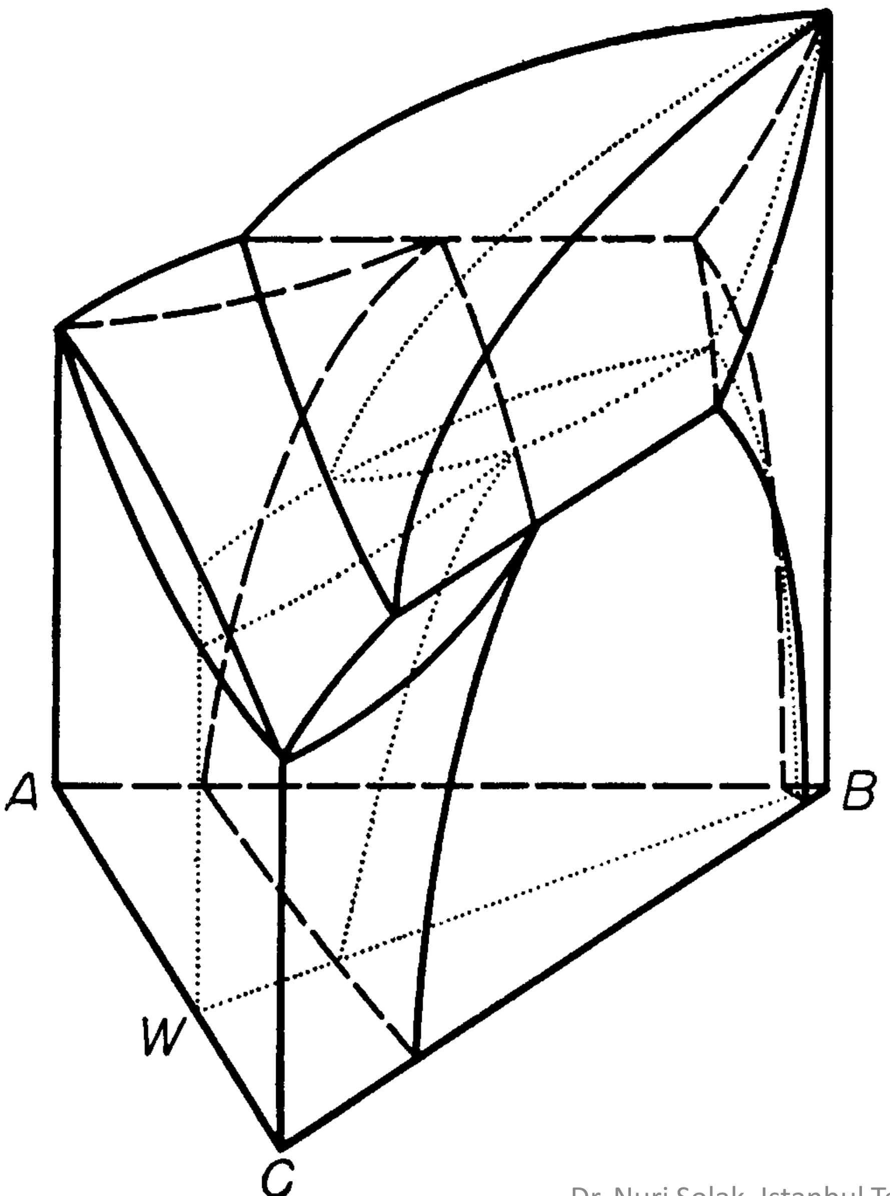
Isopleths

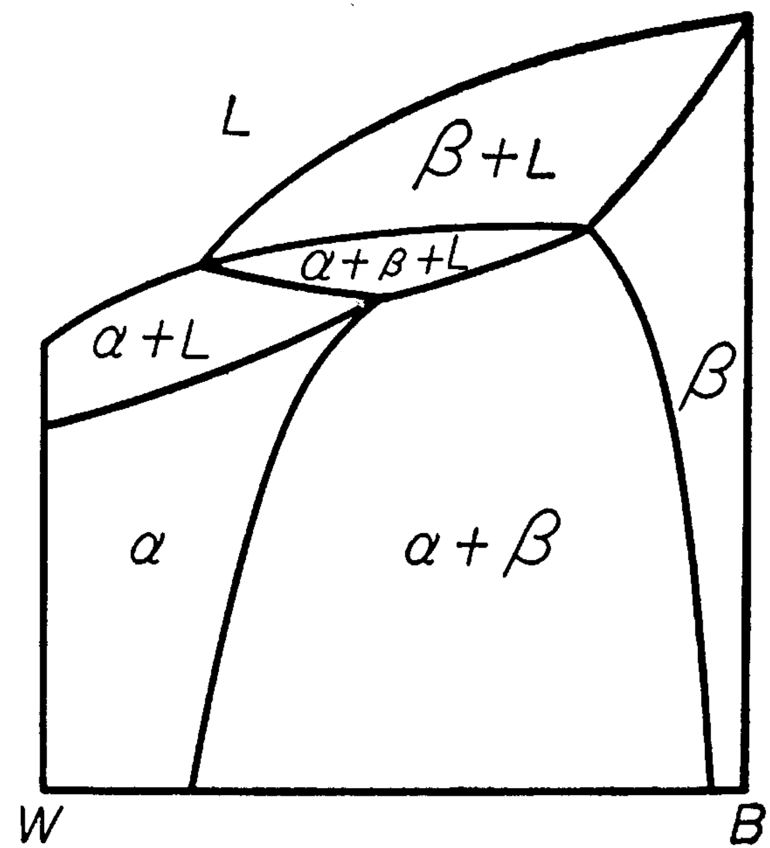
$T_{p1} > T > T_{p2}$

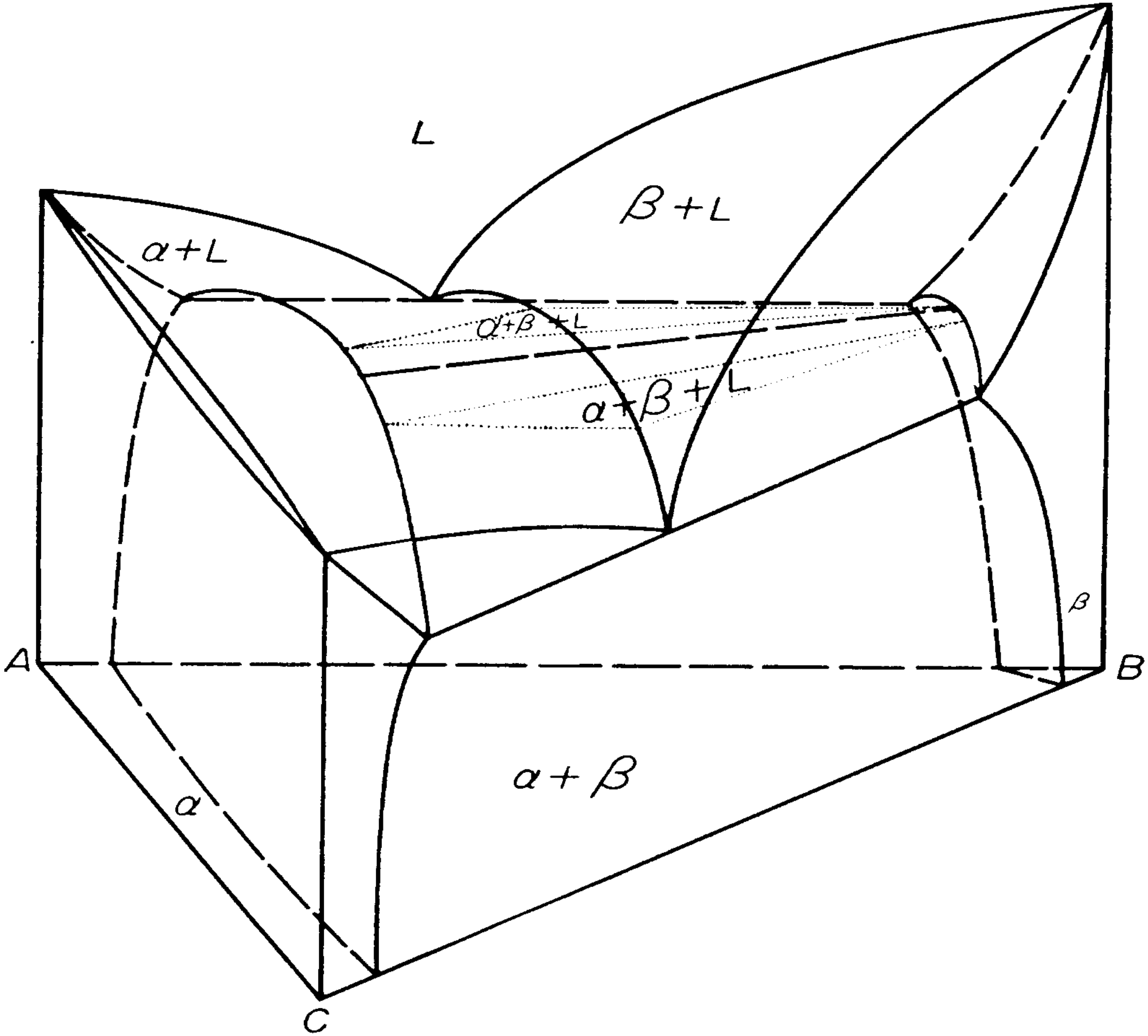
$T < T_B$

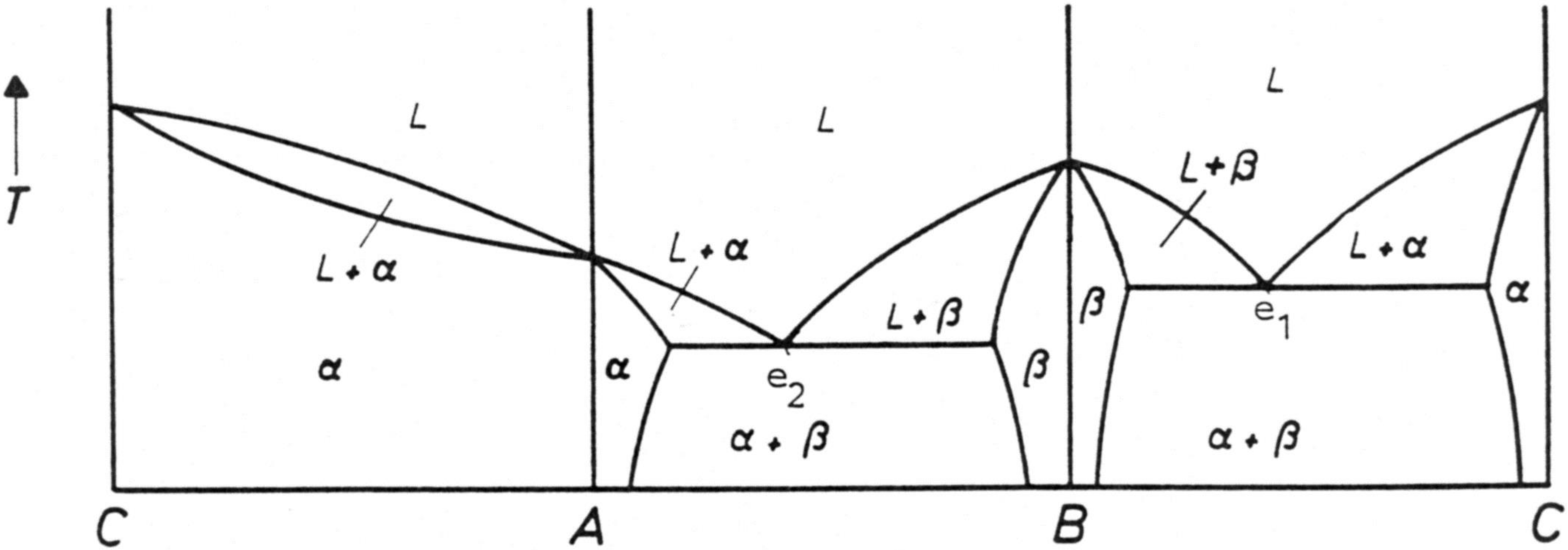


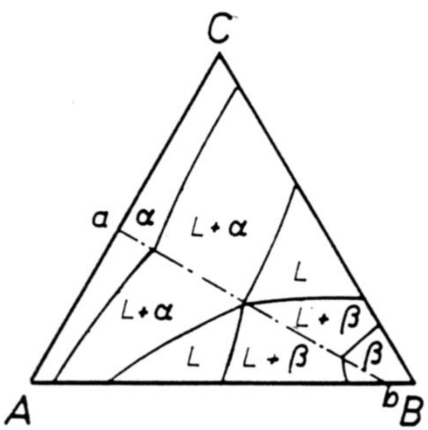
L
L + β
L+α
L+α+β
β
Temperature
A
B
α + β
α
C


A
B
C
W

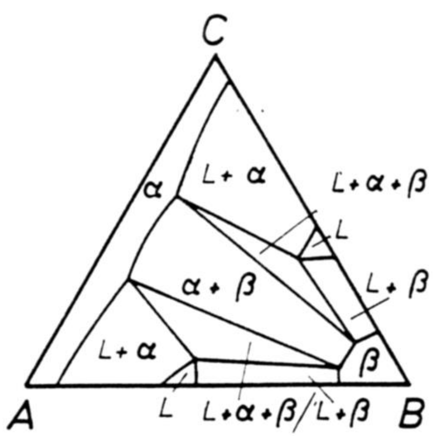

L
β+L
α+β+L
α+L
β
α
α+β
W
B


L
β + L
α + L
α+β +L
α+β+L
β
A
B
α
α + β
C

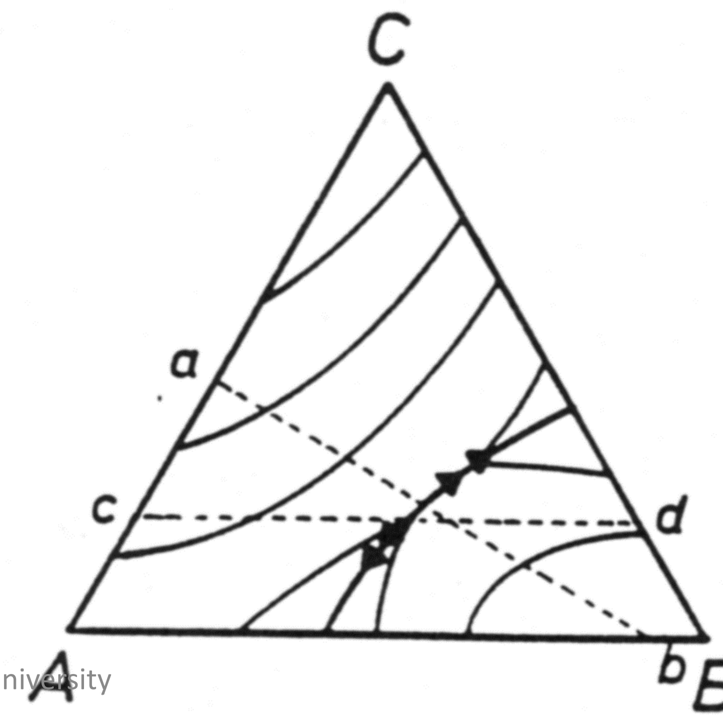


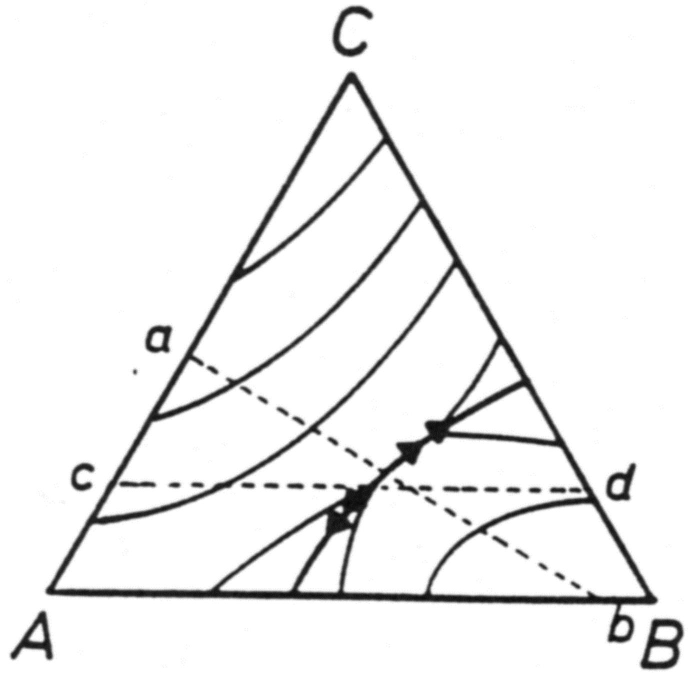


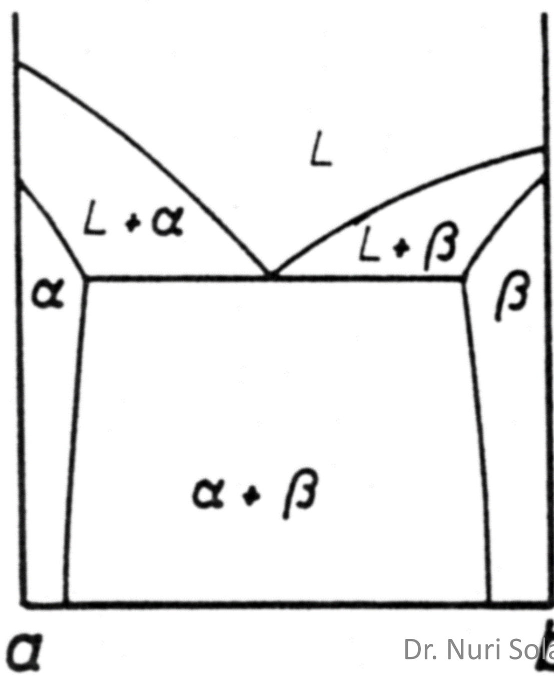
$T = T_{max}$

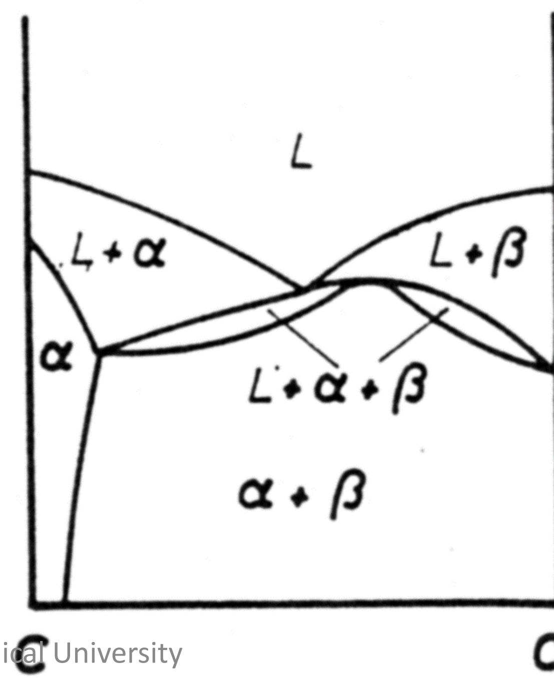


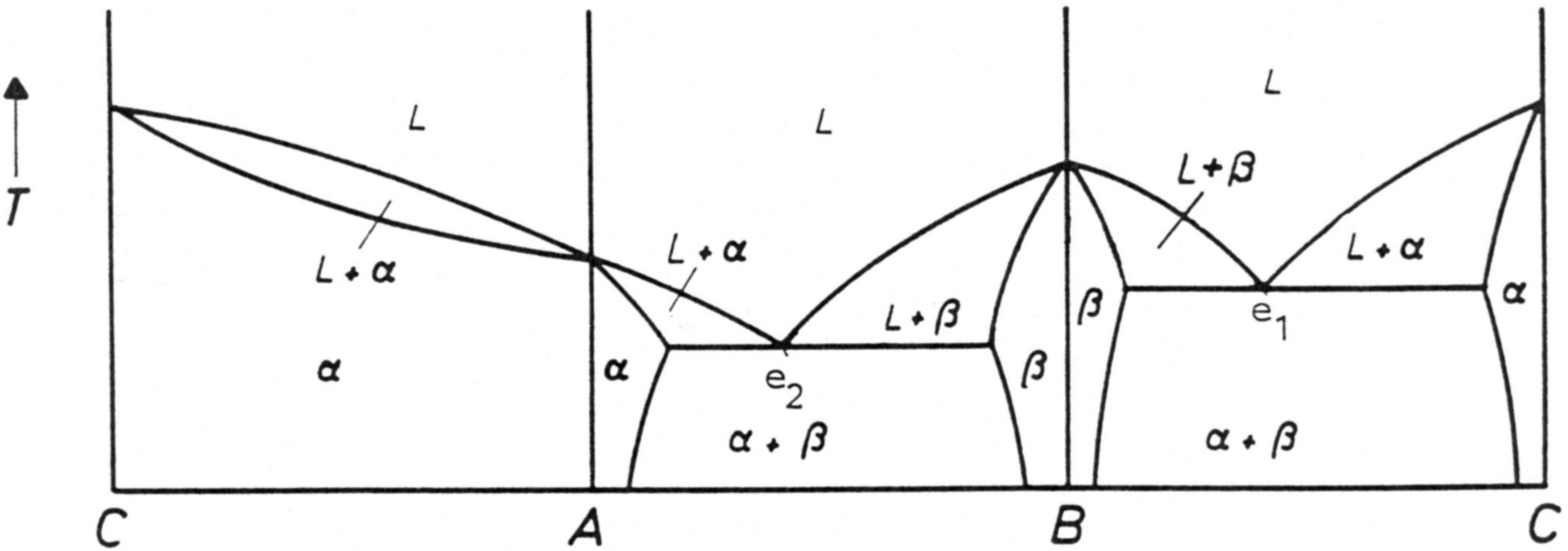
$Te_1 < T < T_{max}$

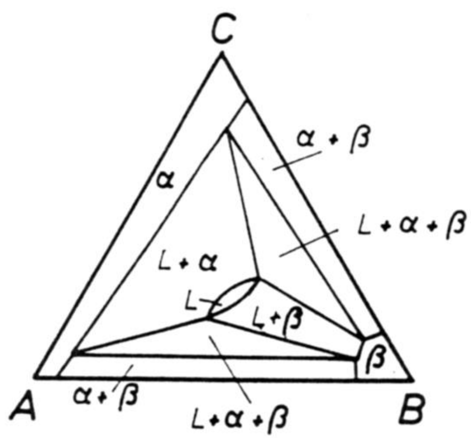



C
a
c
d
A
b
B

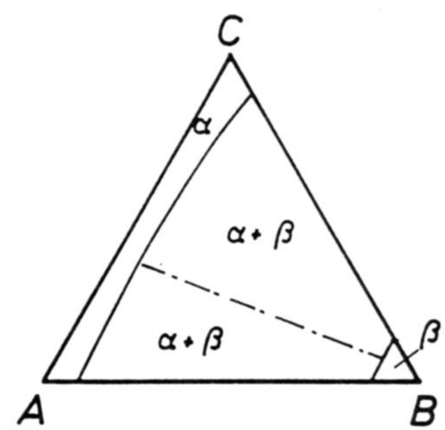

L
L + α
L + β
α
β
α + β
a
b


L
L + α
L + β
α
L + α + β
α + β
c
d

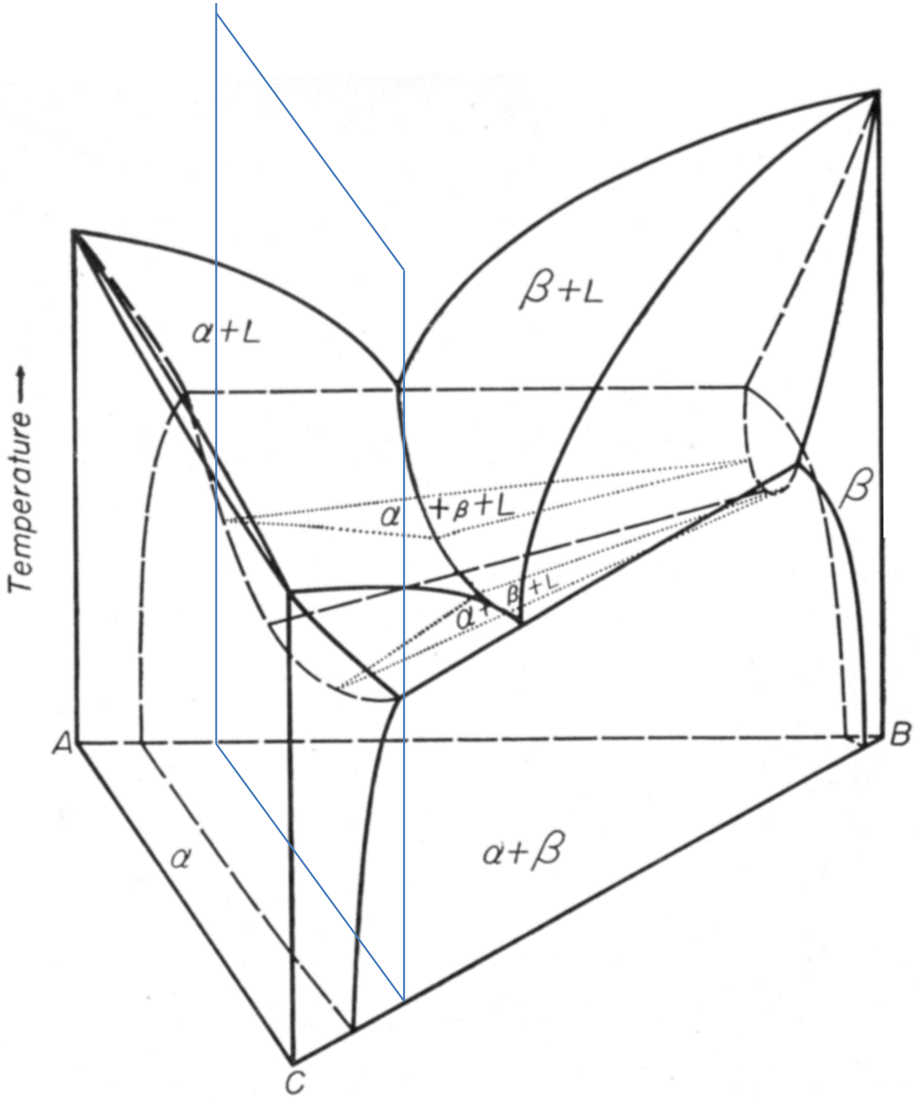


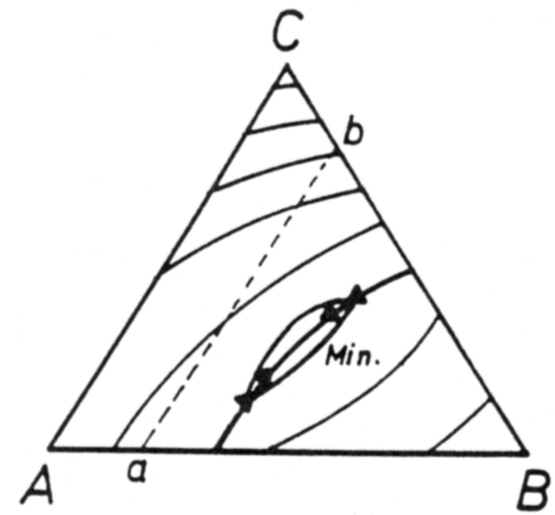


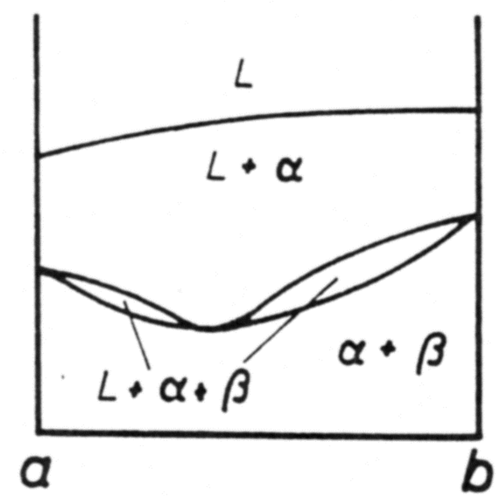
$T_{e_2} > \mathbf{T} > T_{min}$

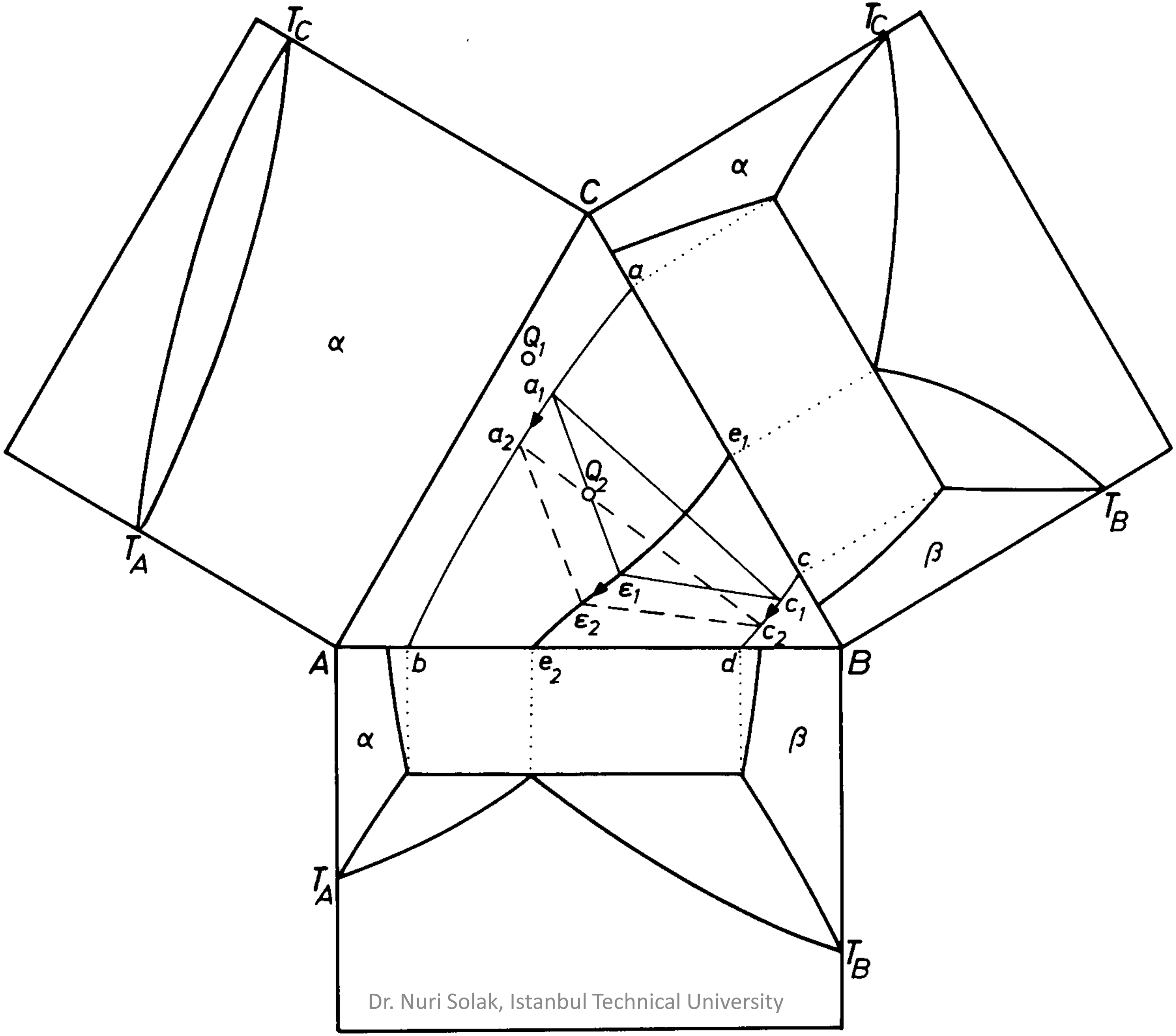


$\mathbf{T} = T_{min}$

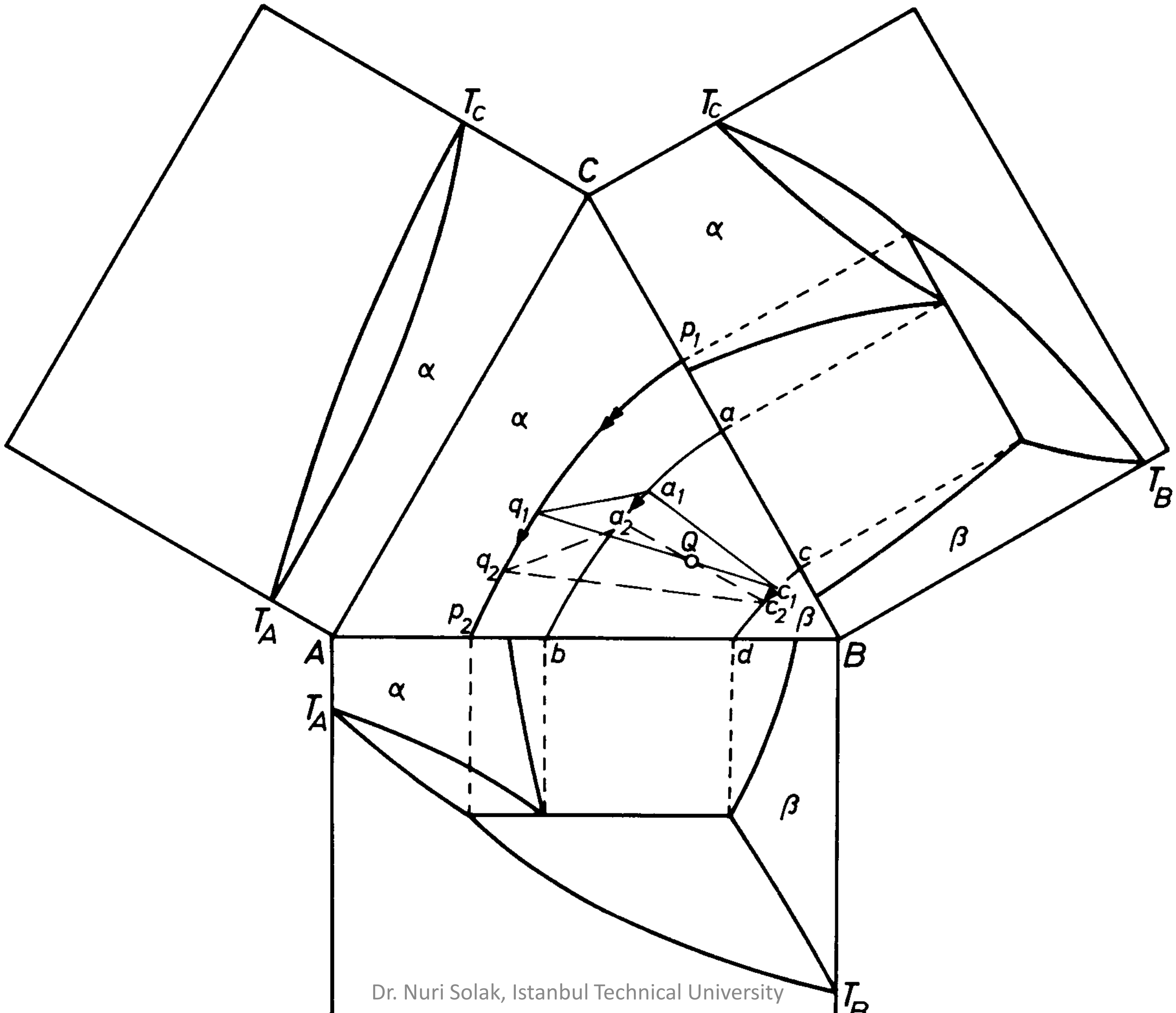

α+L
β+L
α +β+L
β
α+β+L
α
α+β
A
B
C
Temperature →


C
b
Min.
A
a
B

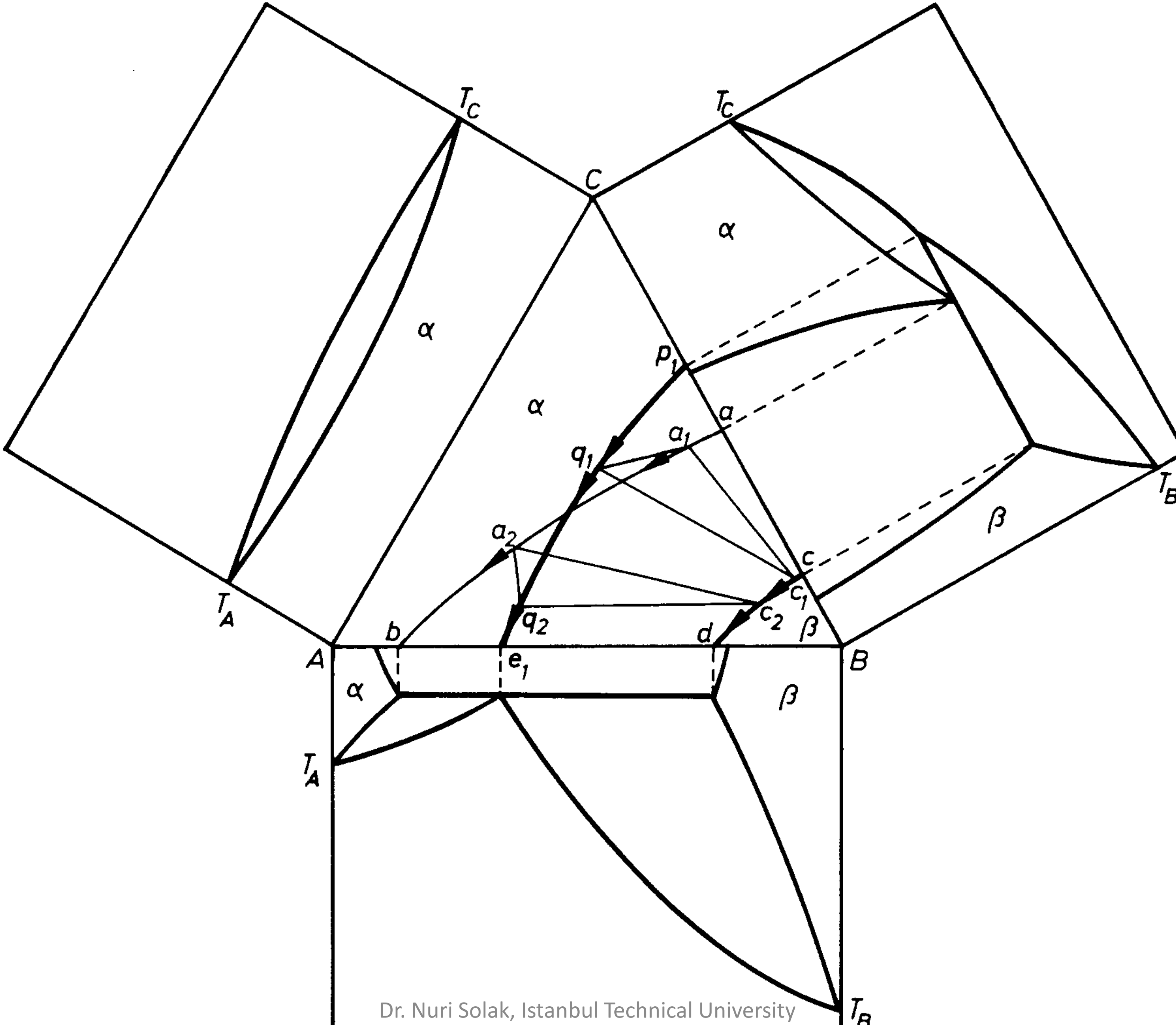

L
L + α
L + α + β
α + β
a
b



T_C
T_C
α
α
C
a
Q_1
a_1
a_2
e_1
Q_2
T_A
T_B
c
β
ε_1
c_1
ε_2
c_2
A
b
e_2
d
B
α
β
T_A
T_B

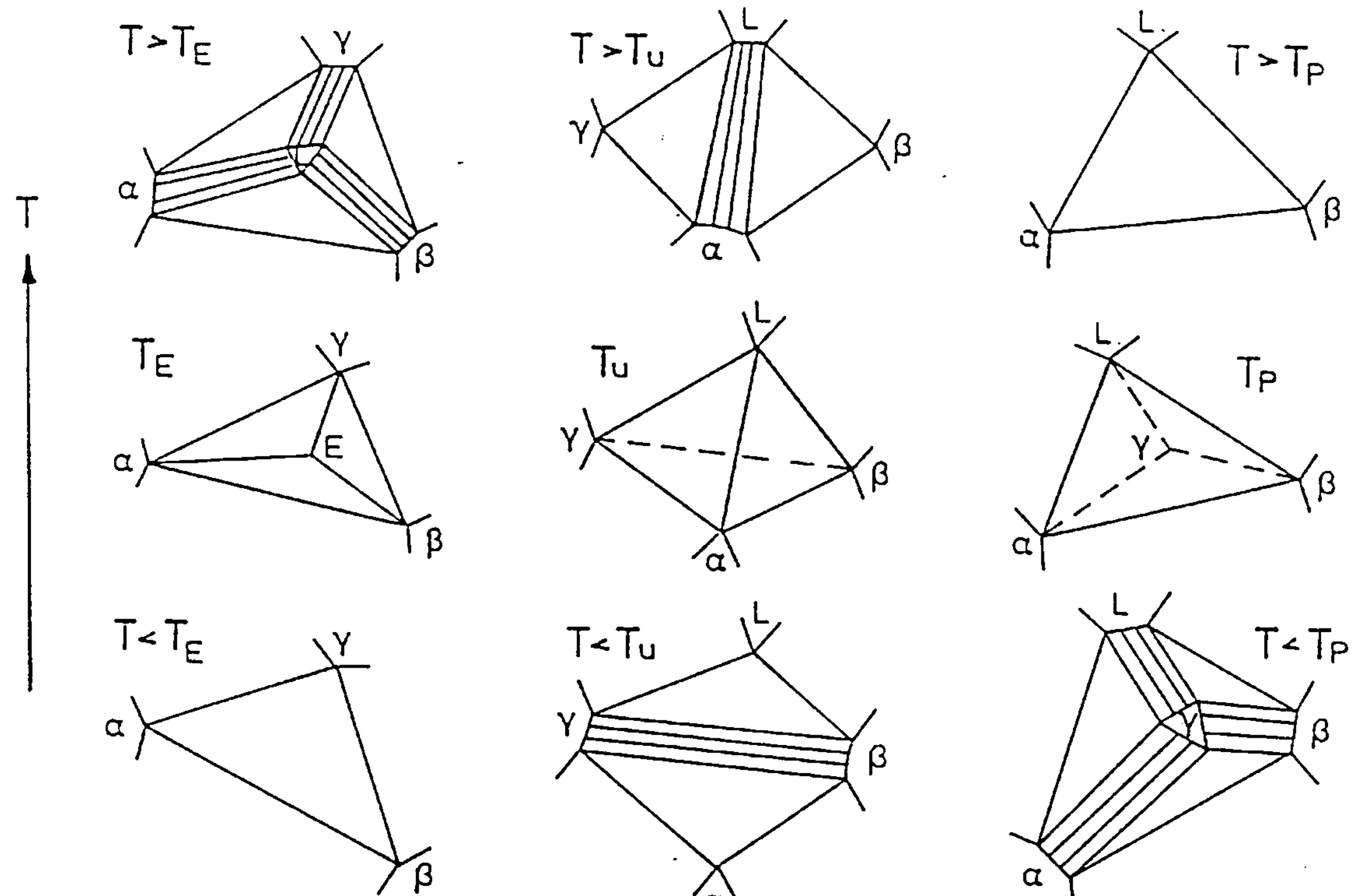


T_C
T_C
C
α
α
α
α
p_1
a
a_1
q_1
a_2
Q
q_2
c
c_1
c_2
β
β
p_2
T_A
A
b
d
B
T_B
α
T_A
β
T_B



T_C
T_C
C
α
α
α
p_1
a
a_1
q_1
T_B
β
a_2
c
c_1
c_2
q_2
T_A
b
d
β
A
B
e_1
α
β
T_A
T_B

Type:	Eutectic	Transition	Peritectic
Reaction:	$L \rightleftharpoons \alpha + \beta + \gamma$	$L + \alpha \rightleftharpoons \beta + \gamma$	$L + \alpha + \beta \rightleftharpoons \gamma$



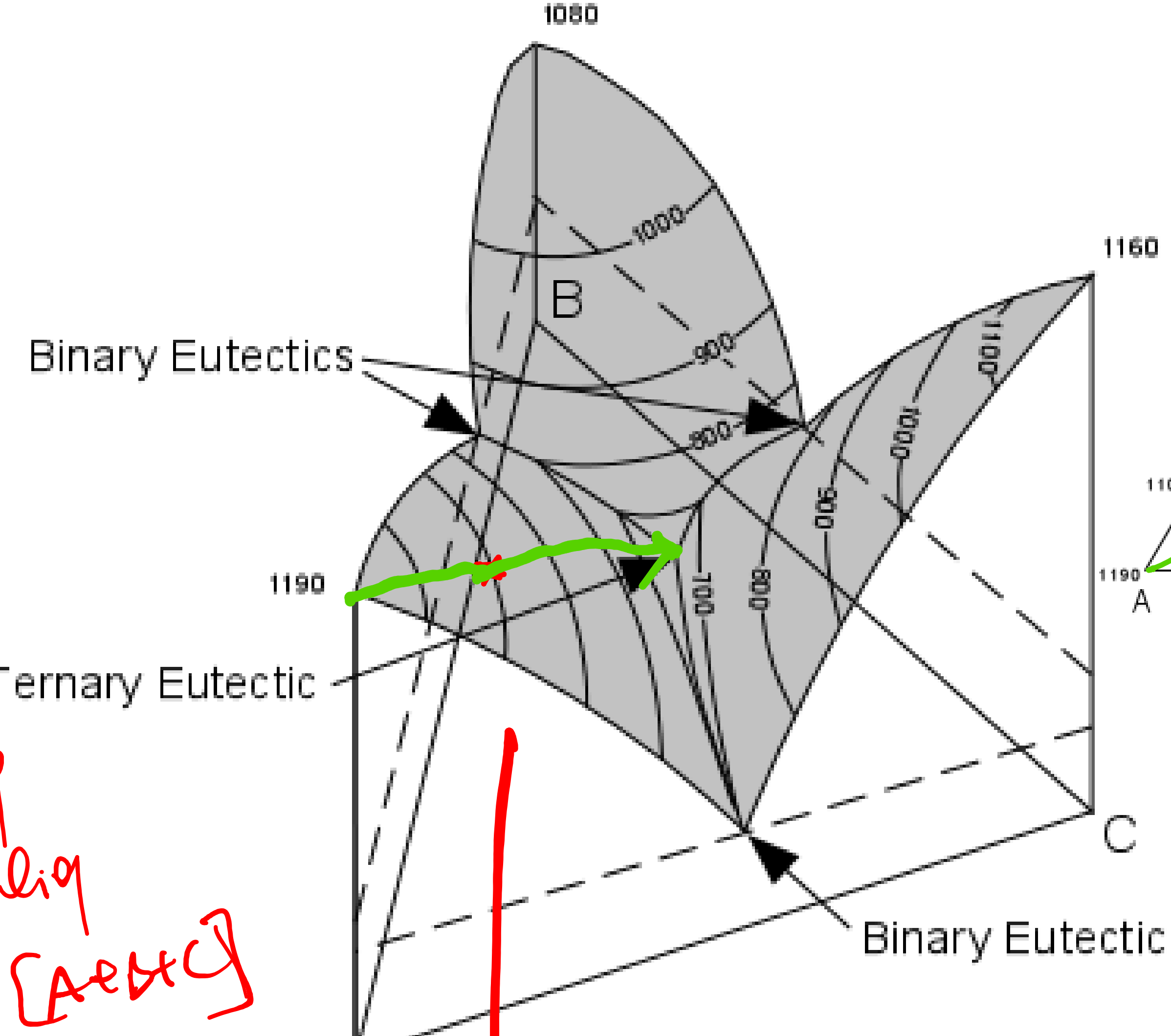


Figure 1

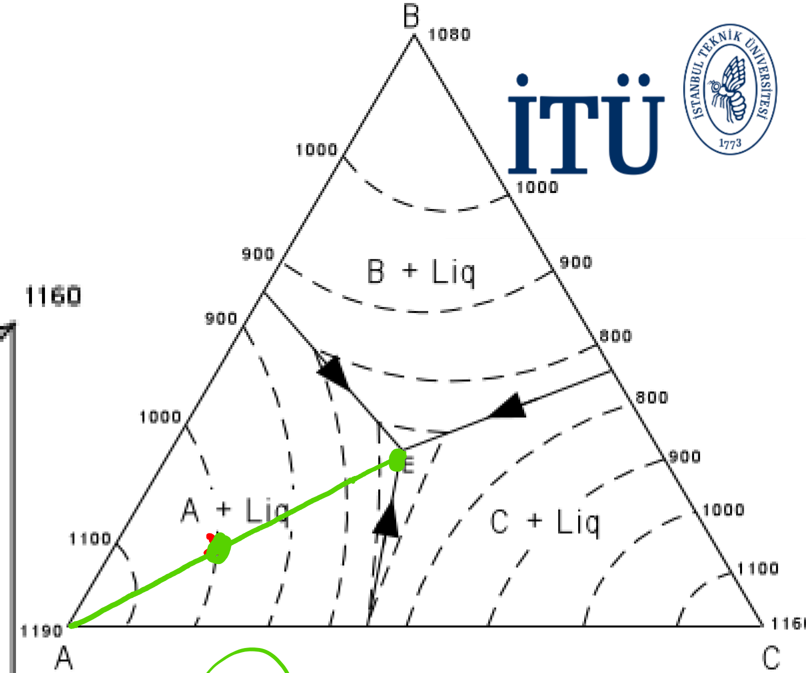


Figure 2

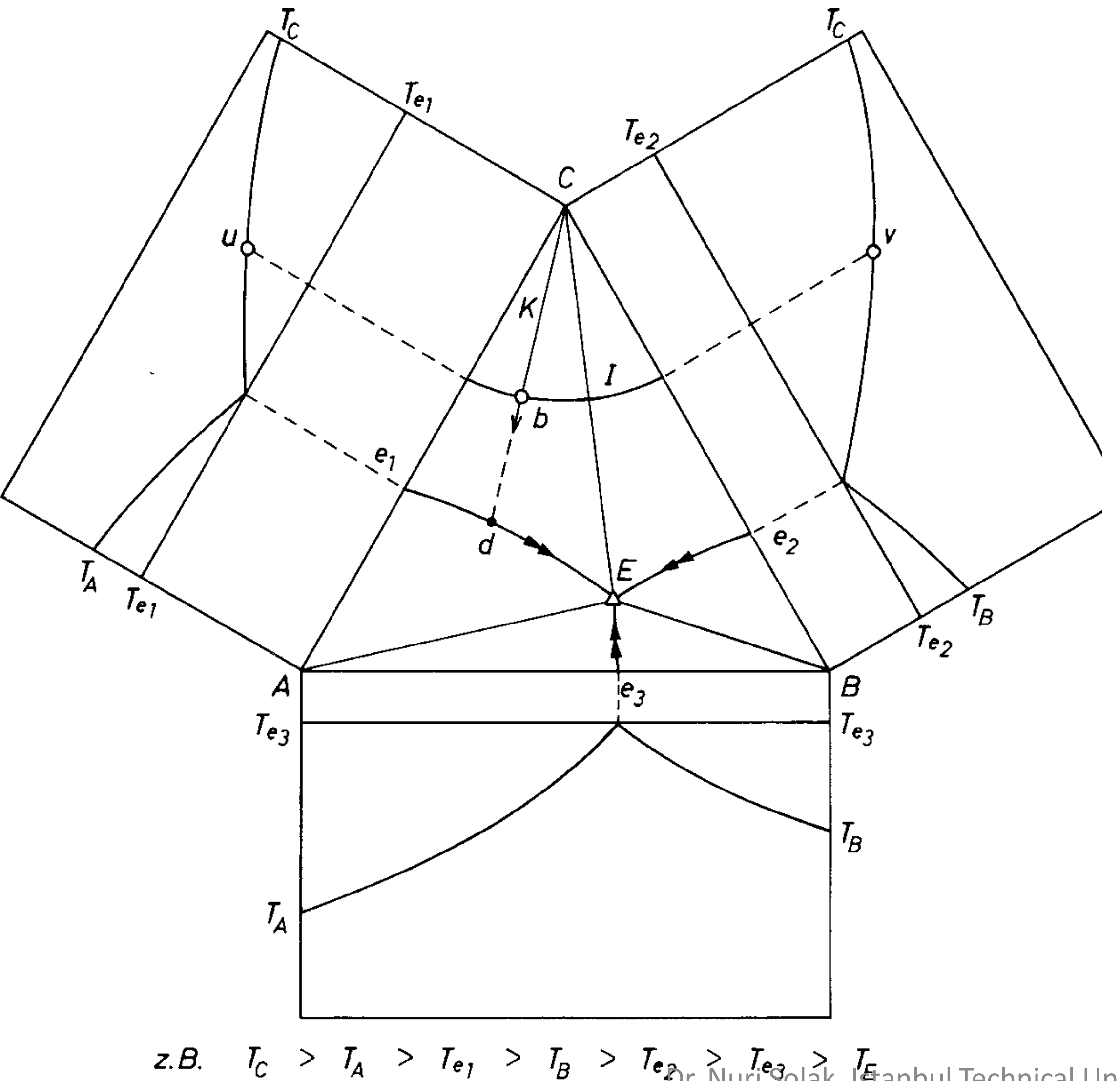
liq
[A+B+C]

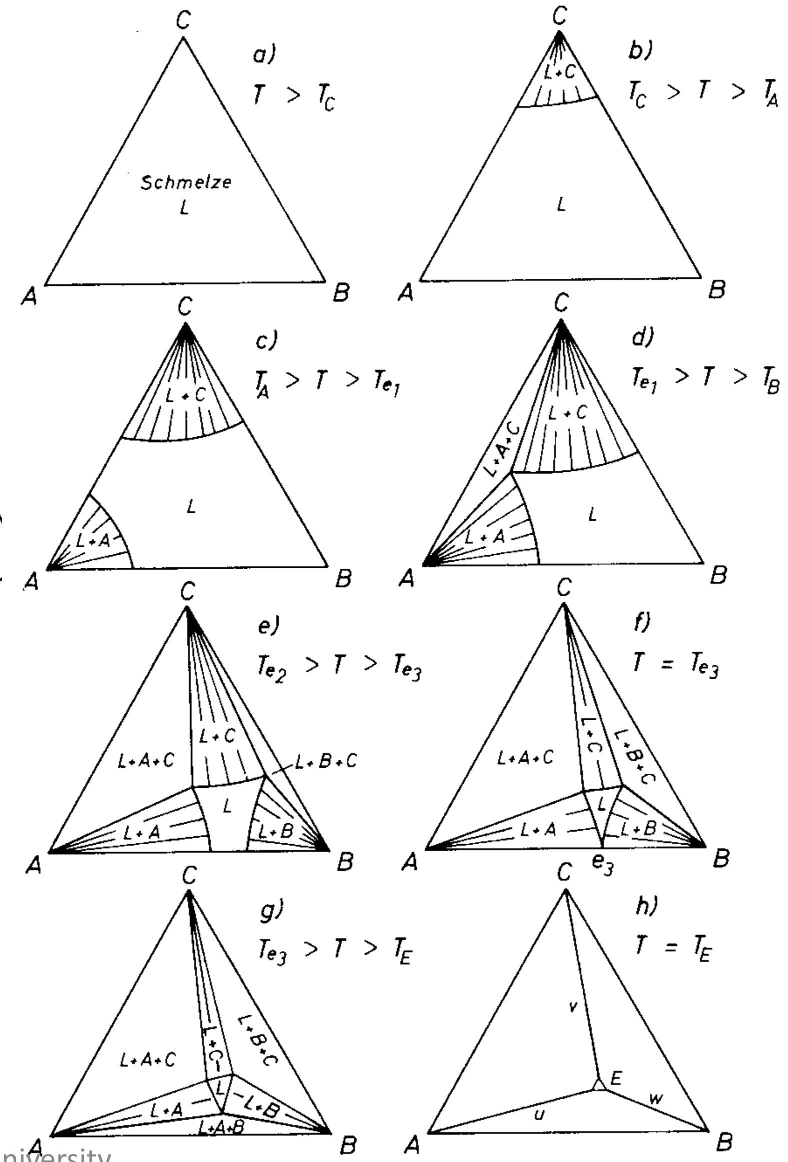
liq

liq
A + liq
A + [A+B+C]

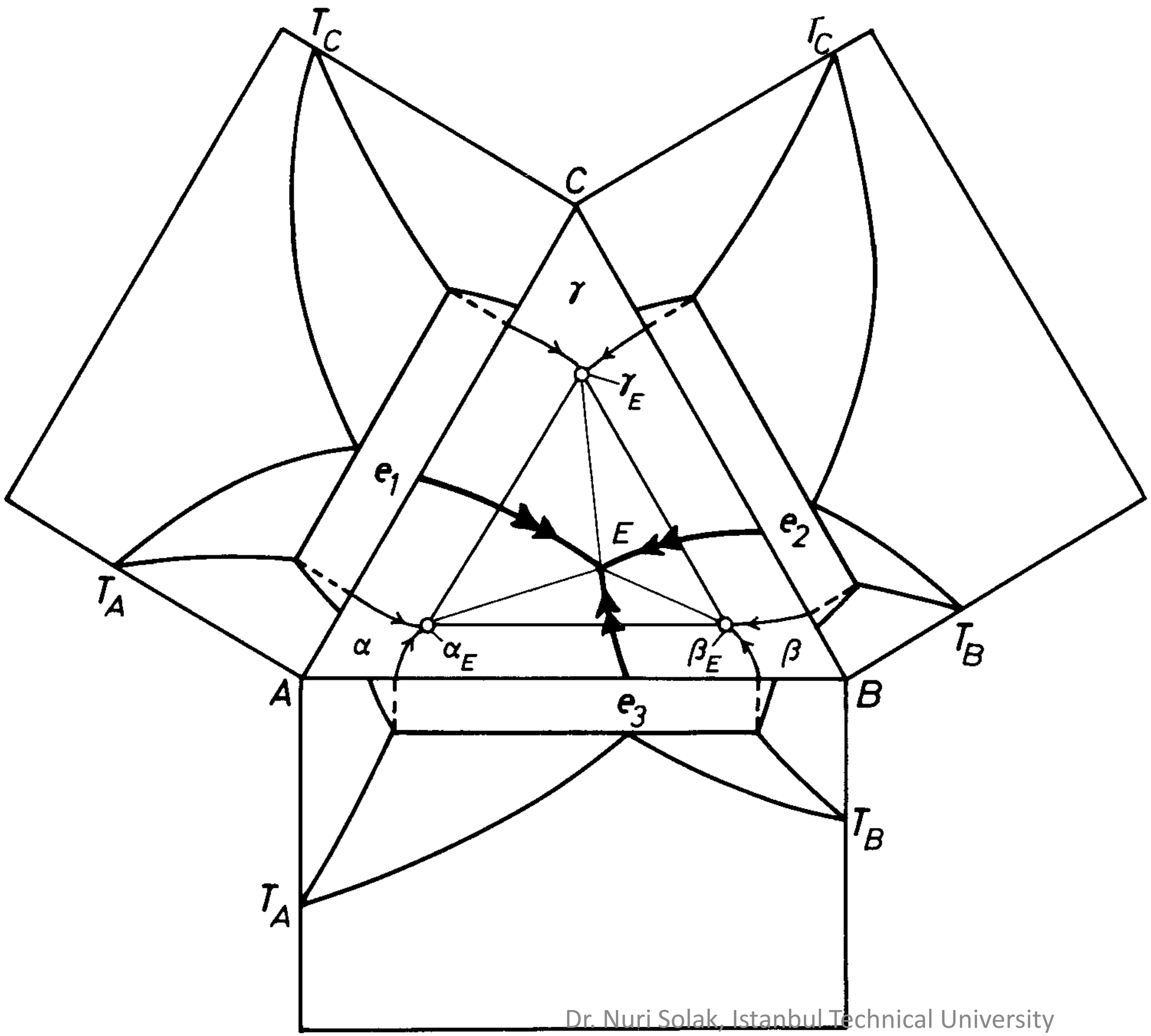
liq

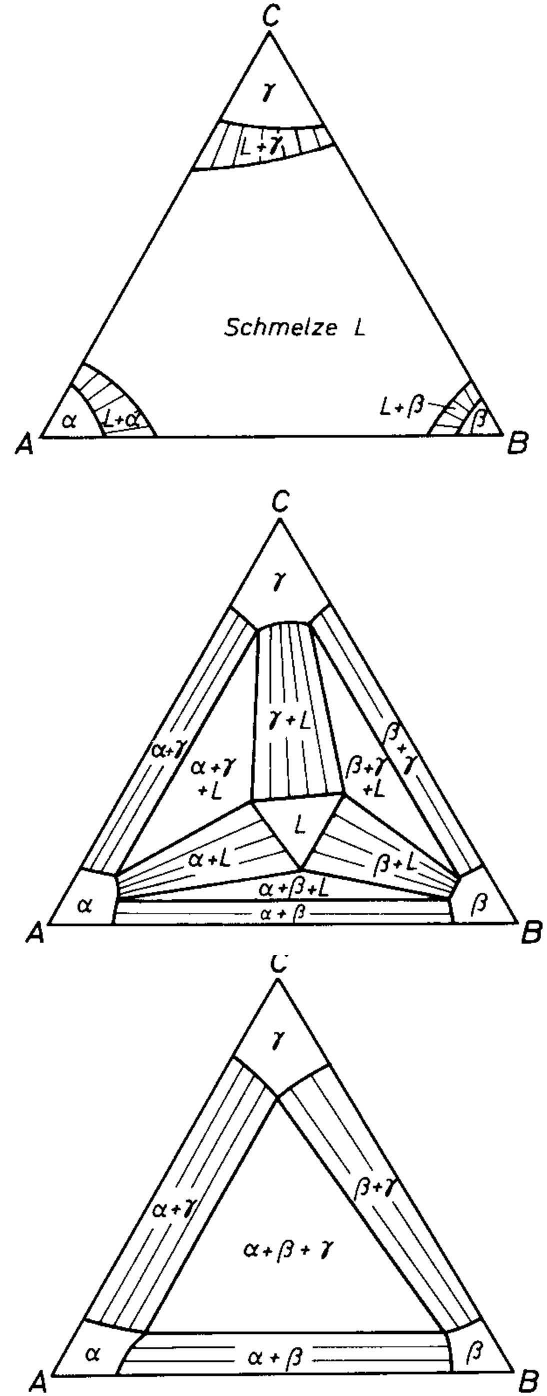
No Solubility



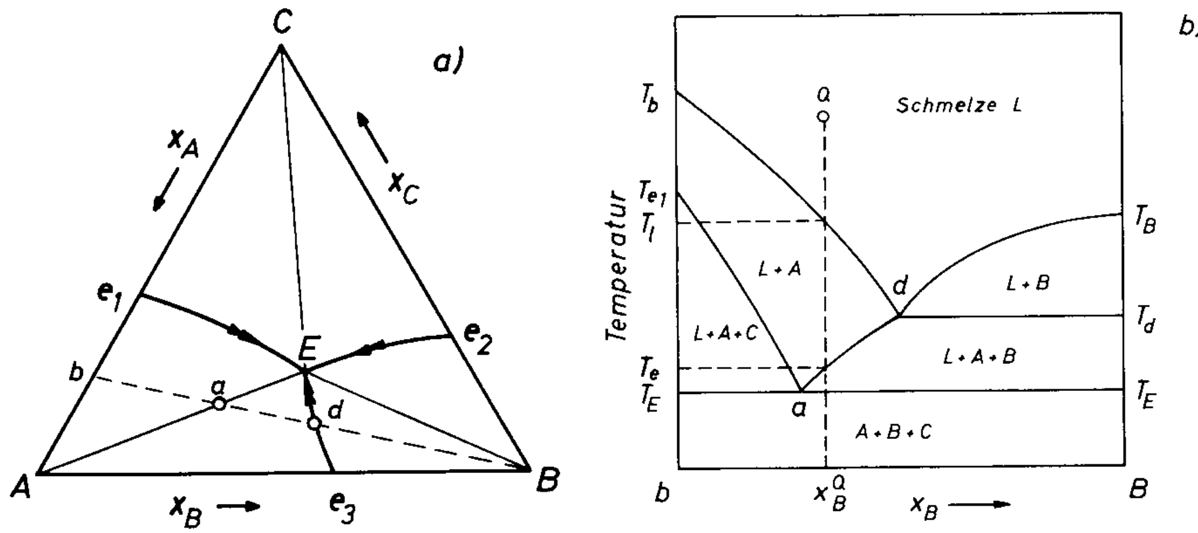


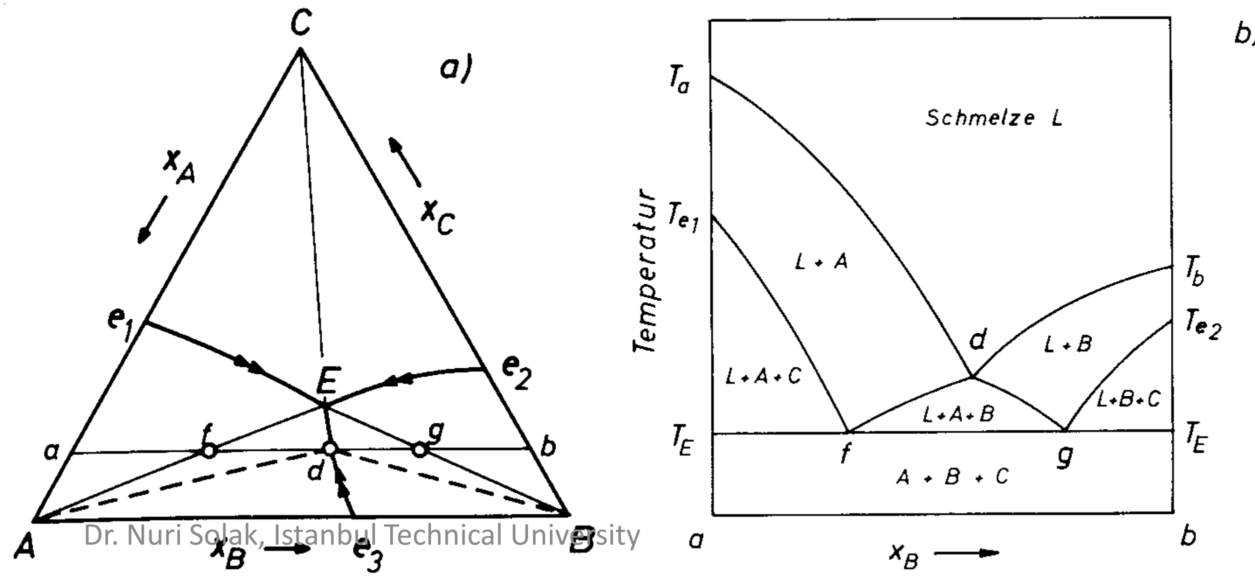
Solid Solution



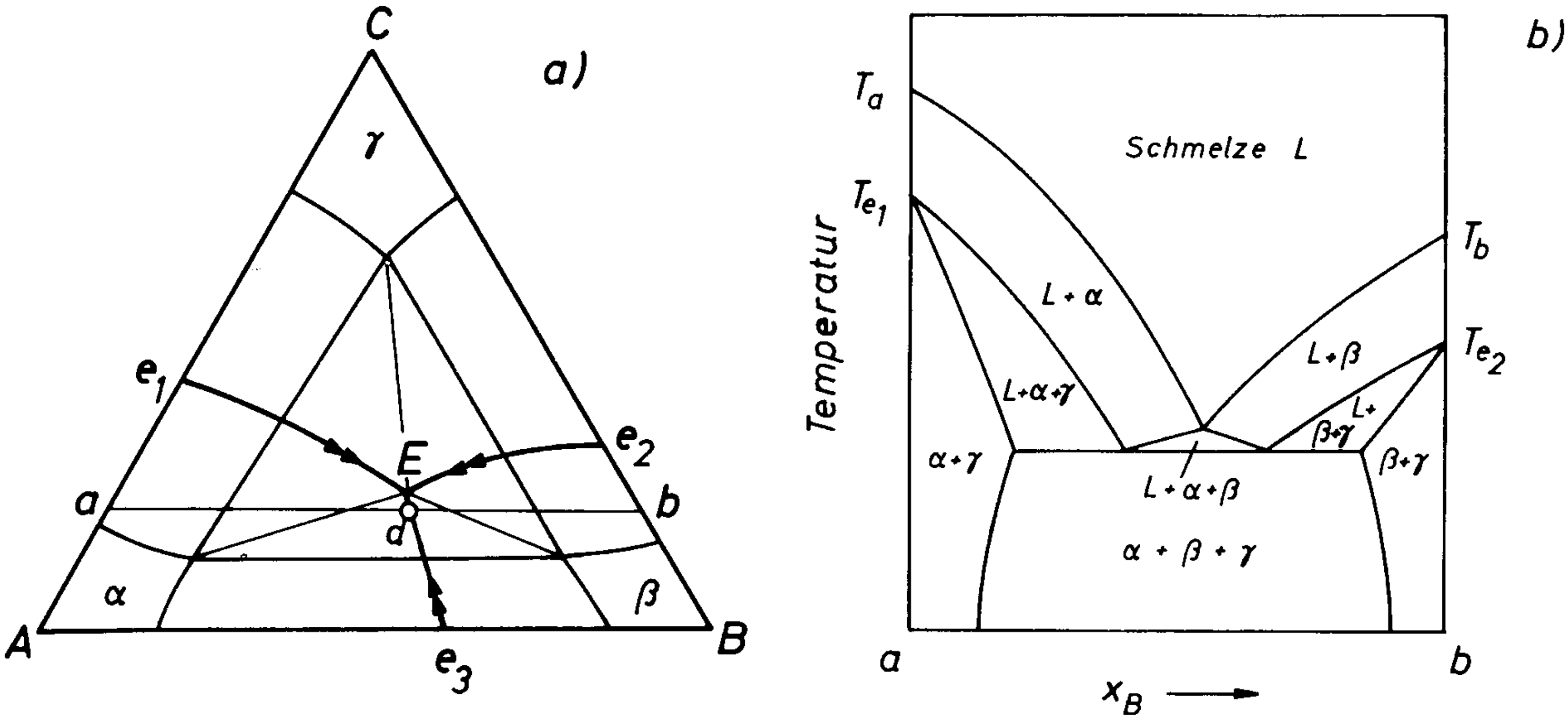


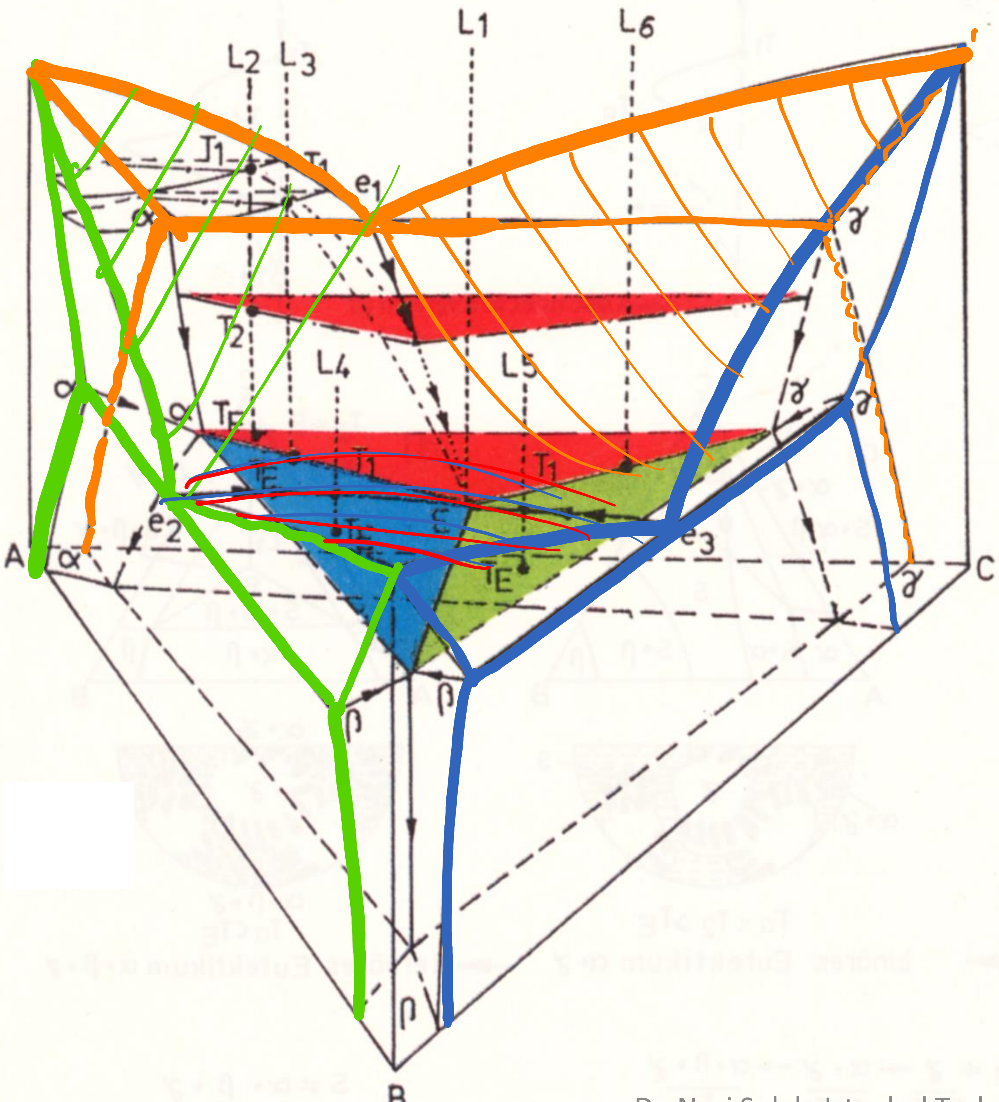
No Solid Solution



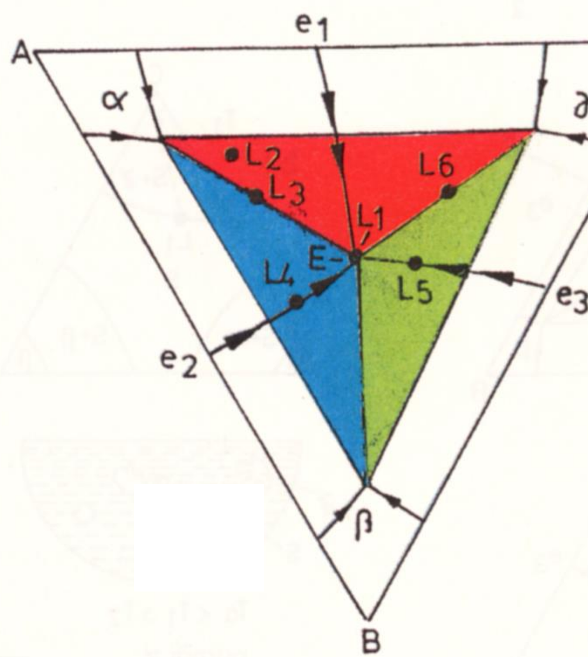


With Solid Solution





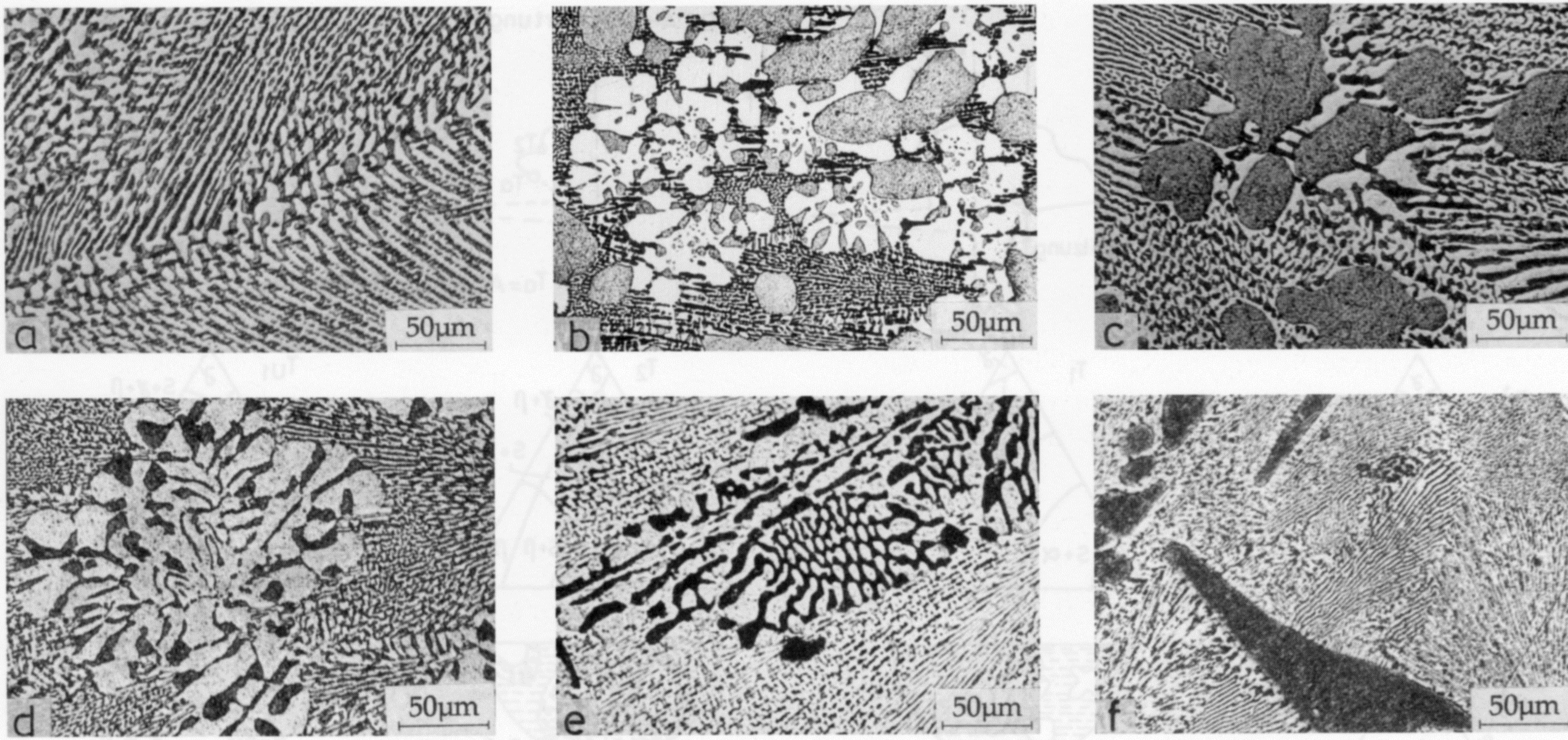
Gefügeformel	DTA-Effekte
L1 = α + β + γ	1
L2 = α → α + γ → α + β + γ	3
L3 = α → α + β + γ	2
L4 = α + β → α + β + γ	2
L5 = β + γ → α + β + γ	2
L6 = γ → α + β + γ	2



L1 = $\alpha + \beta + \gamma$

L2 = $\alpha \rightarrow \alpha + \gamma \rightarrow \alpha + \beta + \gamma$

L3 = $\alpha \rightarrow \alpha + \beta + \gamma$

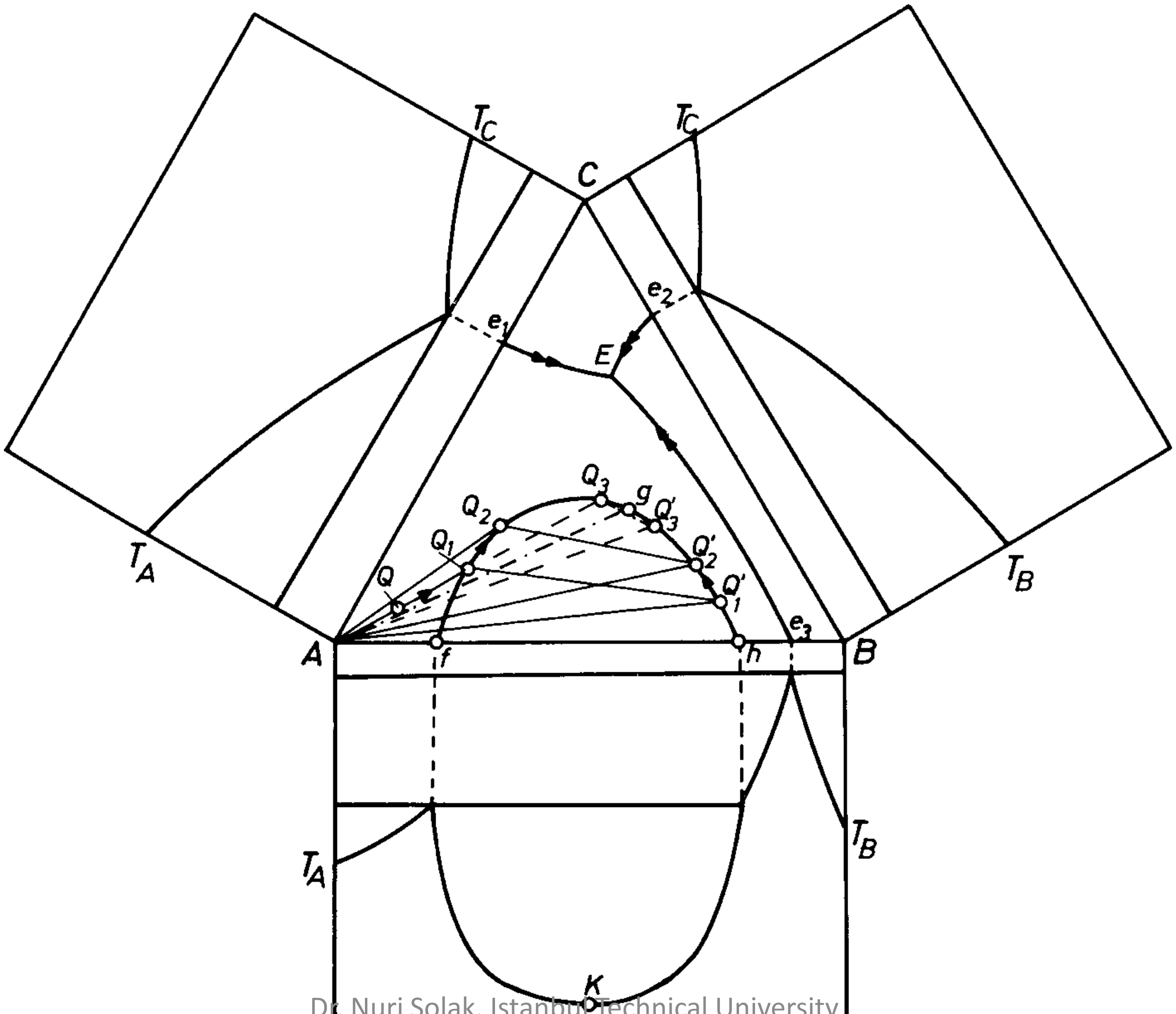


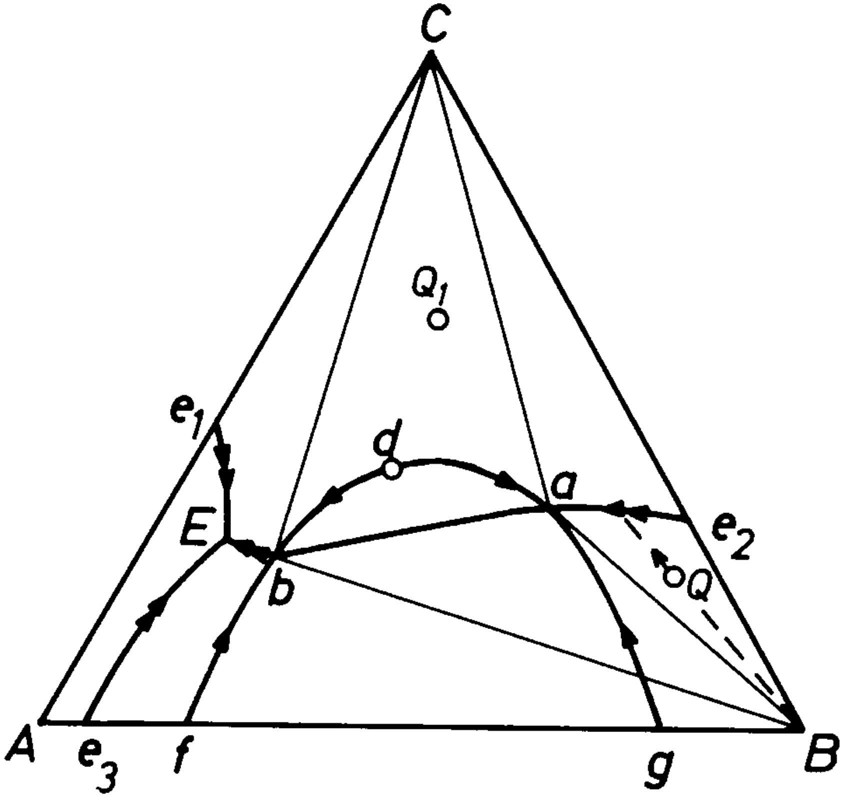
L4 = $\alpha + \beta \rightarrow \alpha + \beta + \gamma$

L5 = $\beta + \gamma \rightarrow \alpha + \beta + \gamma$

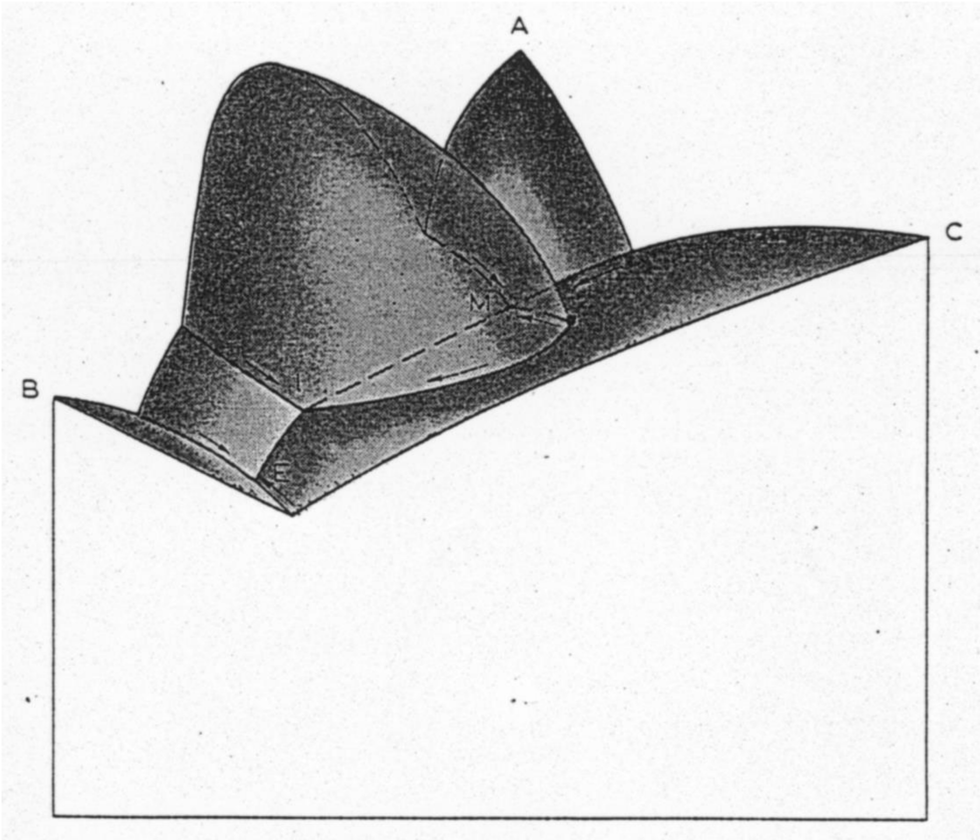
L6 = $\gamma \rightarrow \alpha + \beta + \gamma$

Monotectic

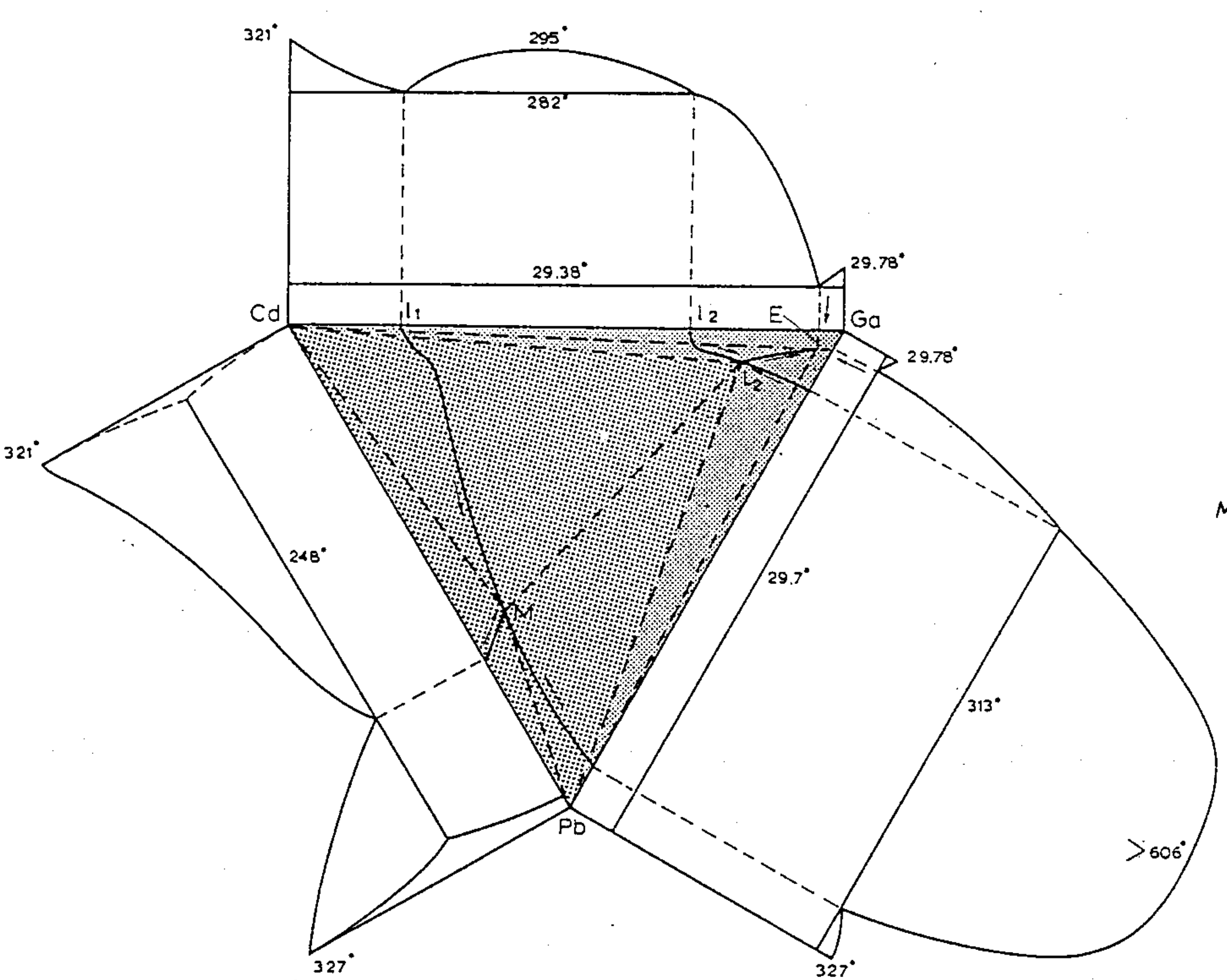


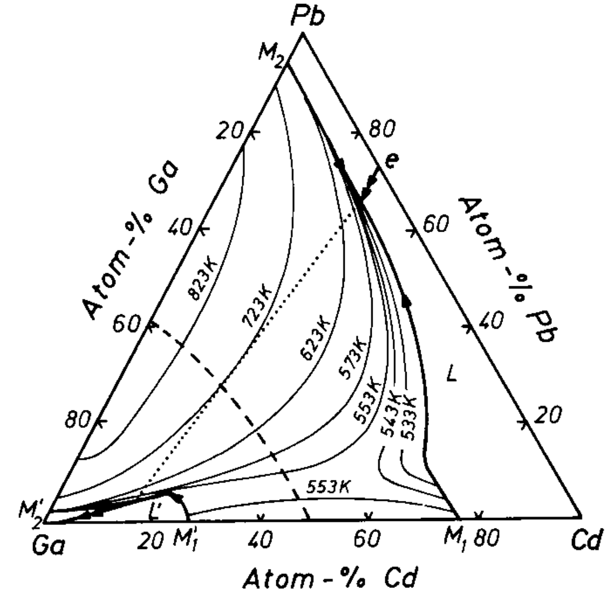


Schmelzflächenprojektion



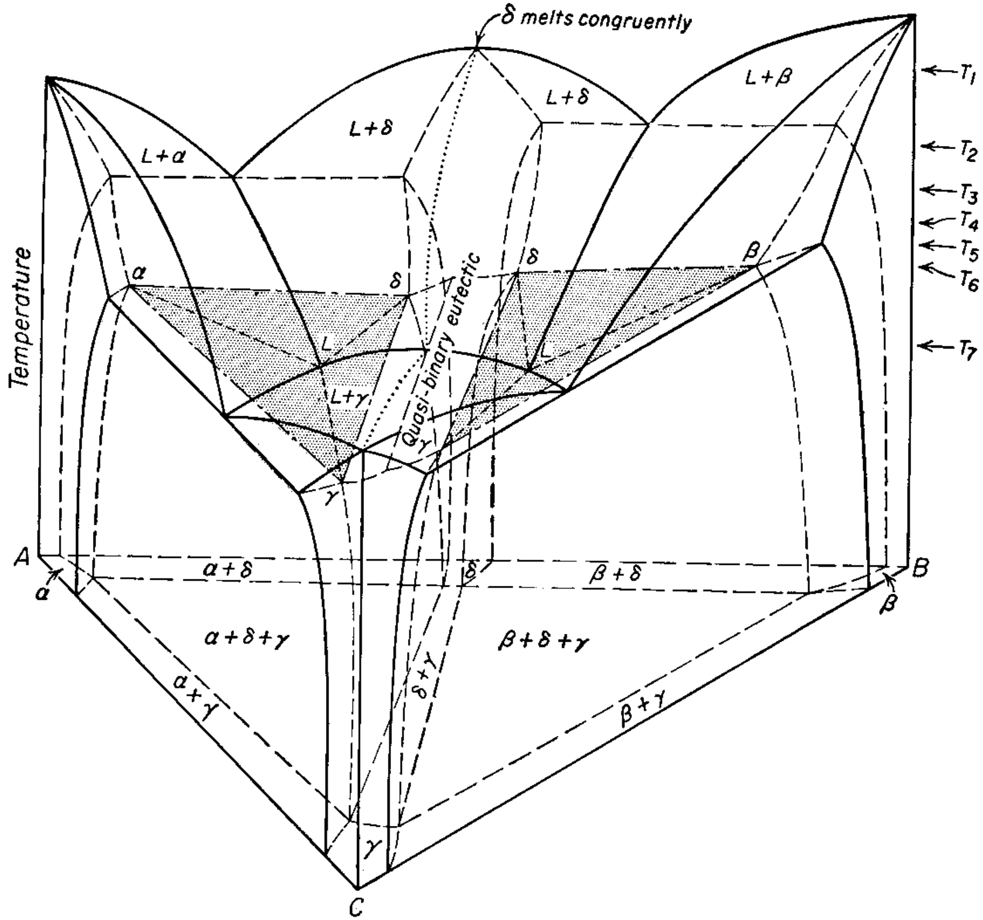
räumliche Darstellung

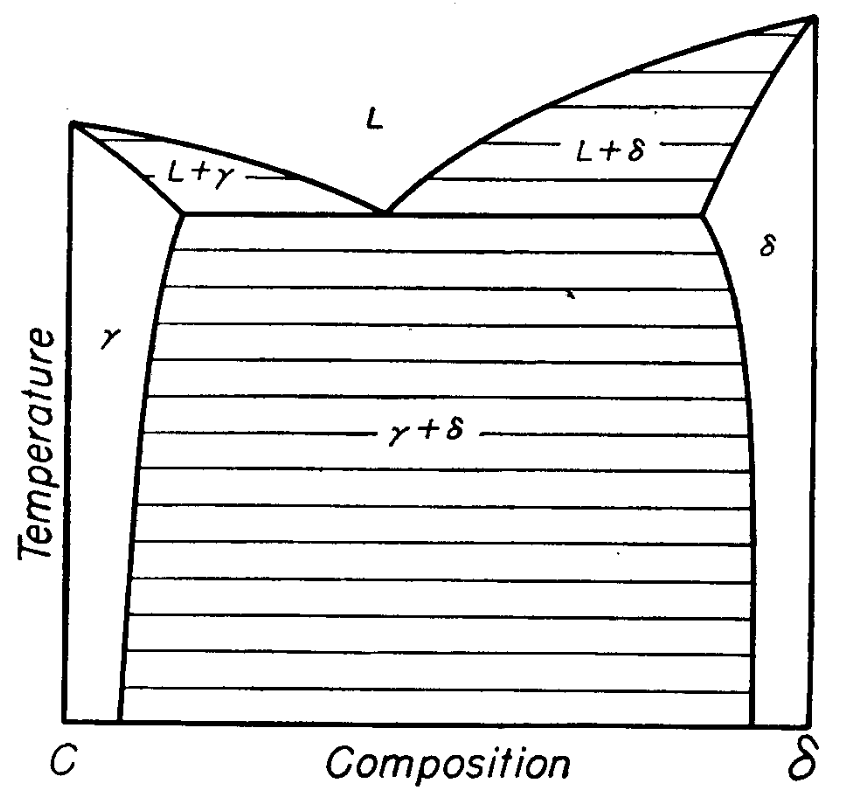


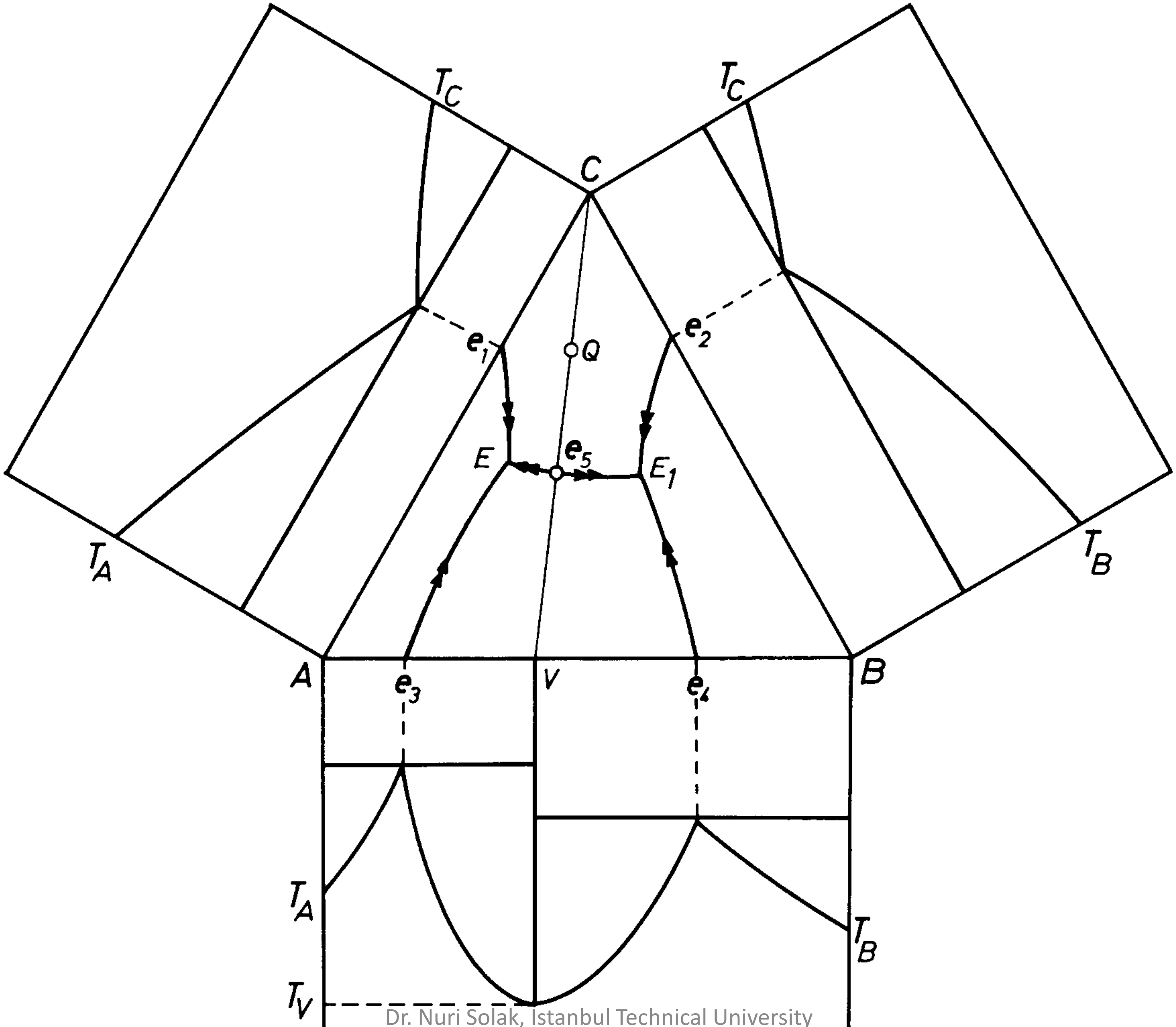


Beispiel: Ga-Cd-Pb

With a Ternary Compound

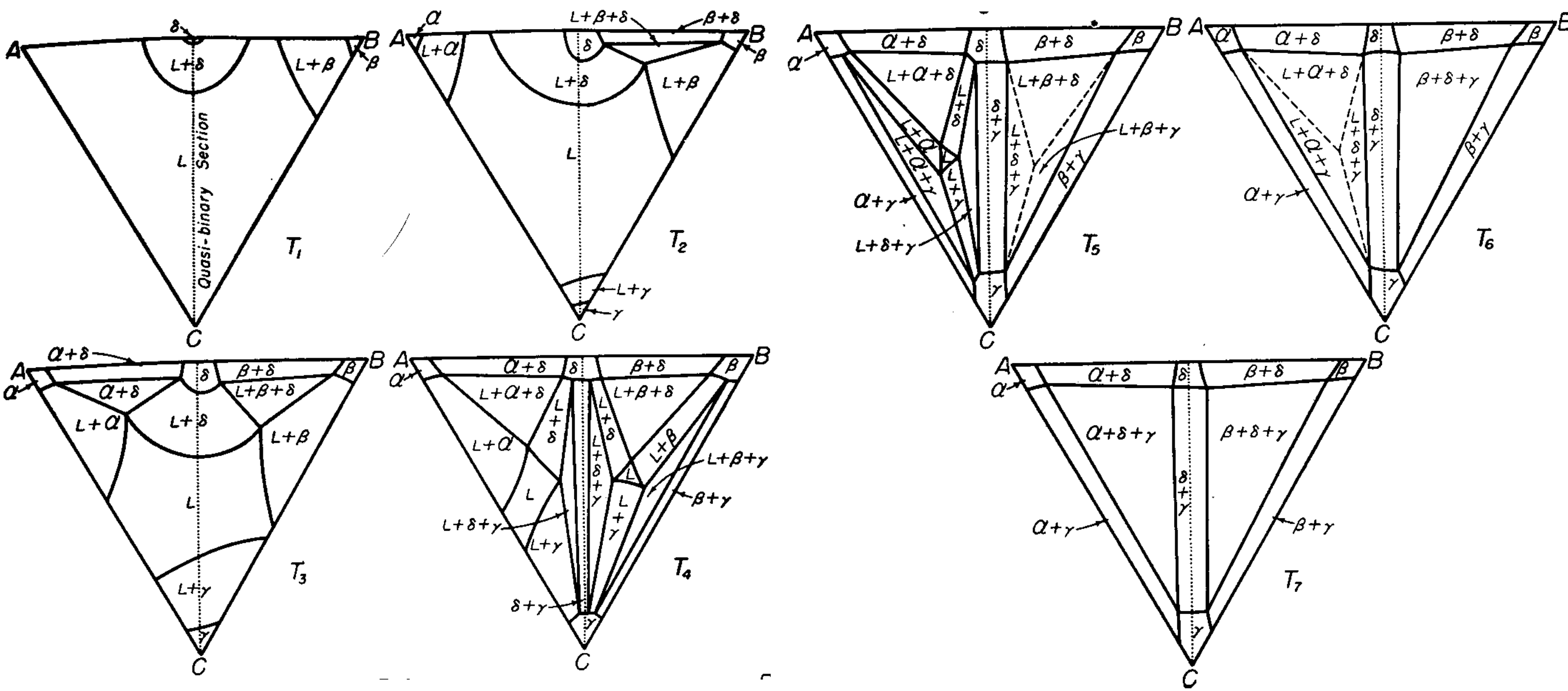


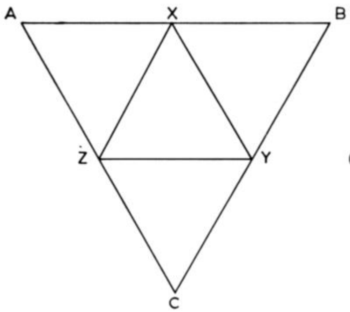




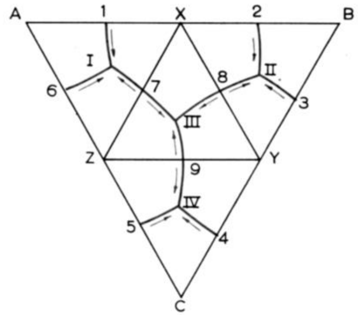
T_C
T_C
C
e_1
e_2
Q
E
e_5
E_1
T_A
T_B
A
e_3
V
e_4
B
T_A
T_B
T_V

Isothermal Sections

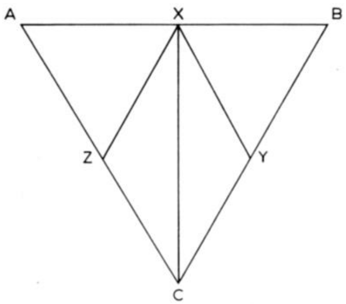




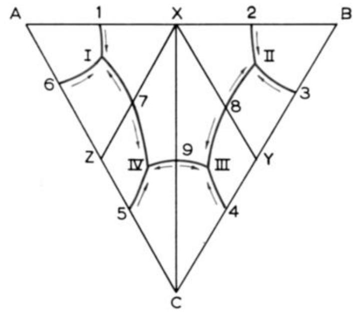
(a) 1



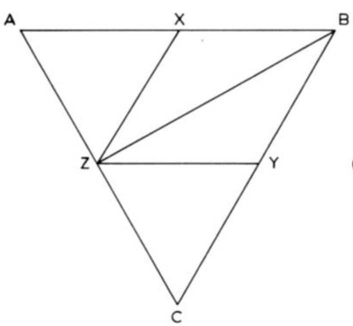
(b) 1



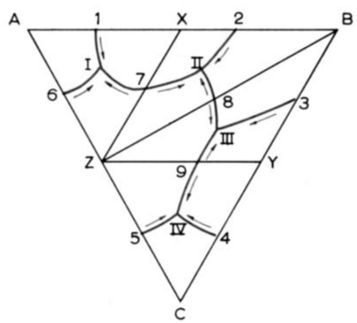
(a) 2



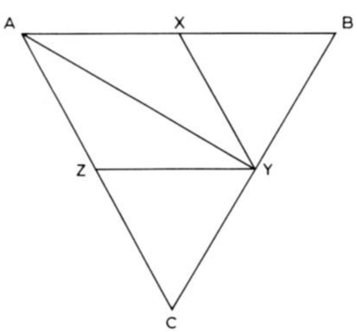
(b) 2



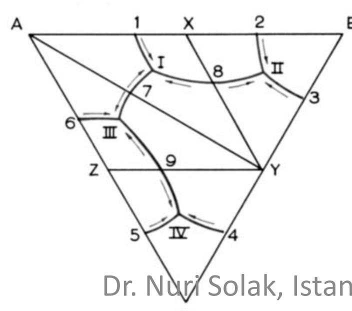
(a) 3



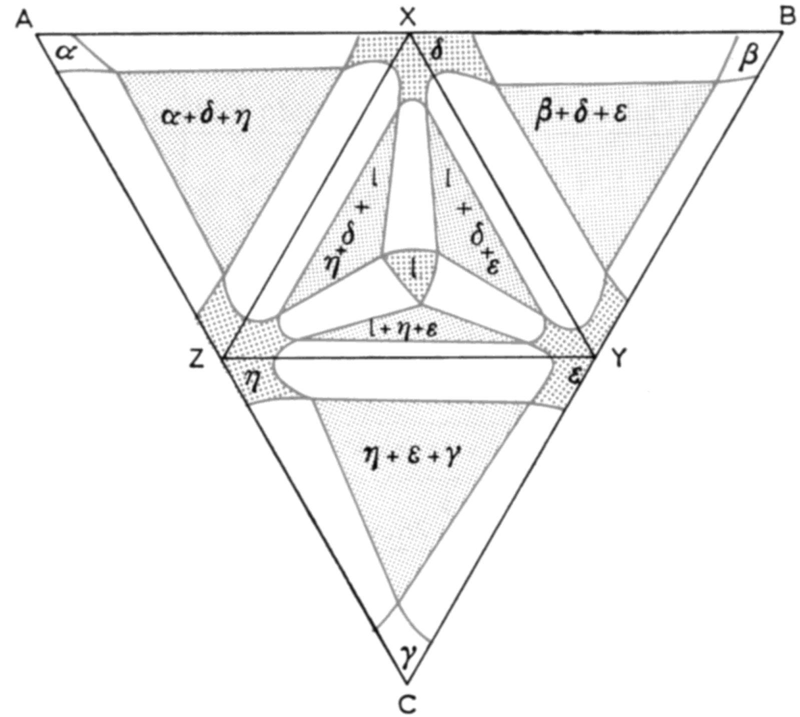
(b) 3

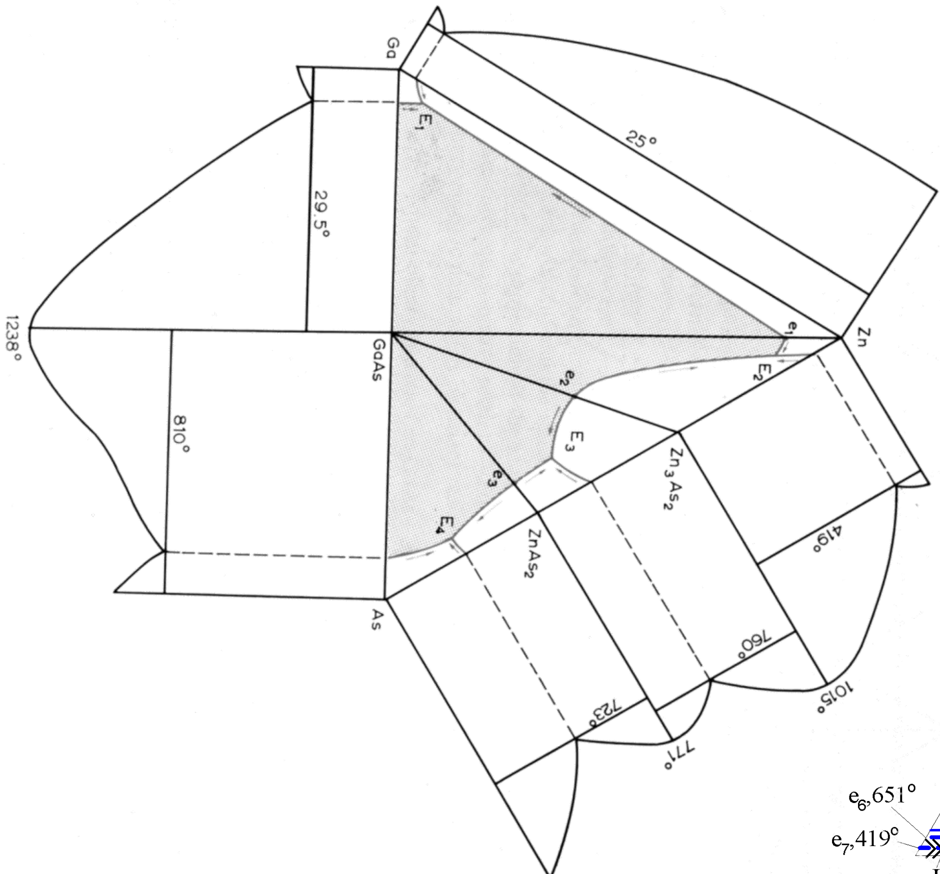


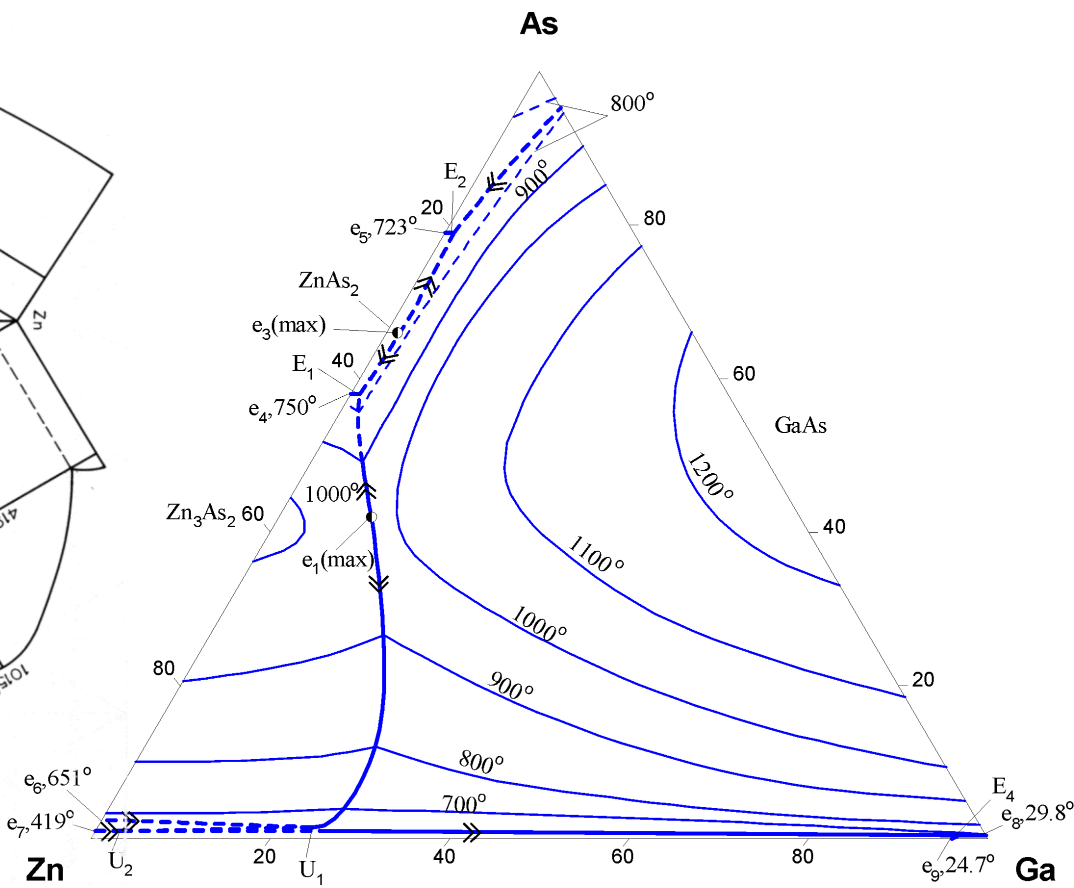
(a) 4

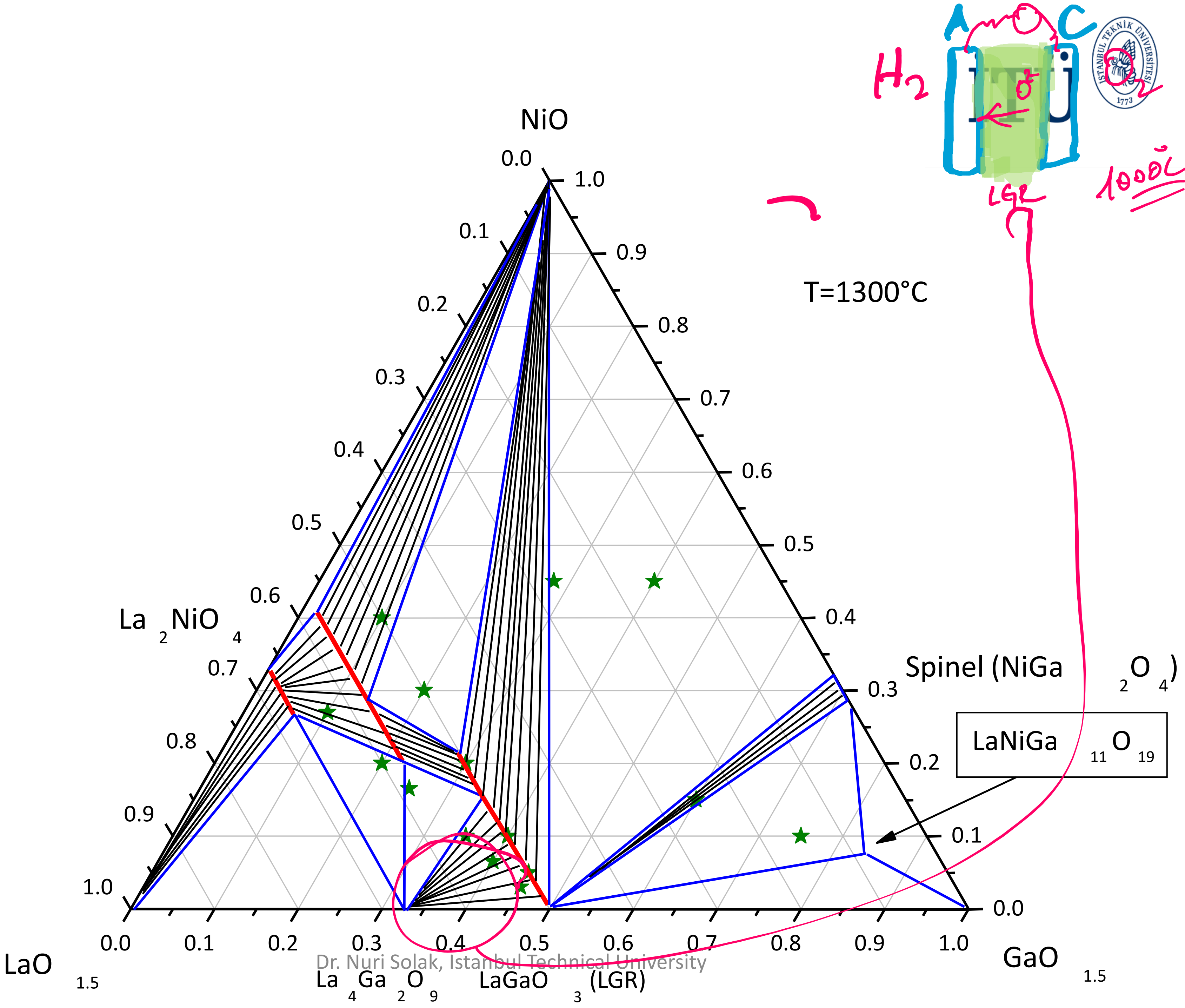


(b) 4



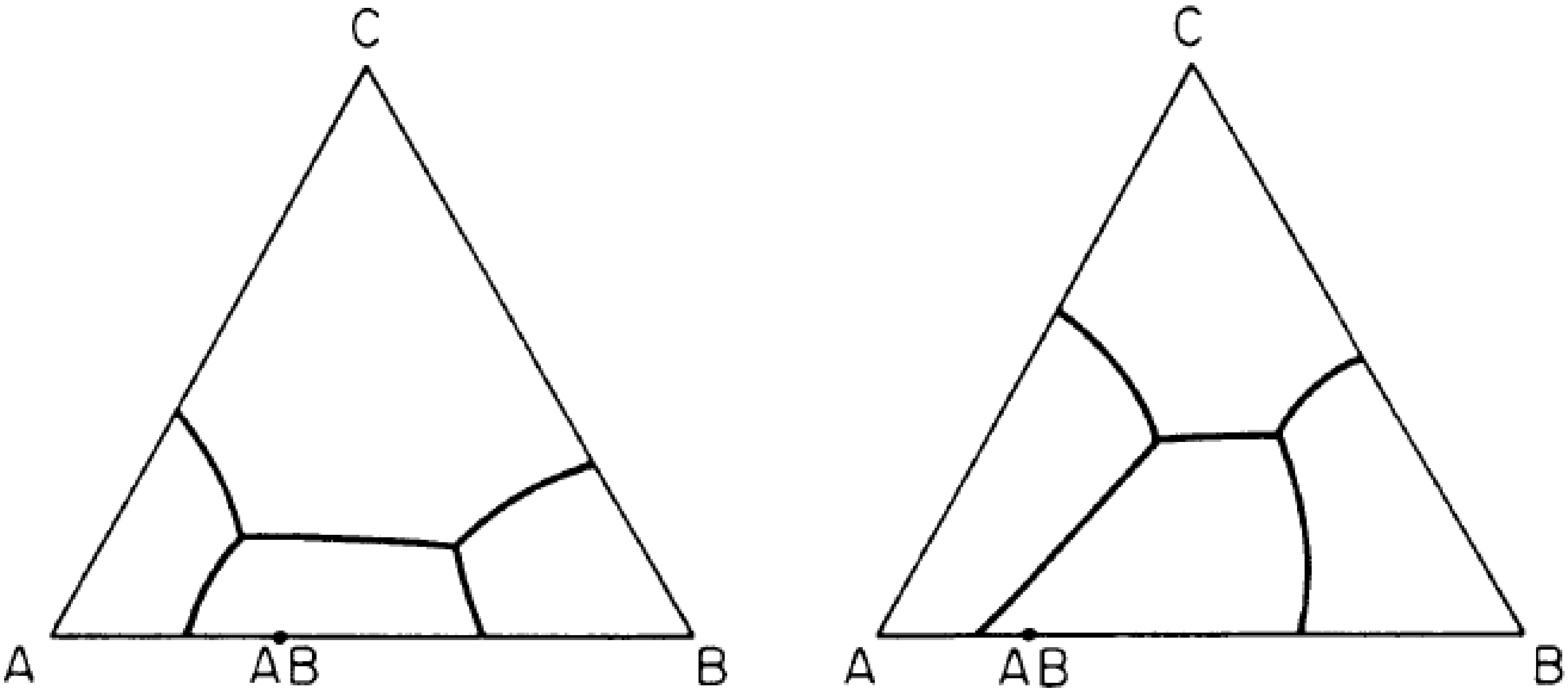

Ga
25°
29.5°
1238°
GaAs
Zn
810°
E1
e1
E2
e2
E3
e3
E4
Zn3As2
ZnAs2
419°
As
760°
723°
771°
1015°


As
800°
E2
900°
20
e5,723°
80
ZnAs2
e3(max)
E1
40
e4,750°
60
GaAs
1000°
1200°
Zn3As2 60
e1(max)
1100°
40
1000°
80
900°
20
800°
e6,651°
700°
E4
e7,419°
e8,29.8°
Zn
U2
20
U1
40
60
80
e9,24.7°
Ga

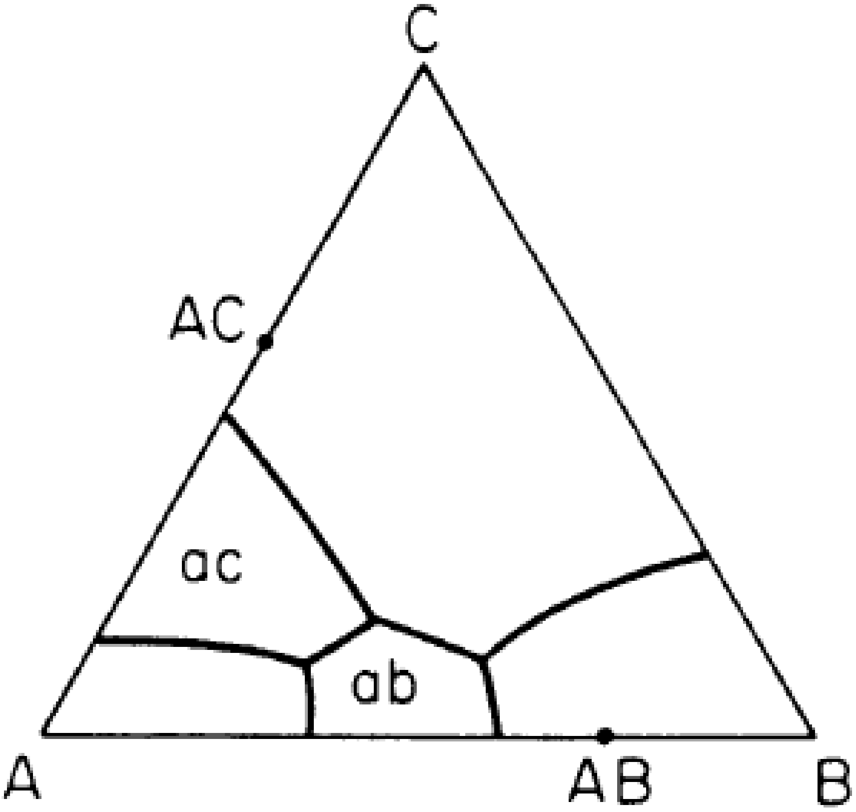


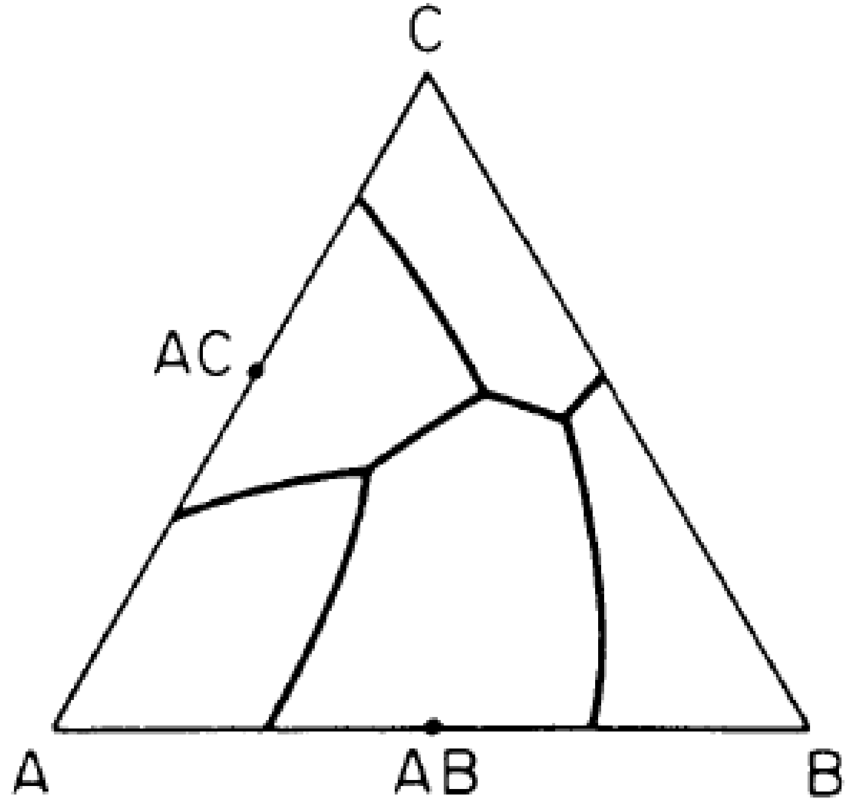
NiO
T=1300°C
La2NiO4
Spinel (NiGa2O4)
LaNiGa11O19
LaO1.5
GaO1.5
La4Ga2O9
LaGaO3 (LGR)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
H2
A
C
O2
LGR
1000°C

For the given figures:
Label primary phase fields.
Construct Alkemade lines.



For the given figures:
Label primary phase fields.
Construct Alkemade lines.

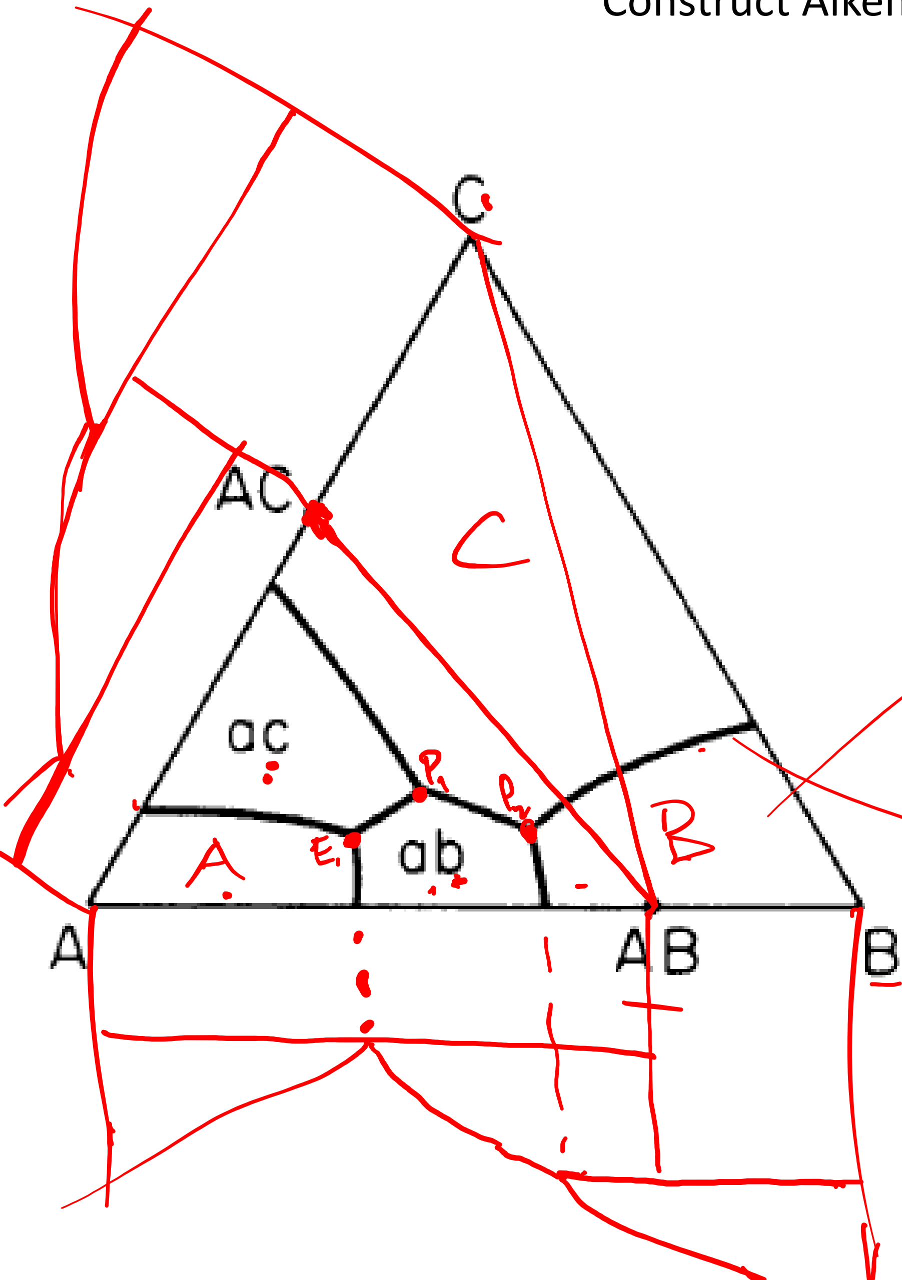


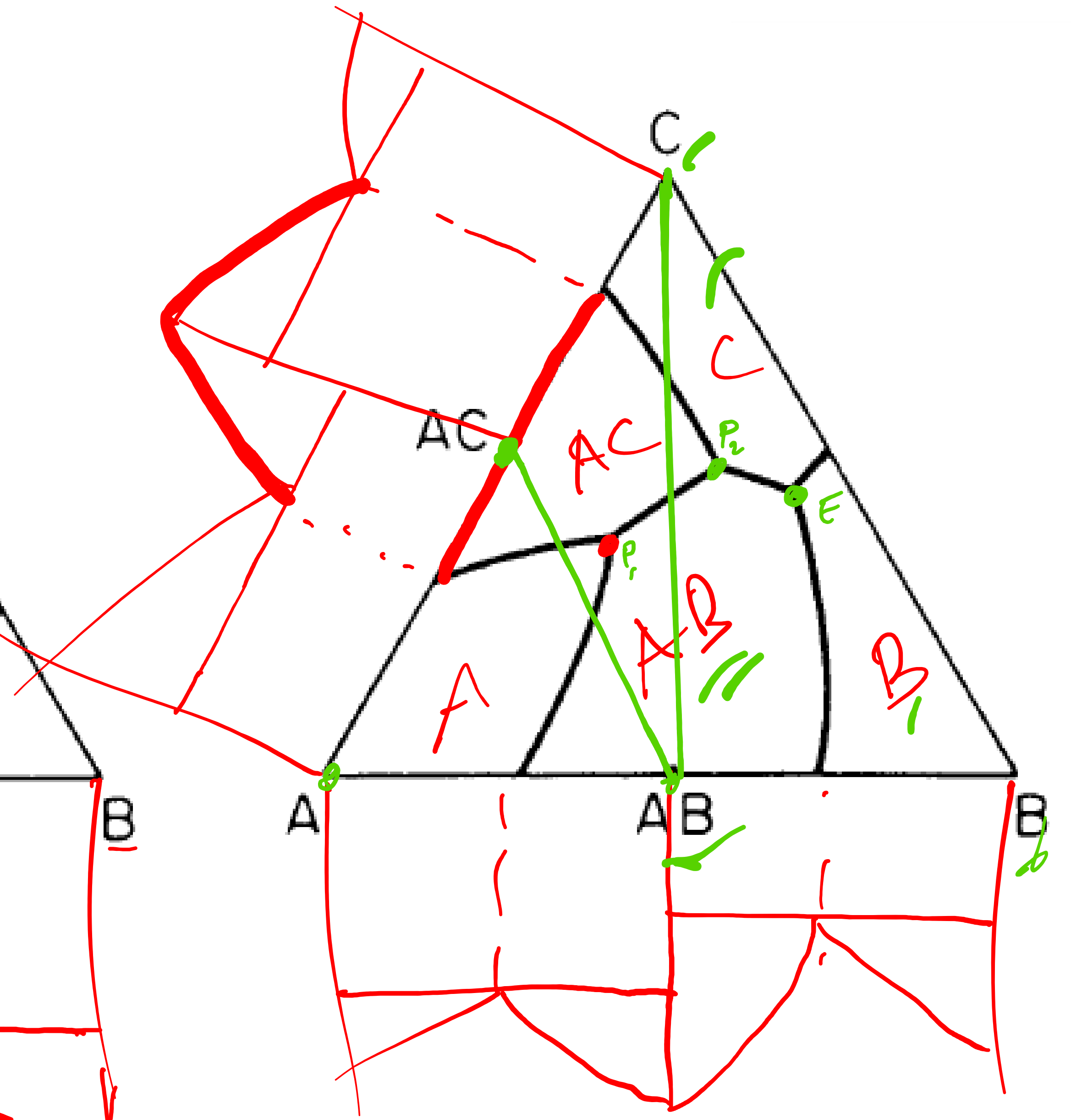


For the given figures:

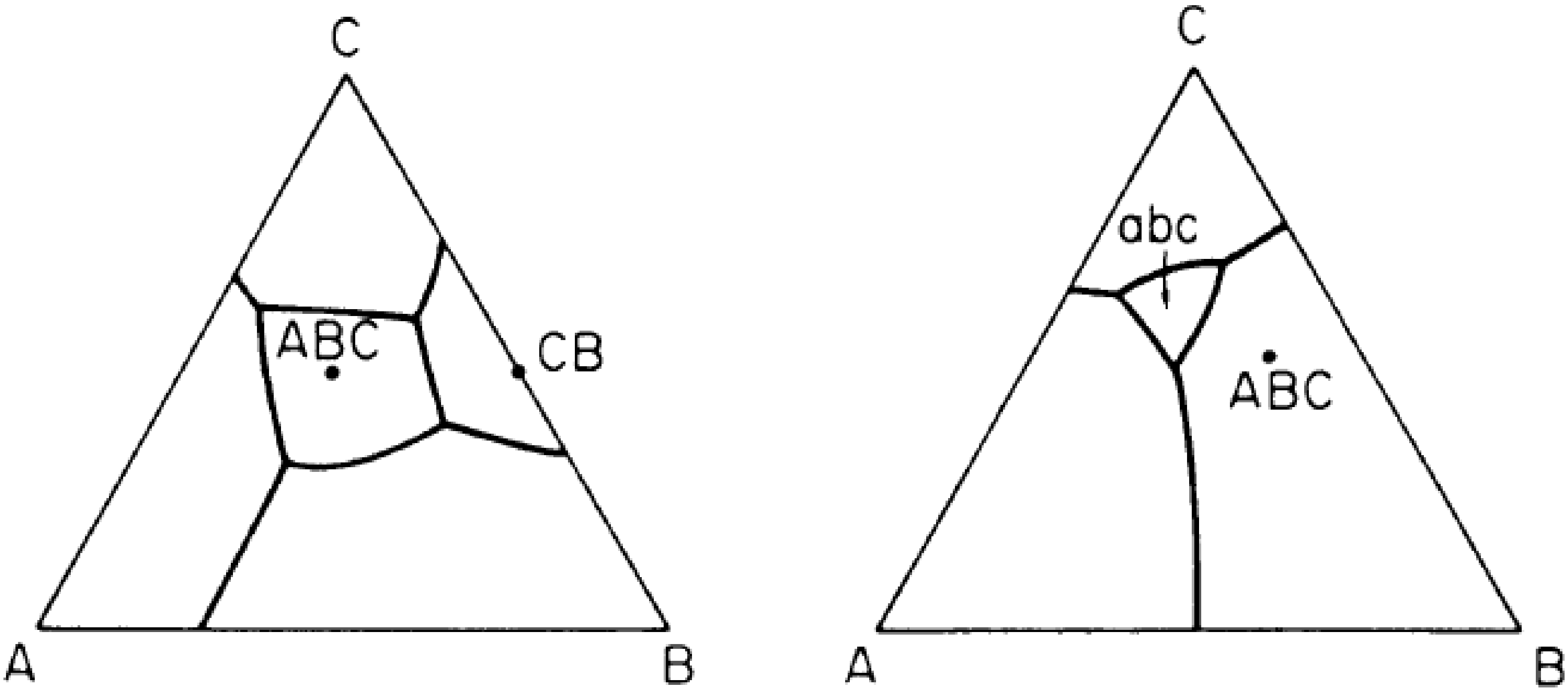
Label primary phase fields.

Construct Alkemade lines.

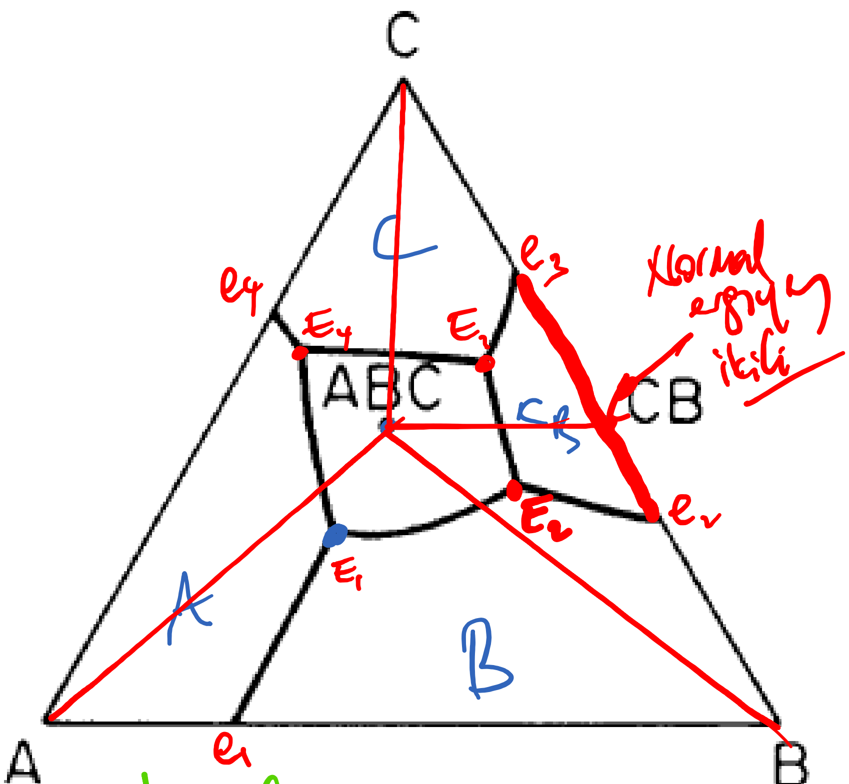


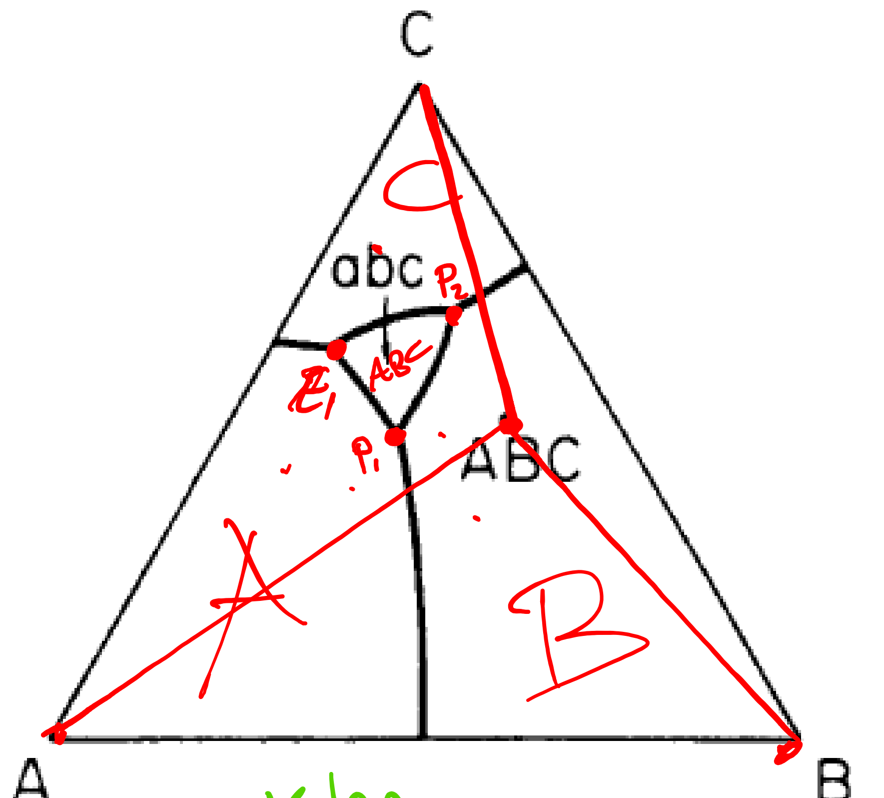


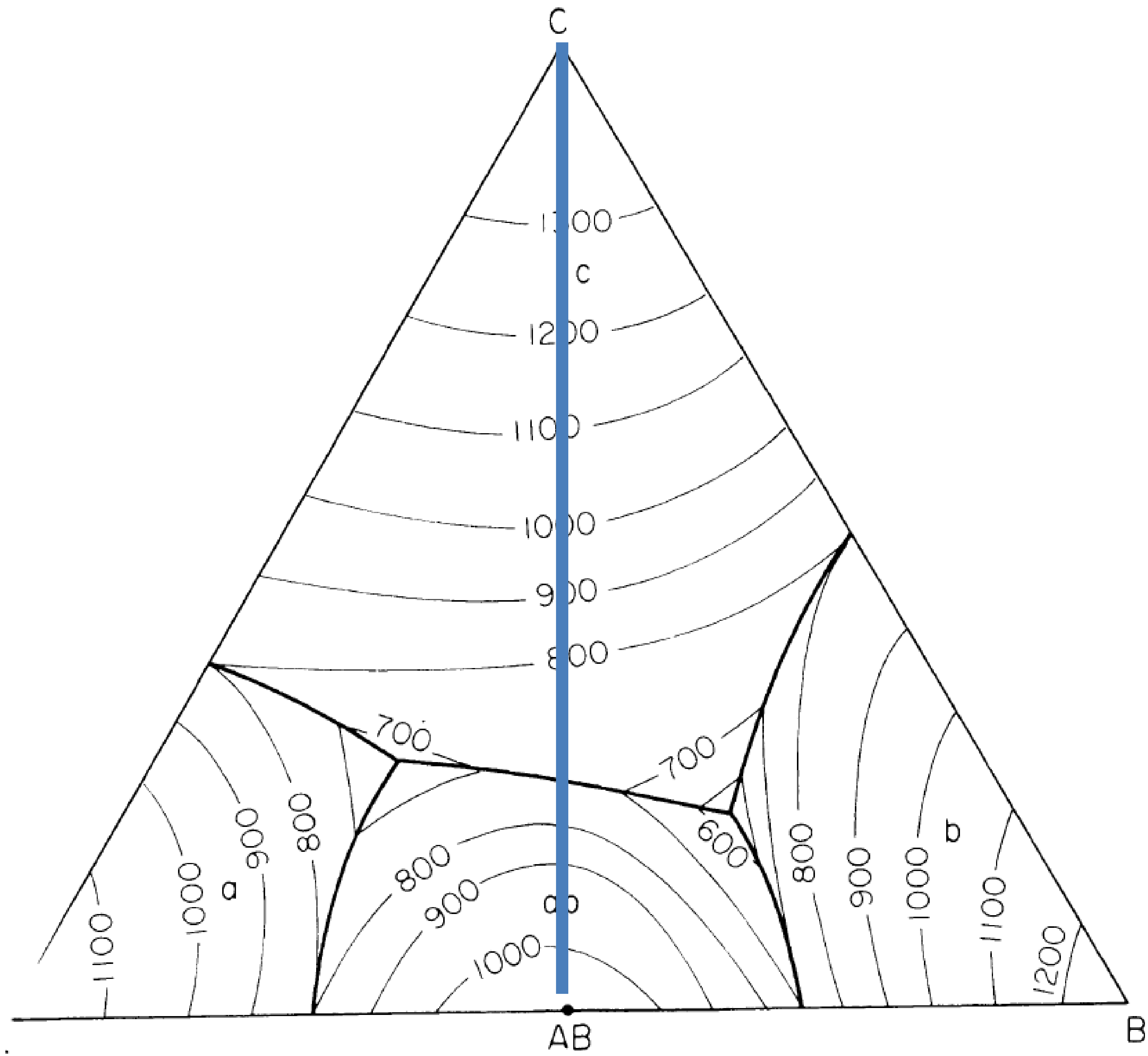
For the given figures:
Label primary phase fields.
Construct Alkemade lines.



For the given figures:
Label primary phase fields.
Construct Alkemade lines.



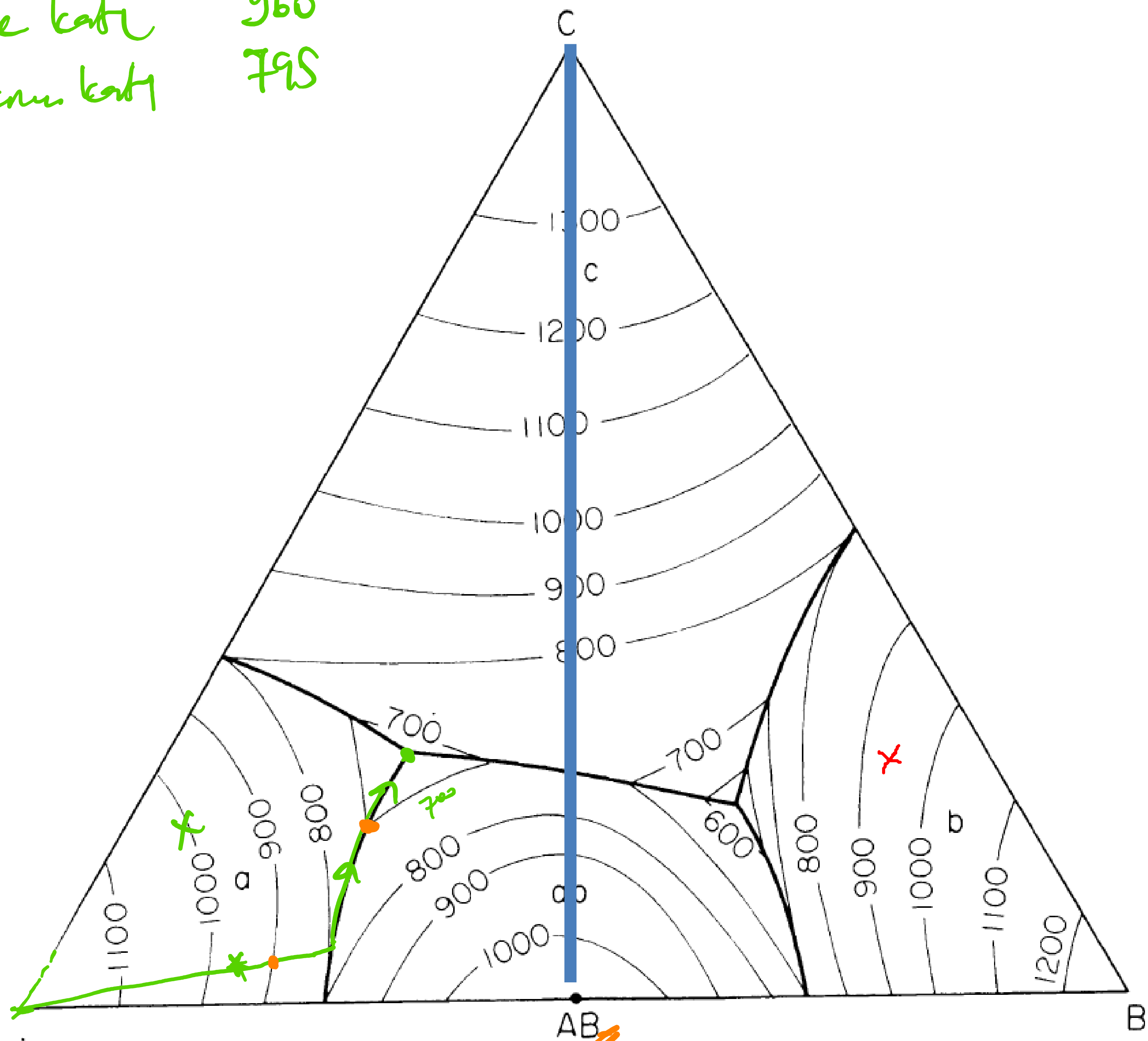


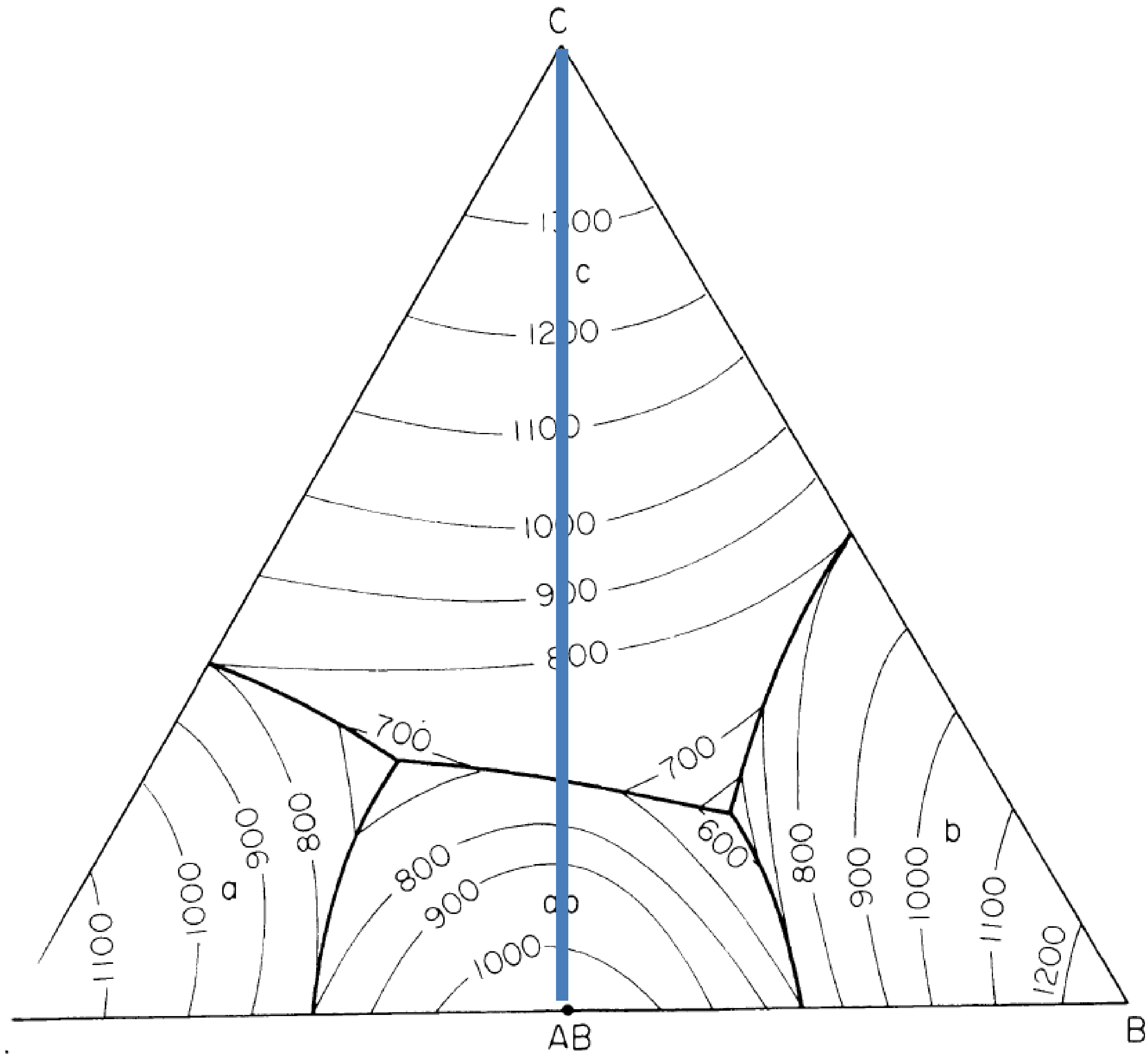


C
1300
c
1200
1100
1000
900
800
700
700
600
a
1100
1000
900
800
800
900
1000
ab
b
800
900
1000
1100
1200
AB
B

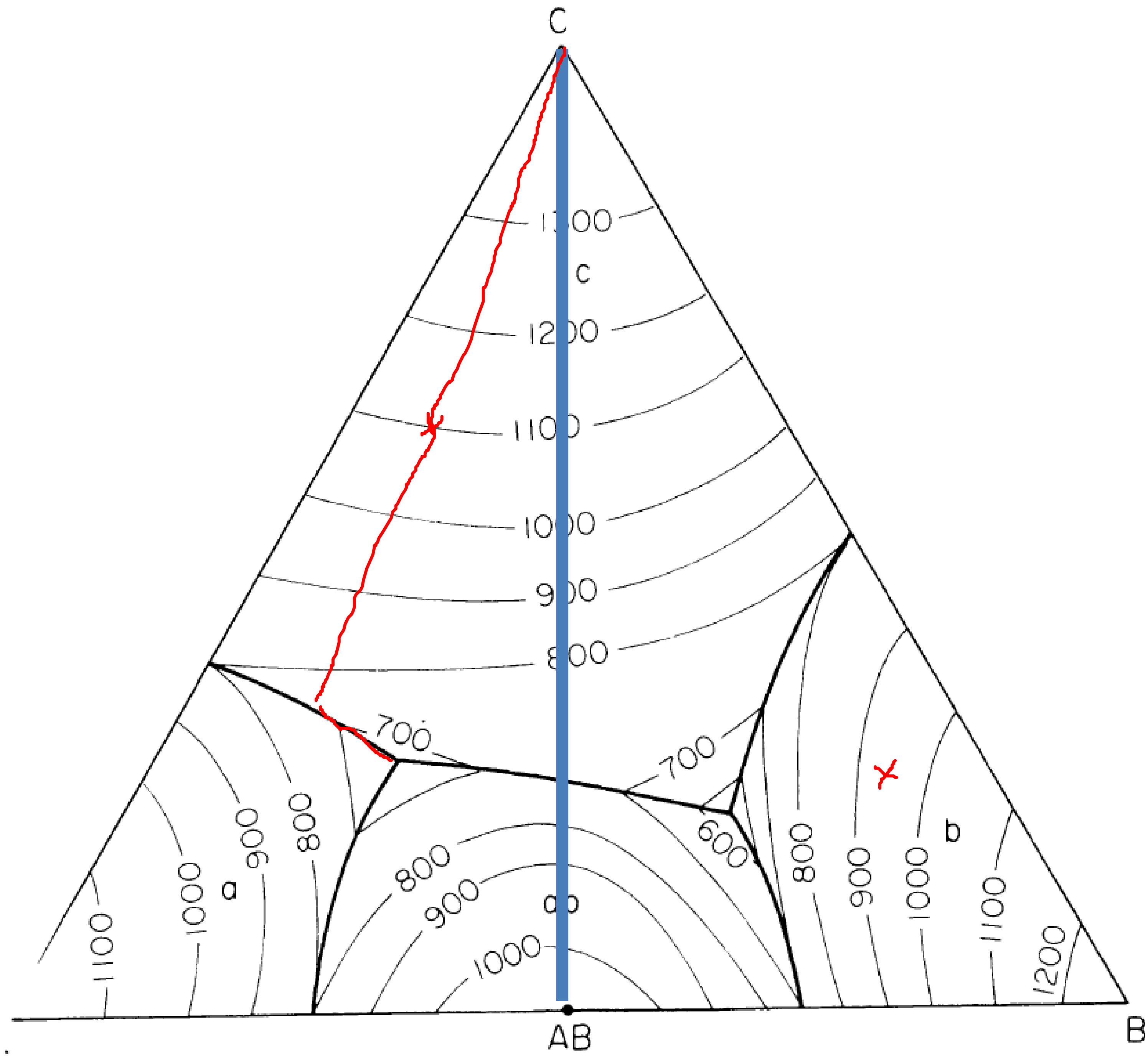
A ilk katı 960

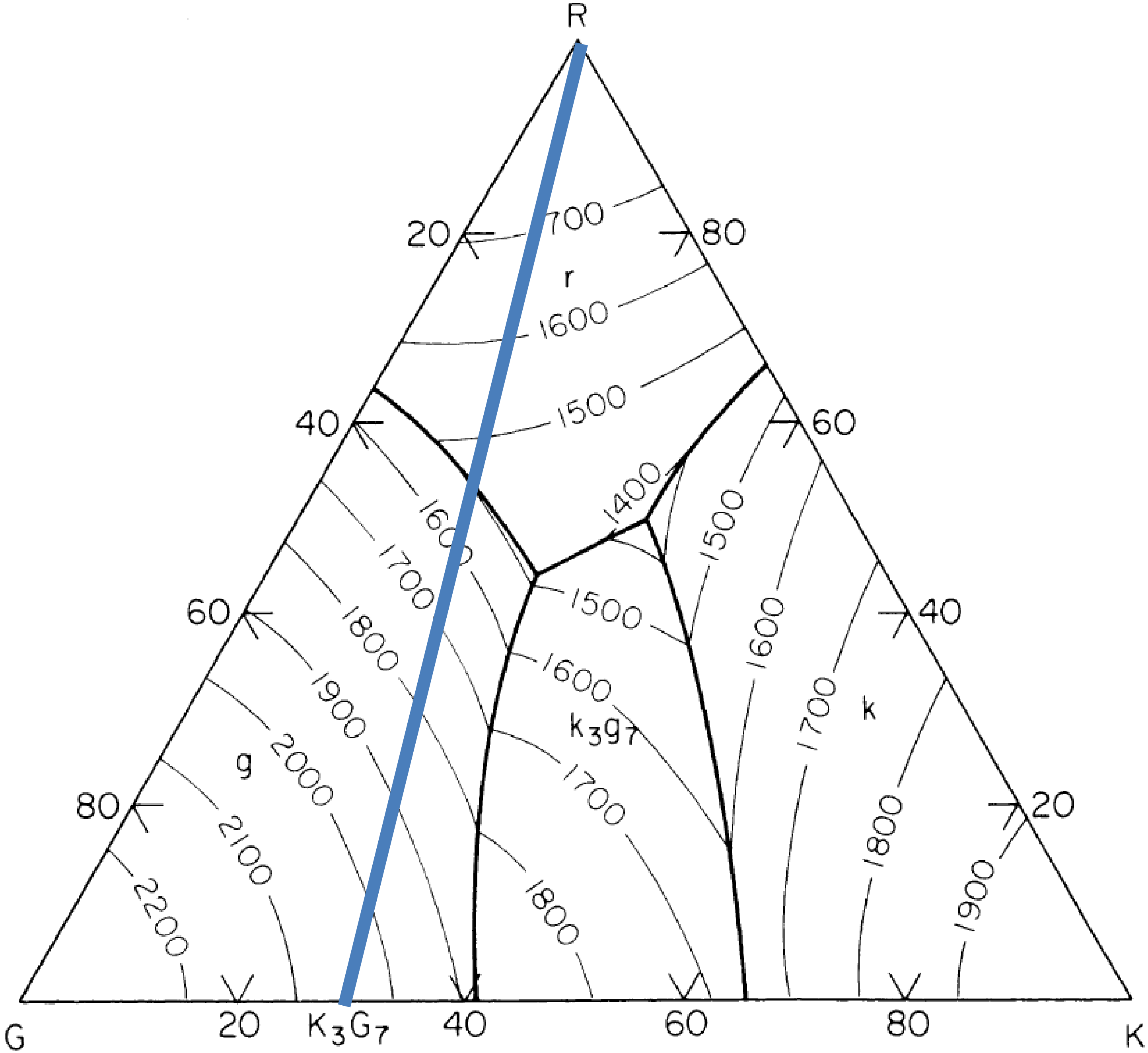
AB ikinci katı 795

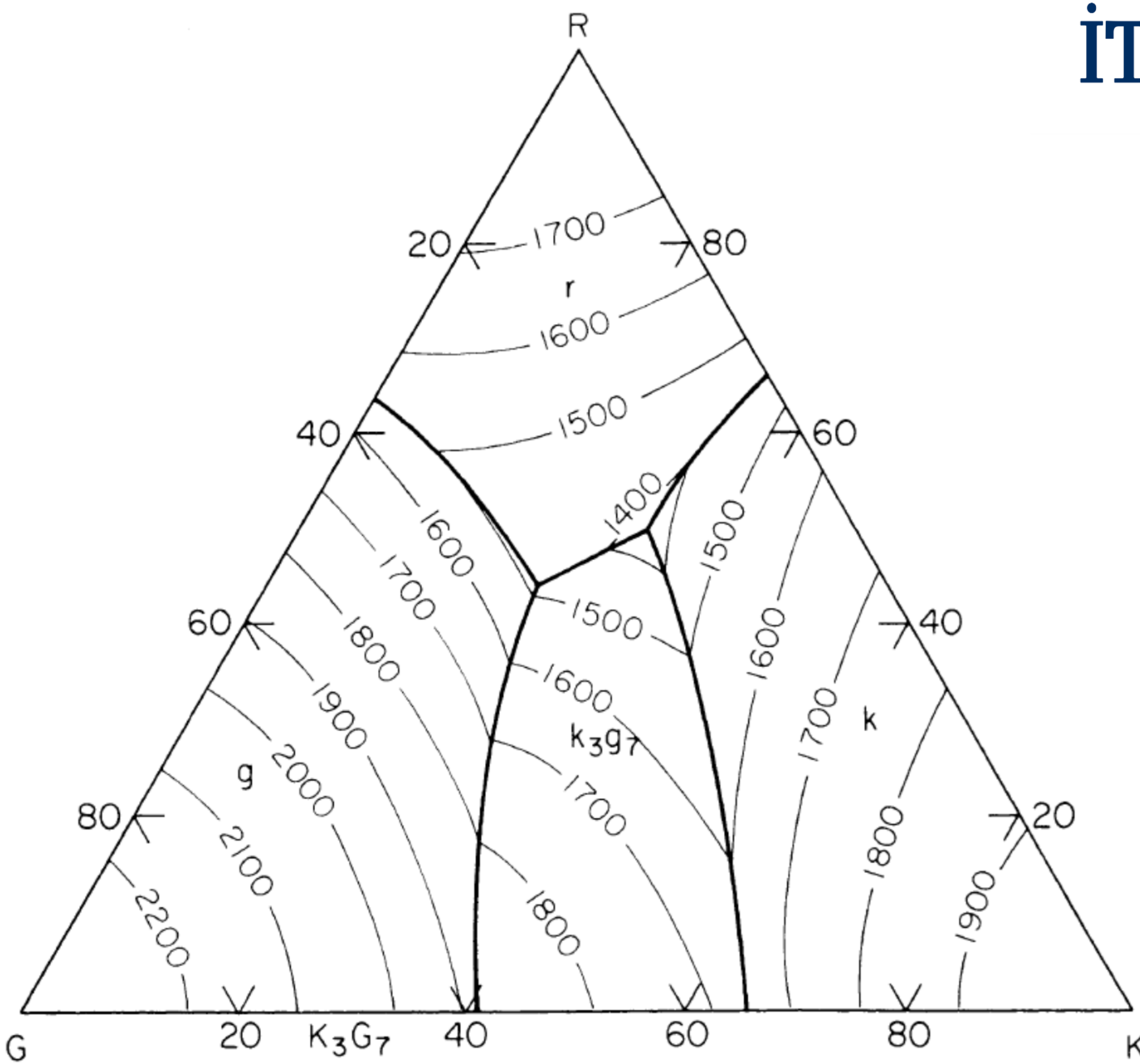




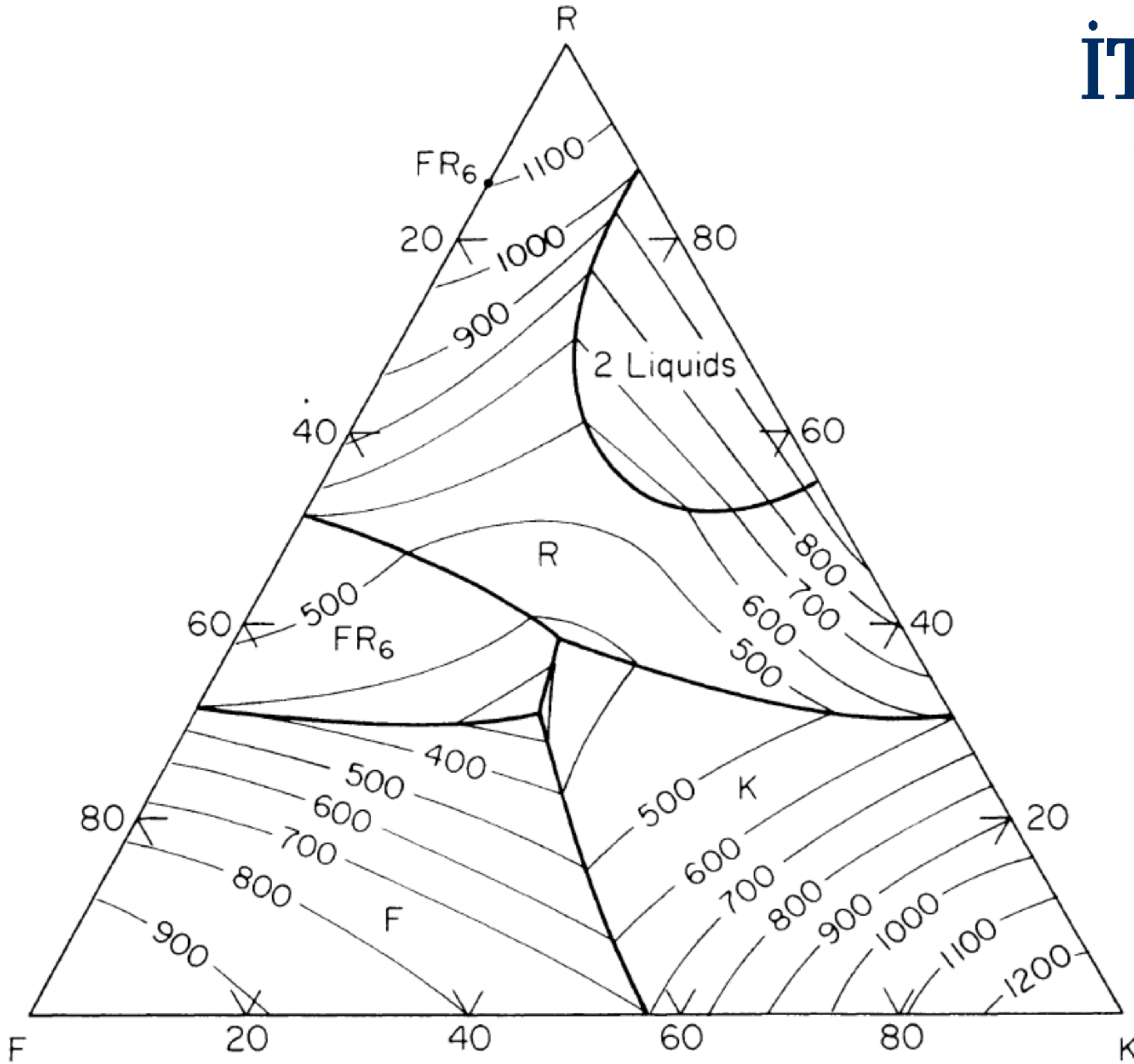
C
1300
c
1200
1100
1000
900
800
700
700
600
800
900
1000
1100
1200
b
800
900
1000
1100
a
800
900
1000
ab
AB
B

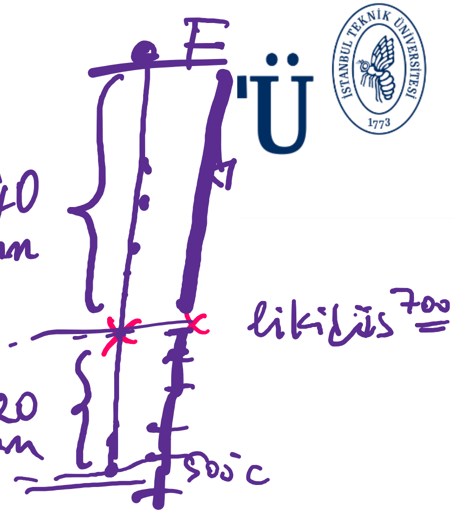

C
1300
c
1200
1100
1000
900
800
700
700
600
800
900
1000
1100
1200
b
1100
1000
900
800
a
800
900
1000
ab
AB
B

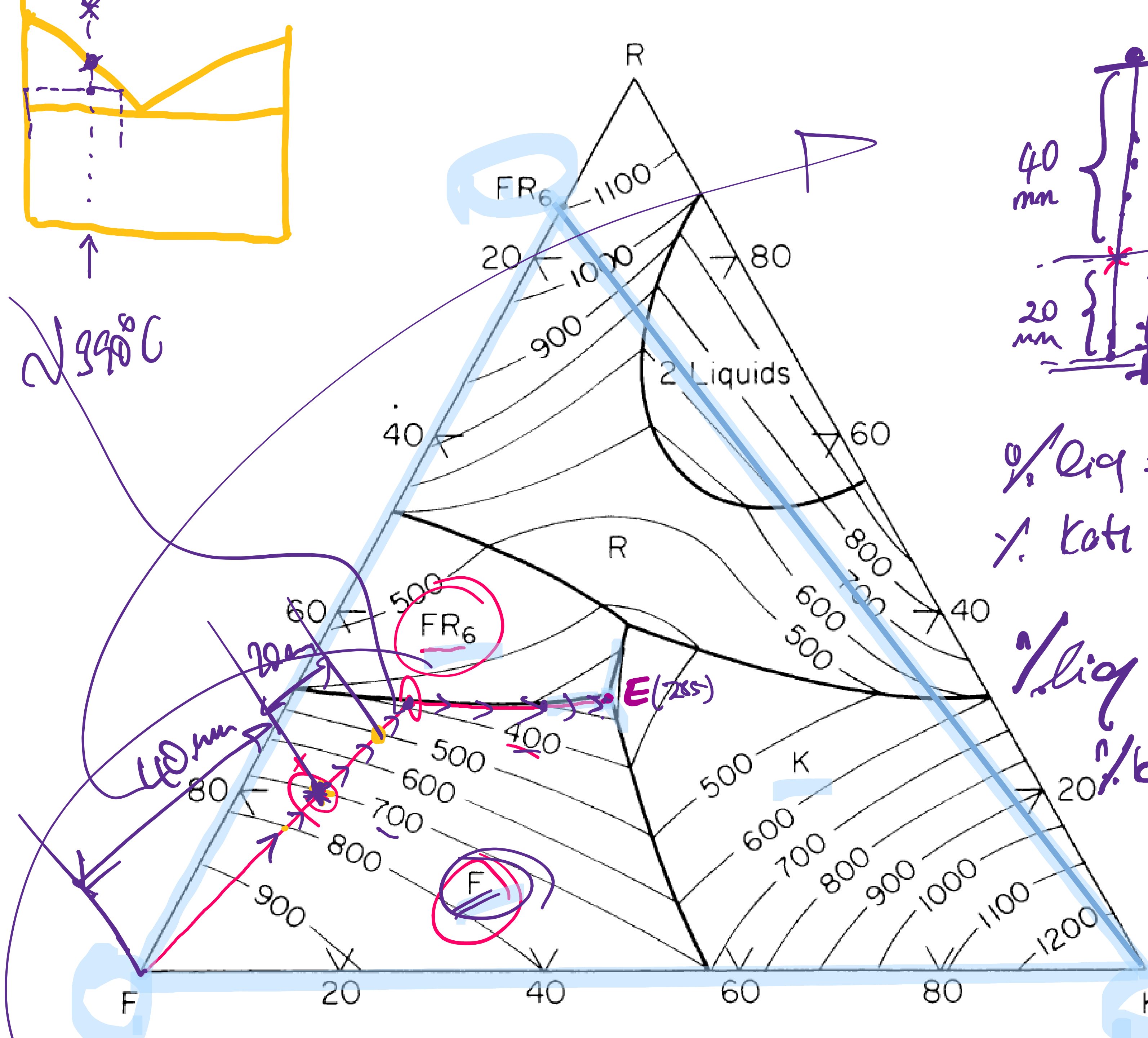

R
G
K
20
40
60
80
K_3G_7
r
g
k
k_3g_7
1700
1600
1500
1400
1800
1900
2000
2100
2200



R
G
K
20
40
60
80
r
g
k
k_3g_7
K_3G_7
1700
1600
1500
1400
1800
1900
2000
2100
2200


R
F
K
FR_6
2 Liquids
R
FR_6
K
F
1100
1000
900
800
700
600
500
400
1200
20
40
60
80



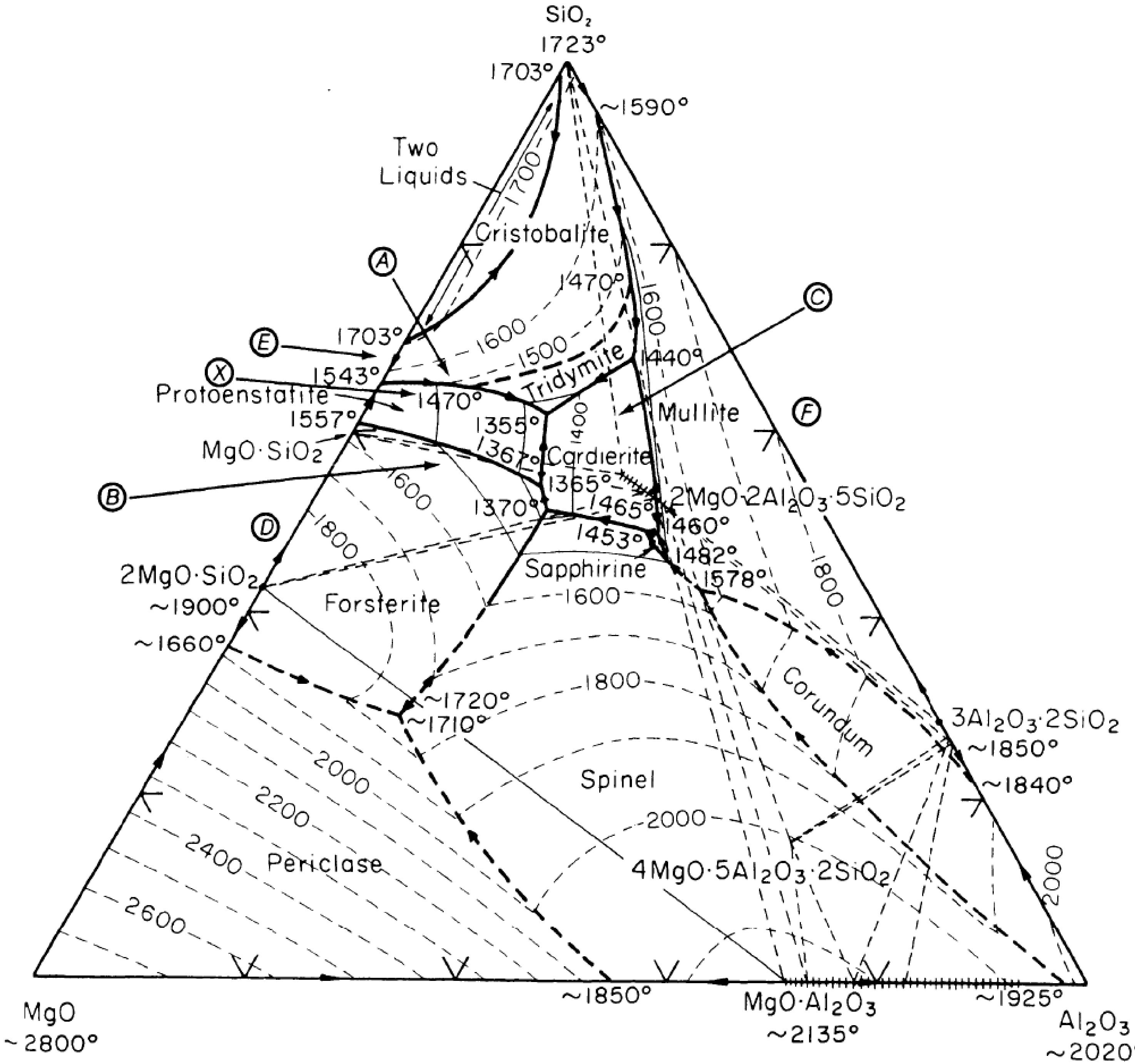


$\% \text{liq} = \frac{40}{40+20}$

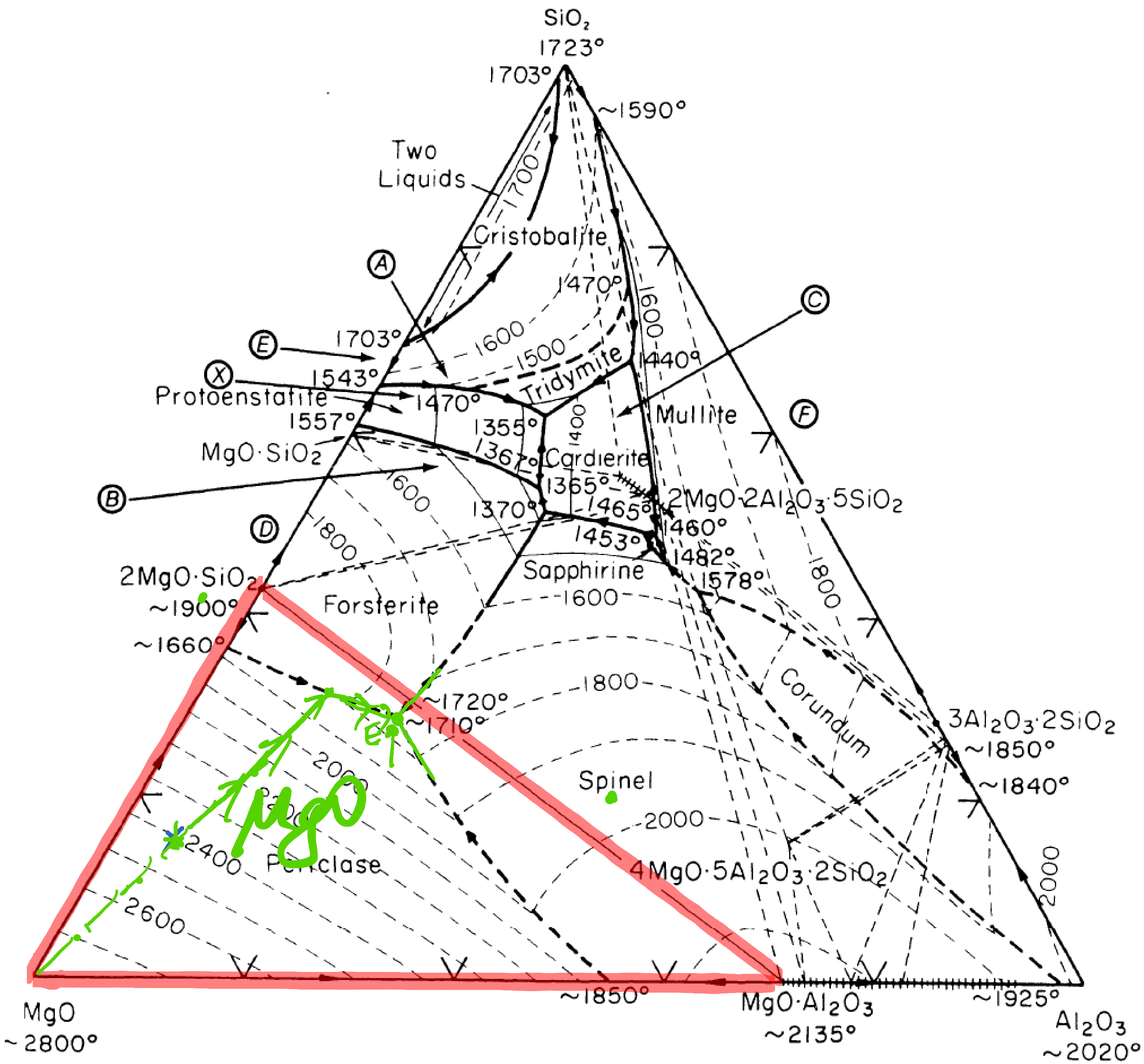
$\% \text{katı} = \frac{20}{40+20}$

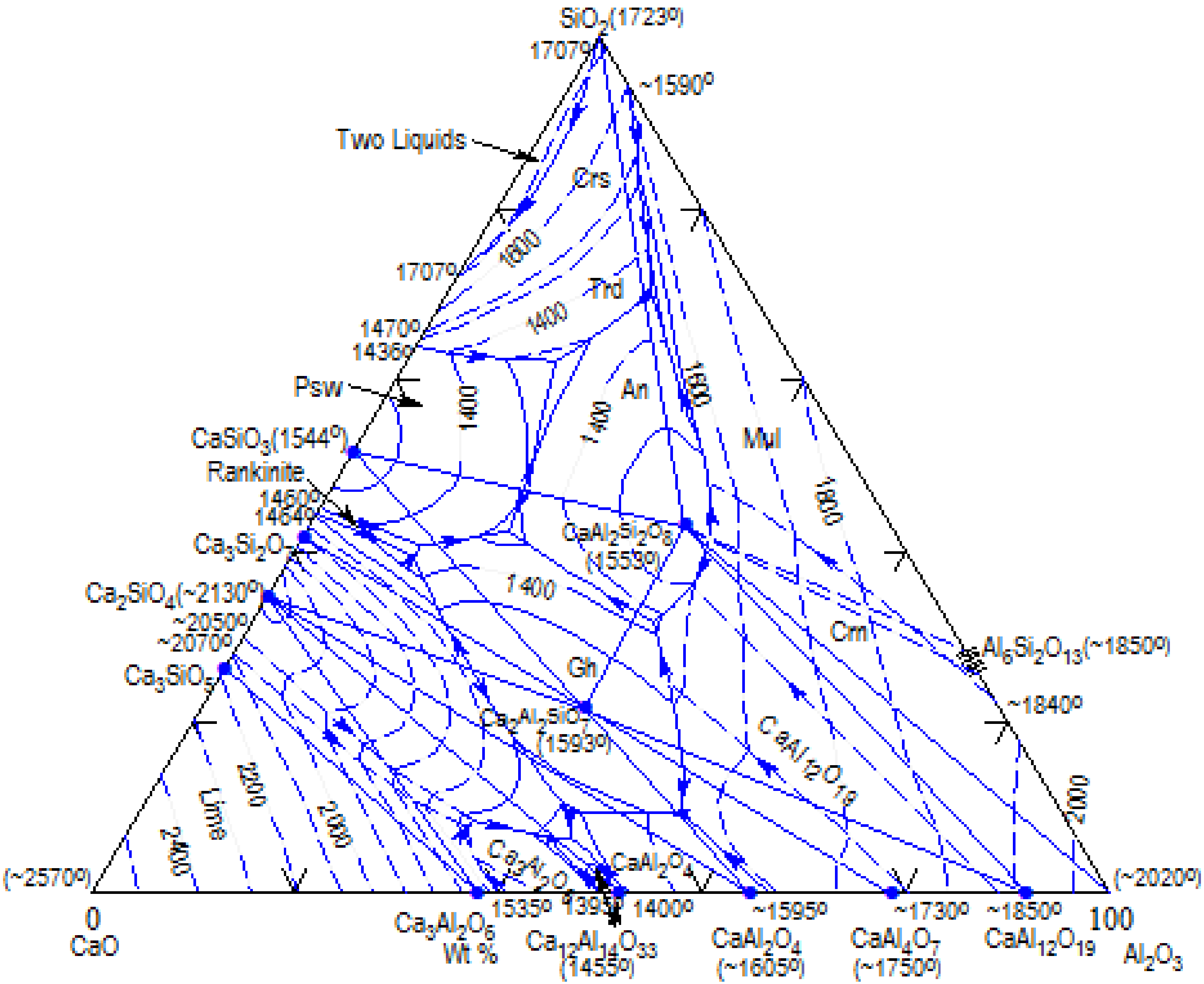
$\% \text{liq} \cong \% 66.6$

$\% \text{katı} \cong \% 33.4$



SiO_2
1723°
1703°
~1590°
Two Liquids
1700
Cristobalite
A
1470°
1600
1600
1500
C
E
1703°
Tridymite
1440°
X
1543°
Protoenstatite
1470°
Mullite
F
1557°
1355°
1400
$MgO \cdot SiO_2$
1367°
Cordierite
B
1600
1365°
$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$
D
1800
1370°
1465°
1460°
1453°
1482°
$2MgO \cdot SiO_2$
Sapphirine
1578°
~1900°
Forsterite
1600
1800
~1660°
1800
Corundum
~1720°
~1710°
$3Al_2O_3 \cdot 2SiO_2$
~1850°
2000
~1840°
Spinel
2200
2000
2400
Periclase
$4MgO \cdot 5Al_2O_3 \cdot 2SiO_2$
2000
2600
~1850°
~1925°
MgO
~2800°
$MgO \cdot Al_2O_3$
~2135°
Al_2O_3
~2020°


SiO2
1723°
1703°
~1590°
Two Liquids
1700
Cristobalite
1470°
1600
1500
Tridymite
1440°
1600
A
C
E
1703°
X
1543°
Protoenstatite
1470°
Mullite
F
1557°
1355°
1400
MgO·SiO2
1367°
Cardierite
B
1600
1365°
2MgO·2Al2O3·5SiO2
1370°
1465°
D
1800
1460°
1453°
1482°
1578°
2MgO·SiO2
~1900°
Sapphirine
1600
1800
Forsterite
~1660°
1800
Corundum
~1720°
~1710°
3Al2O3·2SiO2
~1850°
~1840°
2000
Spinel
MgO
2000
2400
Periclase
4MgO·5Al2O3·2SiO2
2600
2000
~1850°
MgO·Al2O3
~2135°
~1925°
MgO
~2800°
Al2O3
~2020°



$Ca_{12}Al_{14}O_{33}$