of Pharmacy

The Hashemite University
Faculty of Pharmaceutical Science

Physical Pharmacy I
Phase equilibria and the phase rule

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The Phase

one phase — لما احكي عن *

single component

solution* one phase

suspension* 2 phase

liquid في liquid

miscible

- A phase is a homogenous physically-distinct portion of a system that is separated from other parts of the system by boundary surfaces.
- A system containing water and its vapor is a two-phase system. An equilibrium mixture of ice, liquid water, and water vapor is a three phase system.
- A phase may be gas, liquid or solid.

gas as readily mix → وبشكلها one homogenous phase *

The Phase

- A gas or a gaseous mixture is a single phase.
- Completely miscible liquids constitute a single phase.
- In an immiscible liquid system, each layer is counted as a separate phase.
- Every solid constitutes a single phase except when a solid solution is formed.
- A solid solution is considered as a single phase.
- Each polymorphic form constitutes a separate phase.

Co2 ـــ ice هوا الوحيد بنقدر نعمله Phase diagram وبنقدر نوصل عند الظروف بس بالمختبر

• نقطة الـ Triple : عندي ice وسائل و Boiling بنفس الوقت (الاتزان) ـــ هو مستحيل نوصل لها في النقطة للمي (في الوضع الطبيعي مستحيل نوصلها أبداً)

The Phase diagram

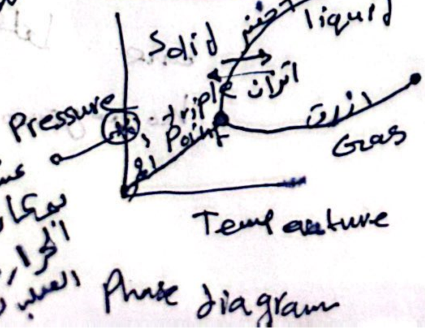
* Phase كل diagram بيختلف عن مادة للأخرى

- Phase diagram shows the multisystem state changes with the temperature, pressure, composition and other intensive properties.

قشال عليهم

Intensive properties are properties that do not depend on size; e.g. pressure, temperature, density, and concentration.

مايعتمدوا على size للمواد



Phase diagram

عندي بدرجة بمكان ما نرفع درجة الحرارة العلبة

solid $\rightleftarrows$ liquid (melting Point / Freezing Point)

بالنسبة للنقطة للمي هي اتزان

liquid $\rightleftarrows$ gas (Boiling Point)

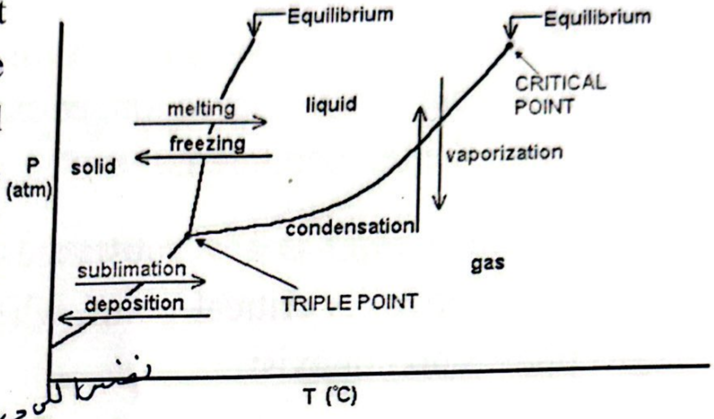
* Triple Point : أهم إشي تتوفر solid و gas وما بين سائل (liquid) ما صدق

دي لعززها ... solid gas

The Phase diagram: One component system

- The simplest phase diagrams are pressure-temperature diagrams of a single simple substance.
- The axes correspond to the pressure and temperature.
- The lines in the phase diagram represent two phase systems, while the spaces between the lines represent one phase systems.

➢The triple point represents the temperature and pressure where all three physical states are in equilibrium (for water 0.01 °C and 0.00603659 atm).

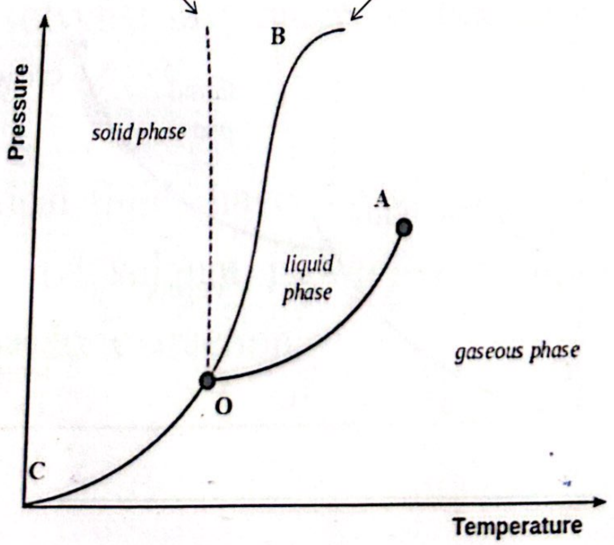


نفس الكلام
بس موضح

The Phase diagram: One component system

The frozen state of water (ice) is actually less dense than the liquid state. Therefore; increasing pressure (which favors compactness of the molecules) will favor the liquid state.

For most substances the solid is denser than the liquid. Therefore; an increase in pressure usually favors the more dense solid phase.



Curve OA: vapor pressure curve

Curve OB: Melting point curve

Curve OC: Sublimation curve

The Phase diagram: One component system

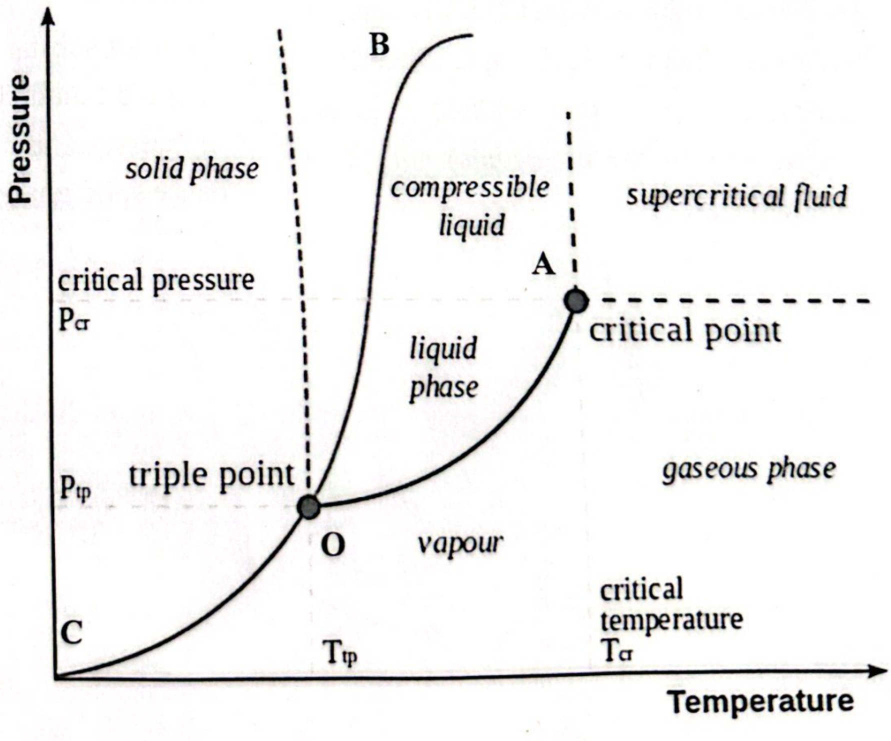
- The critical point is the point on a phase diagram that indicates the critical temperature and pressure.
- The critical temperature of a substance is the temperature above which that substance can no longer exist as a liquid, no matter how much the pressure is increased.
- In the same way, the critical pressure is the pressure above which the substance can no longer exist as a gas, no matter how high the temperature is.
- Supercritical fluid is any substance at a temperature and pressure above its critical point, where distinct liquid and gas phases do not exist.

The Phase diagram: One component system

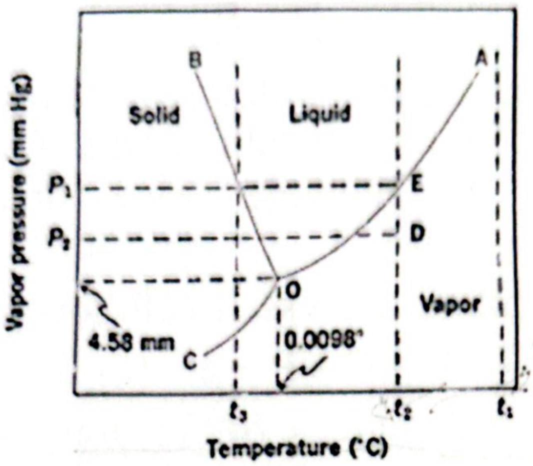
Curve OA: vapor pressure curve

Curve OB: Melting point curve

Curve OC: Sublimation curve



The Phase diagram: One component system



Phase diagram for water at moderate pressure

The supercritical fluids

- In general terms, supercritical fluids have properties between those of a gas and a liquid.
- Supercritical fluids are suitable as a substitute for organic solvents in a range of industrial and laboratory processes.
- Supercritical fluids have the viscosity of a gas, but the densities and solvent power of a liquid, making SC fluids ideal for extraction.

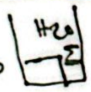
*The Gibbs phase rule

- To understand and define the state of a phase, knowledge of several independent variables is required.
- Independent variables (also called intensive variables) are the variables that do not depend on the volume or size of the phase, e.g. temperature, pressure, density, boiling point and concentration.
- The Gibbs phase rule is expressed as follows:

least number entensive variable اللي بنحتاجها define ال system أي state of matter

$$F = C - P + 2$$

- F: is the number of degrees of freedom of the system which is the least number of intensive variables required to define the system completely (vary independently).
- C: number of components, P: number of phases present



مكعب ثلج وفيه مي H2O بس المكون

2 Phase solid, liquid

liquid اللي بتبخر الإيثانول بتبخر

The Gibbs phase rule

كم phase بالسيستم؟ 2 component 2 phase ← لأنه الغازز والliquid Miscible أما لو بدل الإيثانول نحط organic solvent بيكون 3 Phase

- What is the number of components in the following systems?
- **Mixture of ice, liquid water, and water vapor**
  - **One** because the composition of all three phases is described by the chemical formula **H2O**.
- **Three-phase system CaCO3**
  - **Two,** the composition of each phase can be expressed by a combination of any two of the chemical species present.

    CaO + CO2
- What is the number of phases in the following systems?
- **Liquid water, liquid ethyl alcohol, water vapor , and ethyl alcohol vapor**
  - **Two** , because gases are always miscible in all proportions. Moreover, water and ethyl alcohol are completely miscible.

Application of phase rule to one component system

TABLE 2-7
APPLICATION OF THE PHASE RULE TO SINGLE-COMPONENT SYSTEMS*

System	Number of Phases	Degrees of Freedom	Comments
Gas, liquid, or solid	1	$F = C - P + 2$ $= 1 - 1 + 2 = 2$	System is *bivariant* ($F = 2$) and lies anywhere within the area marked vapor, liquid, or solid in Figure 2–22. We must fix two variables, e.g., P_2 and t_2, to define system D.
Gas–liquid, liquid–solid, or gas–solid	2	$F = C - P + 2$ $= 1 - 2 + 2 = 1$	System is *univariant* ($F = 1$) and lies anywhere along a *line* between two-phase regions, i.e., AO, BO, or CO in Figure 2–22. We must fix one variable, e.g., either P_1 or t_2, to define system E.
Gas–liquid–solid	3	$F = C - P + 2$ $= 1 - 3 + 2 = 0$	System is *invariant* ($F = 0$) and can lie only at the *point* of intersection of the lines bounding the three-phase regions, i.e., point O in Figure 2–22.

*Key: C = number of components; P = number of phases.

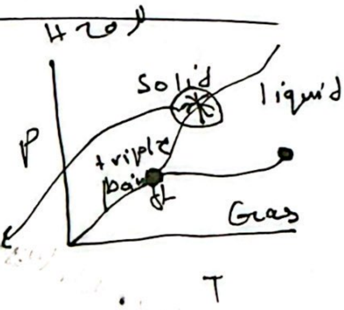
Systems

- Bivariant
- Univariant
- Invariant

$F = C - P + 2$

$F = 1 - 1 + 2$

$F = 2$



*المكان الوحيد اللي فيه الـ 3 component هو

F = 0 zero نقطة triple Bond

لما أوصل عند خط الـ phase = 2 فيصير كم مكون.

$F = 1 - 2 + 2$ phase

$\boxed{F = 1}$

Two component system containing liquid phases

نوعين phase diagram

- Systems in which the vapor phase is ignored and only solid and liquid phases are considered are termed condensed systems.

- Systems containing liquids might be:

1. Completely immiscible (such as mercury and water)
2. Completely miscible in all proportions (e.g. ethanol and water)
3. Partially miscible (e.g. phenol and water)

Two component system containing liquid phases

For two component systems:

$C=2 \qquad F = C - P + 2 \;\Rightarrow\; F = 4 - P$

$P \geq 1 \Rightarrow F \leq 3$

Three variables are required: temperature (1), pressure (2), and composition (3)

If the pressure is fixed, only temperature and composition are required.

* Applications → Partail miscibility

water rich layer

* لو كان مكتوب ال system compressed هيبقى ثلاثة

Two component system containing liquid phases

A
B
Phenol

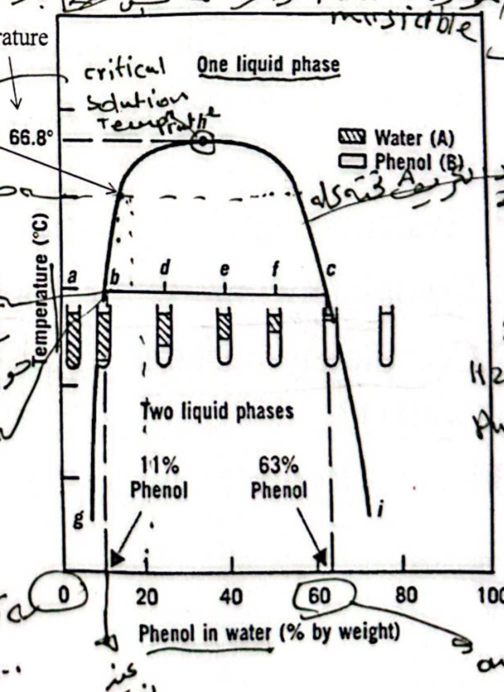
Partial miscible

Upper consolute temperature = critical solution temperature

Phenolic rich layer

critical solution Temperature

Binodal curve



one phase

2phase

Phase diagrams for two component systems are commonly constructed with temperature and composition as the coordinates.

one phase

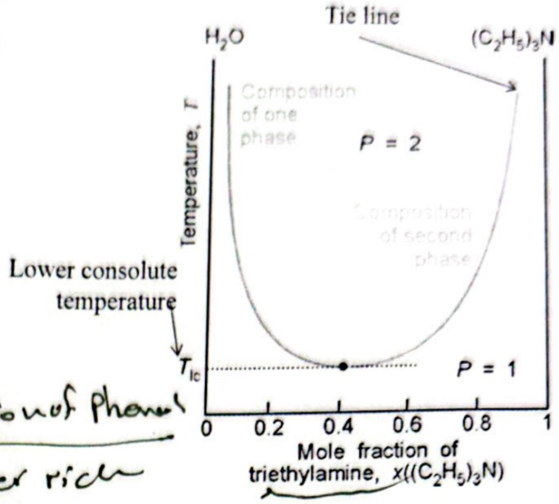
one phase

Phase seperation

ورا الفينول لازم نسخن لنحصل one phase
أو ما الtriethyl amine لازم نبرد " " " "

Two component system containing liquid phases

Other liquid mixtures show no Upper Consolute Temperature but lower Consolute Temperature.



b 11%
Concentration of Phenol in water rich Phase

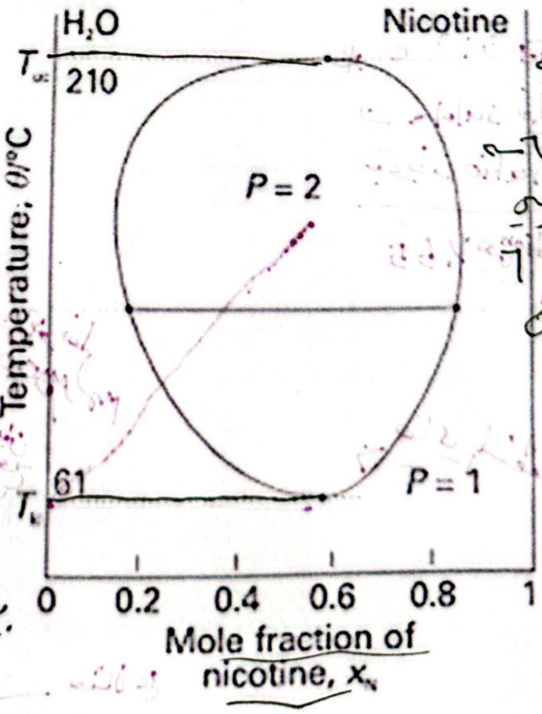
A H_2O

B Phenol → 63% c
% of Phenol in Phenlic layer

Two component system containing liquid phases

upper) عند one phase

Other liquid mixtures show both upper and Lower Consolute Temperatures.



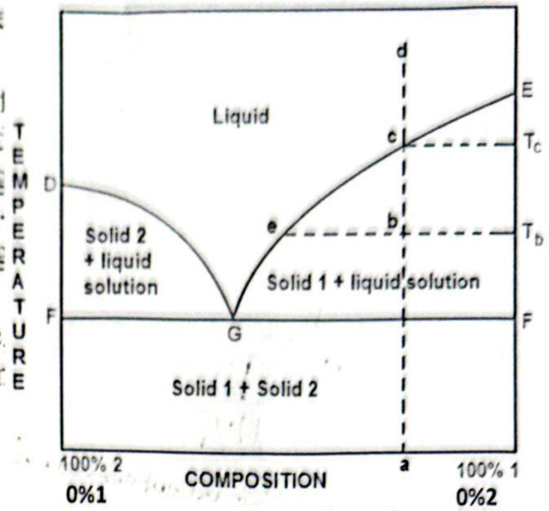
نفس درجة الحرارة 61 نفس lower
أقل من 61 one phase

Concen variable هو الثاني

بين lower و upper بيكون phase من تعدد

Two component system containing solid and liquid phases

- The points of **D** and **E** represent the melting points of **solids 2 and 1**.
- Two component system consisting of two solids **(2 and 1)** when heated to a temperature above the melting points of both **(point d)**, a one-phase system will form consisting of a liquid solution of **2 and 1**.
- When the temperature fall to point c, pure solid 1 will form dispersed in a liquid solution of 1 and 2.



لو بدنا ratio لـ a.b ← 100−60

$\frac{100-60}{60-55} = \frac{40}{5} = \boxed{\frac{8}{1}\ \text{a.b ratio}}$

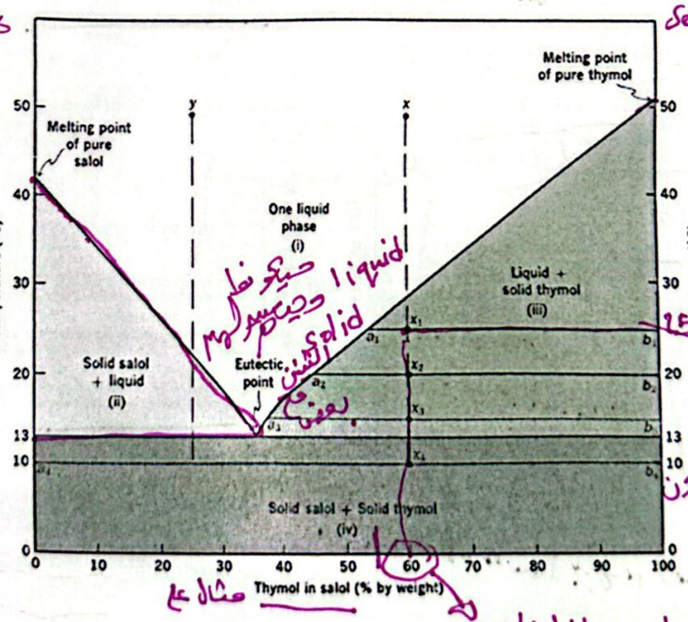
liquid موجود بـ ٦٠٪ باستعمال a₁

Two component system containing solid and liquid phases

* هاد الشكل تقسم إلى ٤ مناطق: بحين ينفصلوا بين solid و liquid —

* عشان نحدد ال thymol و salol في liquid بنوخذ ratio بين A₁ و B₁

composition هي ٥٥٪ لل liquid



هاي المنطقة كلها salol

لما يكون الـ concentration لـ salol أكبر الجزء اللي مشاركة

هون بس يكون thymol solid salol liquid

مثال ع

w/w thymol

Phase diagram for the thymol–salol system showing the eutectic point.

لو سمينا درجة الحرارة عنده x₁ وعند ٦٠٪ w/w

Scanned with CamScanner

- Suppose we prepare a system containing 60% by weight of thymol in salol and raise the temperature of the mixture to 50◦C.
- Such a system is represented by point x.
- On cooling the system, we observe the following sequence of phase changes. The system remains as a single liquid until the temperature falls to 29◦C, at which point a minute amount of solid thymol separates out to form a two-phase solid–liquid system.
- At 25◦C (room temperature), system x (denoted in as x1) is composed of a liquid phase, a1 (composition 53% thymol in salol), and pure solid thymol, b1.
- The weight ratio of a1 to b1 is (100 − 60)/(60 − 53) = 40/7, that is, a1:b1 = 5.71:1.
- When the temperature is reduced to 20◦C (point x2), the composition of the liquid phase is a2 (45% by weight of thymol in salol), whereas the solid phase is still pure thymol, b2. The phase ratio is a2:b2 = (100− 60)/(60− 45)=40/15= 2.67:1.

eutectic mixture → ال m.p أقل من الطبيعية .

Parecetamol ← 170C°

Propyphenazol ← 101C°

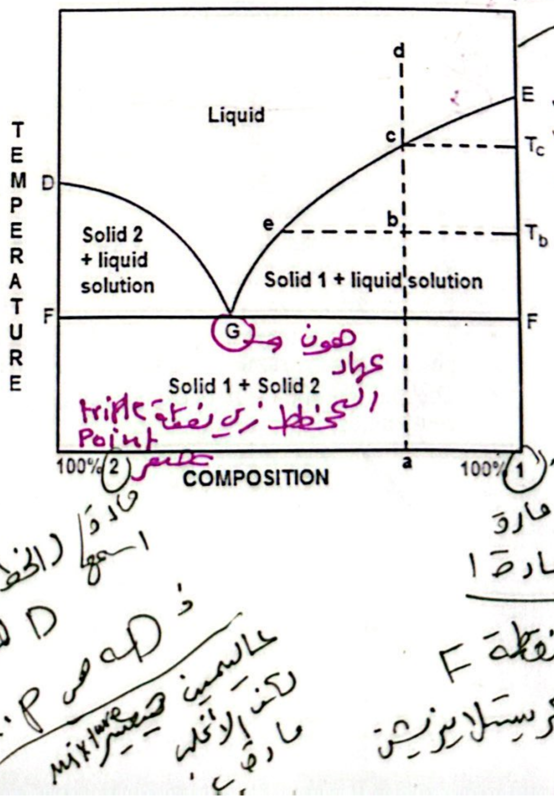
لما اجوا بدهم يكبسوه واجهت مشكلة ولاحظوا انه خلال عملية كبس الtablet بتحول melting و بصير powder

eutectic نقطة (G)

Two component system containing solid and liquid phases

G ← تحول مباشرة من سائل لصلب

- At point **G** solid **1**, solid **2** and solution phase are in mutual equilibrium (exist together).
- The solid phase at this point is a finely divided two-phase dispersion of crystalline 1 and 2 called a eutectic, and G is the eutectic point. Eutectic melts at a lower temperature than either of its pure components.



الخط عبارة عن فصل بين الحالات.

E نقطة m.p لمادة 1

عند النقطة F بصير كريستلايزيشن

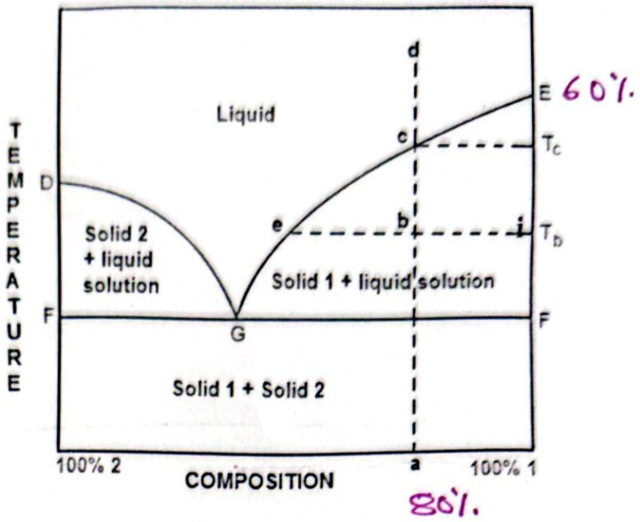
الخط الفاصل من D ل liquid تحول ل solid

m.p لمادة 2

mixture بصير مع السمين لكن الأكثر مادة

Example:
Suppose we prepare a mixture of containing 80% of 1 (point a) and the temperature was raised to point d.

- At point **c** solid 1 starts to separate out to form solid 1 phase and mixture liquid phase
- At point **b** the system is composed of liquid 1 in 2 (point **e** (60%) and pure solid 1 (**i**)
- The W ratio of **e** to **i** = (100-80)/ (80-60)
  - =20/20 = 1



Two component system containing solid and liquid phases

- Examples of such systems:
  1. – Salol–thymol
  2. – Salol–camphor
  3. – Acetaminophen–propyphenazone
- Importance of the phase diagram
  - Determine the composition at any temperature
- The intimacy of the mixture gives rise to the phenomenon of "contact melting," which results in the lowest melting temperature over a composition range.
- Below the eutectic no liquid phase exist
- The eutectic point therefore denotes an invariant system because, in a condensed system, F = 2 − 3 + 1 = 0.
- The eutectic point is the point at which the liquid and solid phases have the same composition (the eutectic composition)
- The melting of the eutectic composition is lower than that of any other mixture of the compounds.

Phase equilibria in three-component systems

For three component systems:

$C = 3 \quad F = C - P + 2 \Rightarrow F = 5 - P$

$\boxed{P \geq 1} \Rightarrow \boxed{F \leq 4} \rightarrow$ 3 لل component

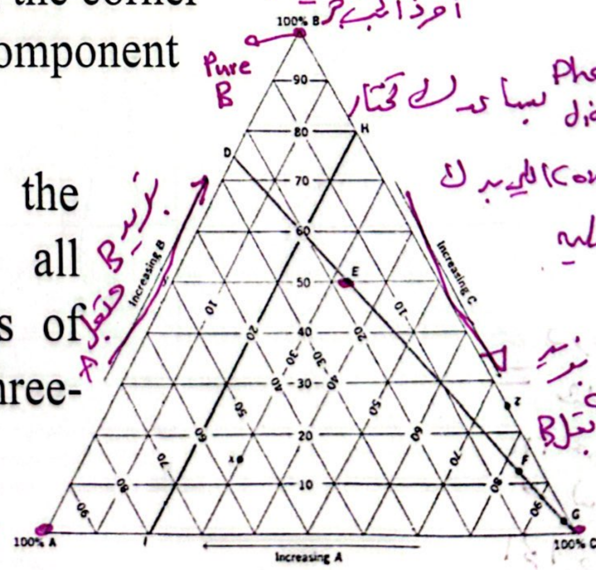
Four variables are required: temperature, pressure, and two compositions.

If the temperature and pressure are both fixed then, only two compositions are required

- ➤ Because we are dealing with a three-component system, it is more convenient to use triangular coordinate graphs

Rules relating to triangular diagram

- Each of the three corners represent 100% by weight of one component.
- The three lines joining the corner points represent two component mixture.
- The area within the triangle represent all possible combinations of A, B , and C to give three-component system



50% B E نقطة

17% A

33% C

Ternary systems with one pair of partially miscible liquids

تداخل جزئي الذوبان

- E.g. Water, benzene and ethanol mixture
- Water and benzene are partially miscible
- Ethanol is miscible with both water and benzene

زي A, B, C هي جاكانوا Completly misCible

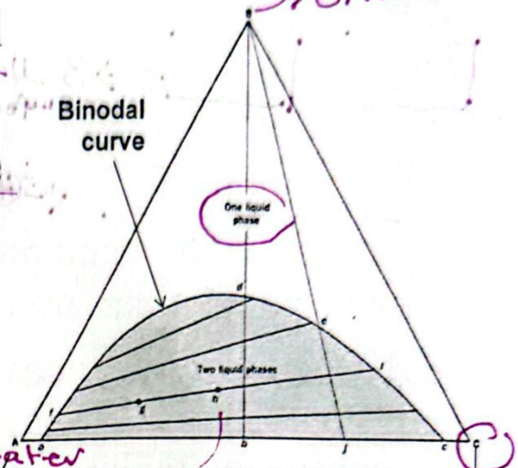


Fig. 2-28. A system of three liquids, one pair of which is partially miscible.

Partially miscible liquids

وبينها عند tow liquid phase

Ternary systems with one pair of partially miscible liquids

بدي ادرس تأثير الحرارة على Miscible

لو أعطيت energy للsystem

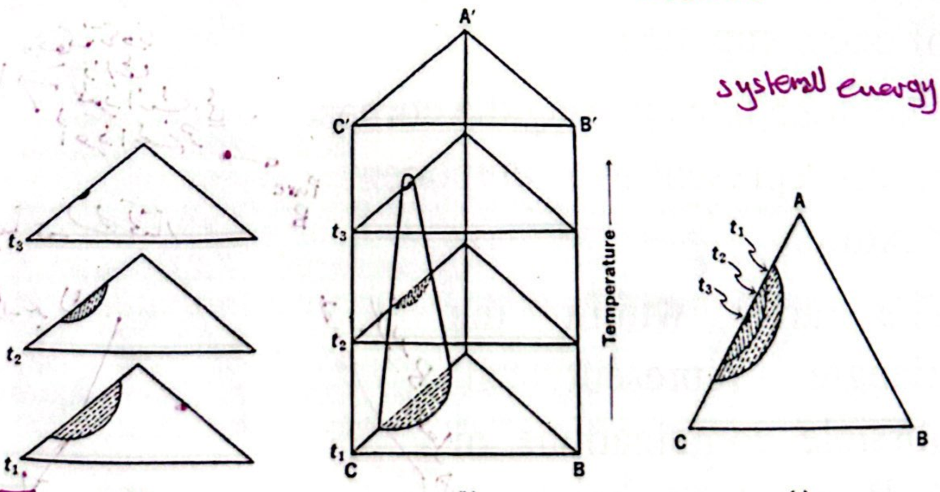


Fig. 2-29. Alterations of the binodal curves with changes in temperature. (a) Curves on the triangular diagrams at temperatures t_1, t_2, and t_3. (b) The three-dimensional arrangement of the diagrams in the order of increasing temperature. (c) The view one would obtain by looking down from the top of (b).

درجة الحرارة مثلاً ٢٠ عند t1 هون كانت أعلى منطقة ولو رفعت الحرارة ل ٣٥

تأثير زيادة الحرارة تقلل area under

Ternary systems with two or three pairs of partially miscible liquids

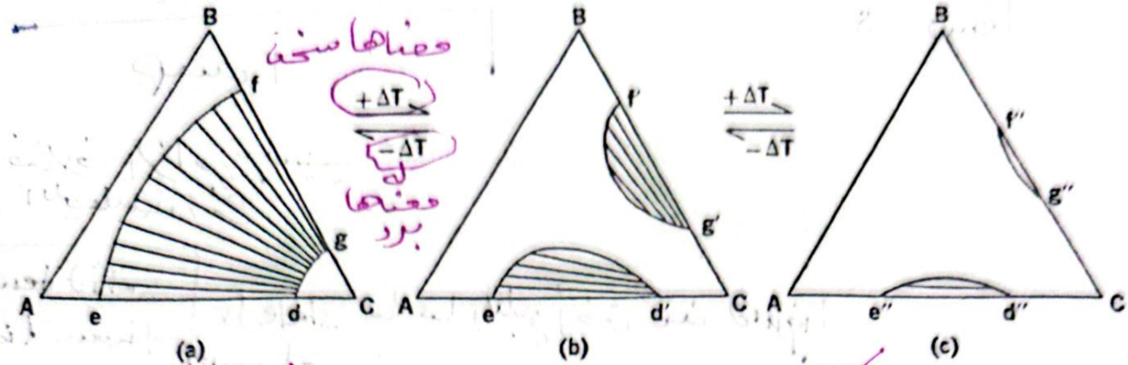


Fig. 2–30. Effect of temperature changes on the binodal curves representing a system of two pairs of partially miscible liquids.

Partially miscible

A & B miscible

A C, B C immiscible

Ternary systems with two or three pairs of partially miscible liquids

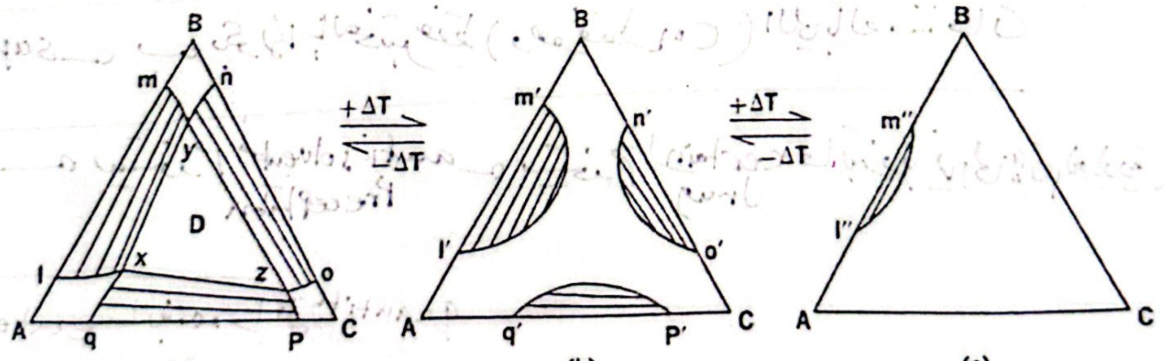
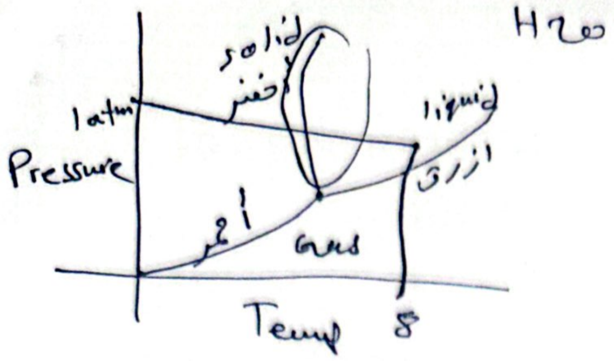
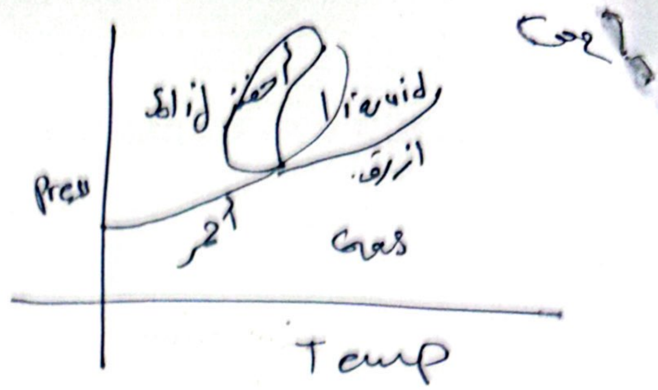


Fig. 2–31. Temperature effects on a system of three pairs of partially miscible liquids.

miscible

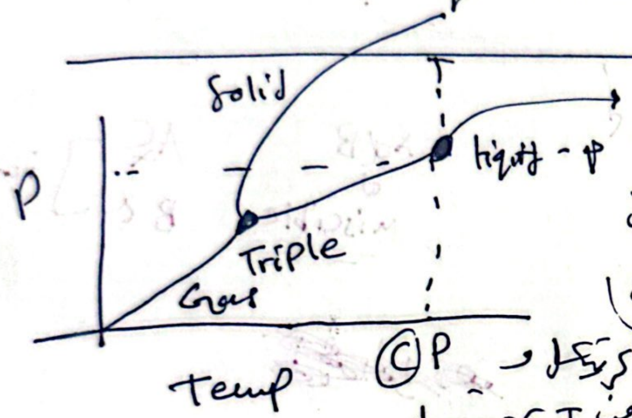




اختلاف الزاوية بسبب
الي عليها دايرة

كل states of matter ما عدا الثلج أخف من liquid

solid denser than liquid



ماي النقطة مهمة فاصلة بين

(supercritical) Point

عبارة عن CT و CP

أي حرارة أعلى من CT مستحيل
في water أو liquid اسه سائل
يكون gas

D الحا و
سولفينت Power
تابعت السائل
والزوجة
تابعت الغاز

اعرف + اصدرها

supercritical fluid ← بس بكونوا بالمختبر فقط (وهو فقط CO_2) الي بالصناعات

supercritical (CO_2) ← بيستخدم ← anti solvent precipitation ← بستخدم certain drug ما بنذوب في الحالات العادية).

extensive variable ← ما بتعتمد على quantity

extensive variable ← تعتمد على quantity