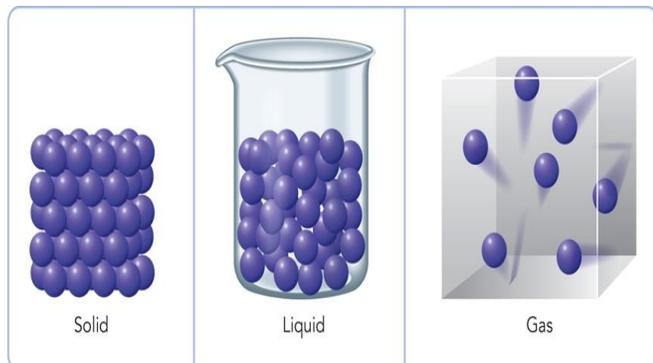


# Chapter 11

## States of Matter: Liquids and Solids

## Comparing Gases, Liquids, and Solids:

مقارنة الغازات والسوائل والمواد الصلبة:

الغازات هي موائع (يحدث فيها جريان) **قابلة للضغط**.

السوائل هي موائع غير قابلة للضغط نسبياً.

المواد الصلبة غير قابلة للضغط تقريباً و متماسكة.

**Table 12.1** Characteristic Properties of Gases, Liquids, and Solids

State of Matter	Volume/Shape	Density	Compressibility	Motion of Molecules
Gas	Assumes the volume and shape of its container	Low	Very compressible	Very free motion
Liquid	Has a definite volume but assumes the shape of its container	High	Only slightly compressible	Slide past one another freely
Solid	Has a definite volume and shape	High	Virtually incompressible	Vibrate about fixed positions

• **A change of state or phase transition:**

تحولات المادة

1. Solid  $\longrightarrow$  Liquid

صلب

سائل

(Melting, Fusion)



(ذوبان، انصهار)

2. Liquid  $\longrightarrow$  Solid

سائل

صلب

(Freezing)



(التجمد)

3. Liquid  $\longrightarrow$  Gas

سائل

غاز

(Evaporation, Vaporization)



(التبخّر)

4. Gas  $\longrightarrow$  Liquid

غاز

سائل

(Condensation)



(التكاثف)

5. Solid  $\longrightarrow$  Gas

صلب

غاز

(Sublimation)



(التسامي)

6. Gas  $\longrightarrow$  Solid

غاز

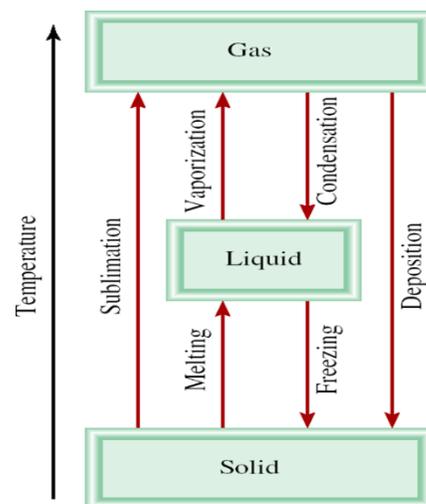
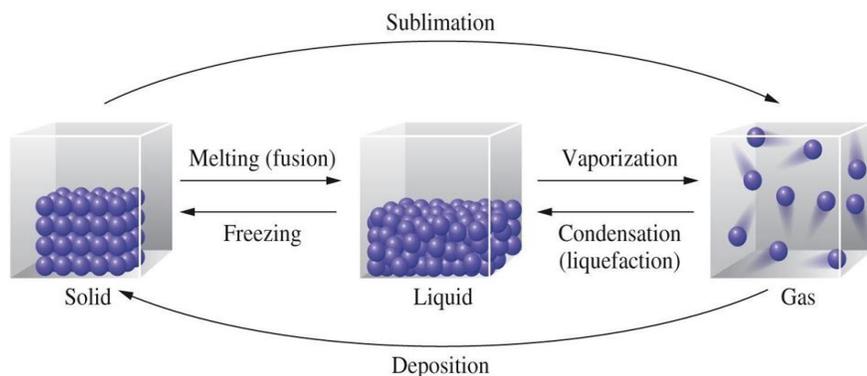
صلب

(Deposition)



(الترسيب)

# A change of state or phase transition



## Example 1:

What is the name for the following phase change?



1. Condensation
2. Vaporization
3. Melting
4. Sublimation
5. Freezing

## Example 2:

What is the name for the following phase change?



1. Condensation
2. Vaporization
3. Melting
4. Sublimation
5. Freezing

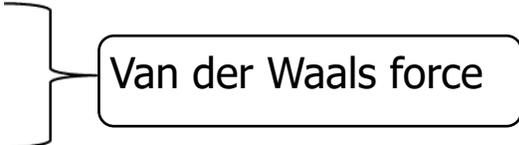
# Intermolecular Forces

- **Intermolecular forces are attractive forces between molecules.**
- **Intramolecular forces hold atoms together in a molecule.**

( **Intra**molecular forces are much **stronger** than **inter**molecular forces )

## Types of Intermolecular Forces :

1. Hydrogen bonding ( H – bond ) : special case of dipole – dipole force for (H + N , O , F)
2. Dipole – dipole: between polar molecules
3. London (dispersion) forces: between polar or **nonpolar** molecule
4. Ion-dipole: between ion + polar molecule
5. Ionic forces



Van der Waals force

## 1. Hydrogen bonding (الرابطة الهيدروجينية)

- تنتج عند ارتباط ذرة الهيدروجين باحدى الذرات التالية : N , O , F

**Example:**



## 2. Dipole-dipole forces:

- قوى الجذب بين الجزيئات القطبية (polar) فقط

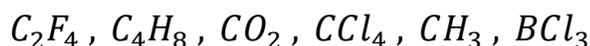
**Example:**



## 3. London (dispersion) forces:

- توجد هذه القوة في جميع الجزيئات القطبية وغير القطبية، ولكن التركيز سيكون على الجزيئات الغير قطبية (nonpolar) لأنها القوة الوحيدة لها، وهي قوة موجودة في جميع الجزيئات.

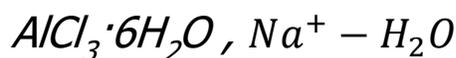
**Example:**



## 4. Ion-dipole :

- قوة تنتج عن ارتباط أيون بجزيء قطبي

**Example:**



## 5. Ionic :

- قوة تنتج عن ارتباط أيونين من فلز ولا فلز

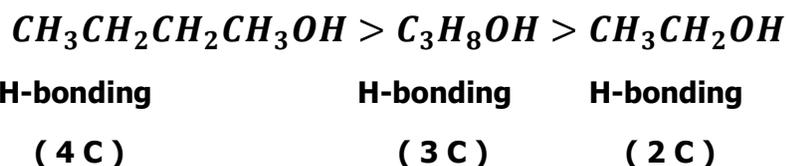
**Example:**



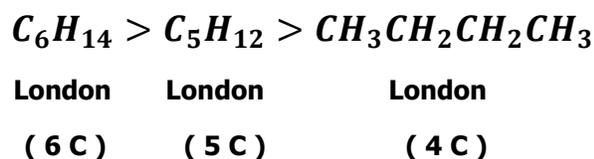


❖ في المركبات العضوية يتم التعبير عن الكتلة المولية بعدد ذرات الكربون

**Example :**



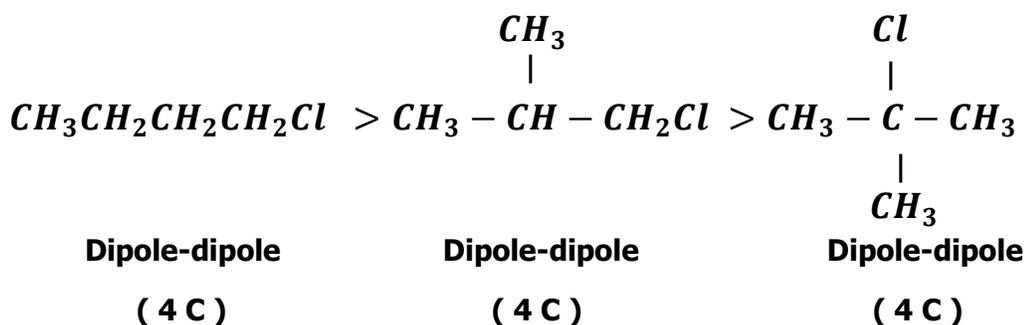
**Example :**



3. في حال تشابهت القوى وتساوت عدد ذرات الكربون يتم المقارنة عن طريق شكل المركب (التفرع **Branching**):

*Branching* ↑ → *Intermolecular force* ↓

**Example:**



### Example 3 :

Which of the following would you expect to have the **least intermolecular force**?



But how can we distinguish whether a compound is **polar** or **nonpolar**?

ولكن كيف يمكننا التمييز اذا كان المركب قطبي أم غير قطبي؟

○ إذا لم تكن جميع الذرات المحيطة بالذرة المركزية غير متشابهة يكون المركب قطبي (**polar**)

#### Example:



❖ إذا كانت جميع الذرات المحيطة بالذرة المركزية متشابهة:  
○ إذا كانت الذرة المركزية تمتلك أزواج منفردة من الإلكترونات يكون المركب قطبي (**polar**)

#### Example:



○ إذا كانت الذرة المركزية لا تمتلك أزواج منفردة من الإلكترونات يكون المركب غير قطبي (**nonpolar**)

#### Example:





### Example 4 :

In the liquid state, which species has the strongest intermolecular forces,  $\text{CH}_4$ ,  $\text{Cl}_2$ ,  $\text{O}_2$  or HF?

- A.  $\text{CH}_4$
  - B.  $\text{Cl}_2$
  - C.  $\text{O}_2$
  - D. HF
  - E. A and D
- 

### Example 5 :

What is the **strongest** type of intermolecular force in  $\text{CHCl}_3$ ?

- A. Ion-dipole
  - B. dipole-dipole
  - C. Dispersion
  - D. Hydrogen bonding
  - E. B and C
- 

### Example 6:

Identify the intermolecular forces that expected for each of the following

substances:

- a. Methane
- b. Trichloromethane  $\text{CHCl}_3$
- c. Butanol  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

### Answer:

- a. Nonpolar molecule - London forces
- b. London forces, dipole-dipole forces
- c. London forces, dipole-dipole forces, hydrogen bonding

**Example 7:**

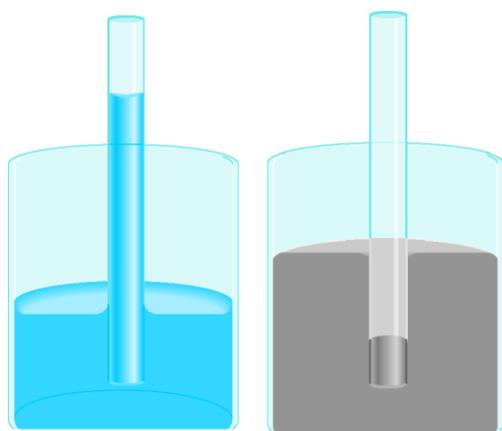
Which of the following concerning intermolecular forces is/are correct?

- i. Intermolecular forces depend in part on the shape of a molecule.
- ii. London forces contribute to the net forces of attraction found in all molecular solids and liquids.
- iii. Hydrogen bonding is a special category of dipole-dipole attractions.

- A. i only
- B. ii only
- C. iii only
- D. i and ii
- E. i, ii, and iii

## Properties of Liquids

- **Cohesion** : attraction force between the same molecule (قوة التماسك)
- **Adhesion** : attraction force between different molecule (قوة التلاصق)



- في الماء قوة التلاصق أكبر من قوة التماسك لذلك يرتفع الماء في الأنبوب الشعري ويعطي شكل مقعر (**concave**)
- في الزئبق قوة التماسك أكبر من قوة التلاصق لذلك لا يرتفع الزئبق في الأنبوب الشعري ويعطي شكل محدب (**convex**)

### Example 10:

Which is the best reason for why water in a glass capillary has a concave meniscus, while mercury in a glass capillary has a convex meniscus?

- Mercury has a greater dispersion force than water.
- The water is attracted more strongly to the glass than the mercury is attracted to the glass.
- The mercury is attracted more strongly to the glass than the water is attracted to the glass.
- Water is a molecular compound while mercury is a metallic element.
- Water has a greater dispersion force than mercury.

## Properties of Liquids

**Viscosity:** is a measure of a fluid's resistance to flow (اللزوجة)

Strong intermolecular forces  High viscosity

- viscosity **decreases** when temperature increases.

• تنخفض اللزوجة عندما ترتفع درجة الحرارة.

## Kinetic energy (KE)

- As temperature increases, kinetic energy increase
- الجزيئات الموجودة في السائل وتمتلك طاقة حركية عالية تغادر سطح السائل وتتبخّر

**Example 11 :**

Which factor affects the viscosity of a liquid?

- A) Temperature
- B) Pressure
- C) Molecular weight
- D) Surface tension

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**Example 12 :**

Which substance is most likely to have the **highest viscosity**?

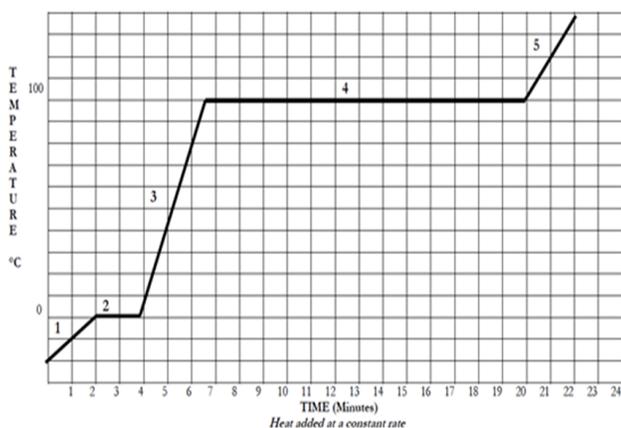
- A)  $C_2H_5Cl$
- B)  $CH_3OH$
- C)  $C_6H_{14}$
- D)  $CH_3CH_2CH_2CH_3$

---

**Example:**

**Using the heat curve, define the segment time(s) that the kinetic energy of the substance is increasing.**

- A. 1, 2, and 5
- B. 2, 3, and 4
- C. 2 and 4
- D. 1, 3, and 5
- E. 0

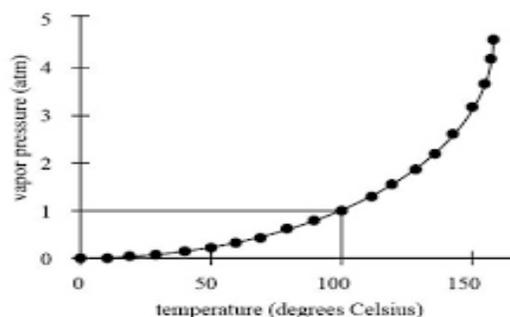


# Properties of Liquids

## Vapor pressure (P)

- Transfer liquid to gas at current temperature.

Strong intermolecular forces  Lower vapor pressure



- **as temperature increases,**
- **vapor pressure increases.**

### Example 13:

What happens to the vapor pressure of a liquid as **temperature increases**?

- A) Decreases
- B) Remains constant
- C) Increases
- D) Becomes zero

**Example 14 :**

What term describes the pressure exerted by a vapor in equilibrium with its liquid phase at a given temperature?

- A) Atmospheric pressure
  - B) Boiling point
  - C) Vapor pressure
  - D) Osmotic pressure
- 

**Example 15:**

Which of the following substances is most likely to have the **highest vapor pressure** at a given temperature?

- A) CH<sub>3</sub>CH<sub>2</sub>OH
- B) CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>OH
- C) CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>OH
- D) CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>OH

# Phase change

❖ Transformations from one phase to another occur when energy is added or removed from a substance

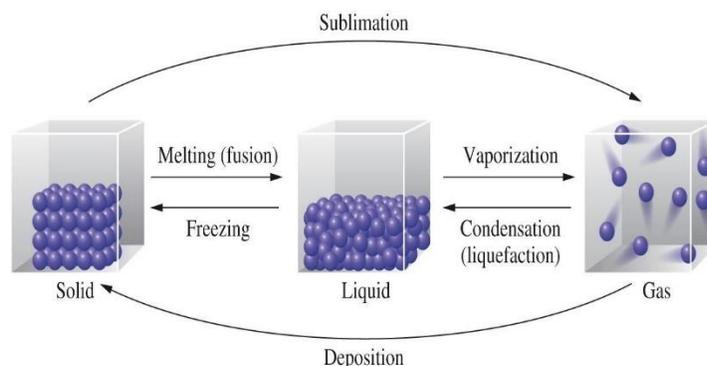
❖ تحدث التحولات من مرحلة إلى أخرى عند إضافة الطاقة أو إزالتها من المادة.

- **Molar heat of fusion ( $\Delta H_{fus}$ ) is the energy required to melt**  
1 mole of a solid substance at its freezing point.
- **Molar heat of vaporization ( $\Delta H_{vap}$ ) is the energy required to boil**  
1 mole of a liquid substance at its melting point.
- **Molar heat of sublimation ( $\Delta H_{sub}$ ) is the energy required to sublime**  
**1 mole of a solid.**

•  $\Delta H_{fus}$ : الطاقة اللازمة لإذابة مادة صلبة.  
•  $\Delta H_{vap}$ : الطاقة اللازمة لتبخير السائل

$$\Delta H_{sub} = \Delta H_{fus} + \Delta H_{vap}$$

(Hess's Law)



## Example 16 :

Which of the following substances is most likely to have the **lowest heat of vaporization?**

- A)  $C_8H_{18}$
- B)  $HF$
- C)  $\underline{CH_3CH_2CH_2CH_2CH_2CH_2CH_3}$
- D)  $CH_3CH_2Cl$
- E)  $CH_3OCH_3$



# Phase change

The heat of phase transition

phase changes involve heat transfer:

- Melting, vaporization, and sublimation are
- **endothermic** (ماص للحرارة)
- Freezing, condensation, and deposition are **exothermic** (طارده للحرارة)

$n$  = number of moles (mol)

$m$  = mass (g or Kg)

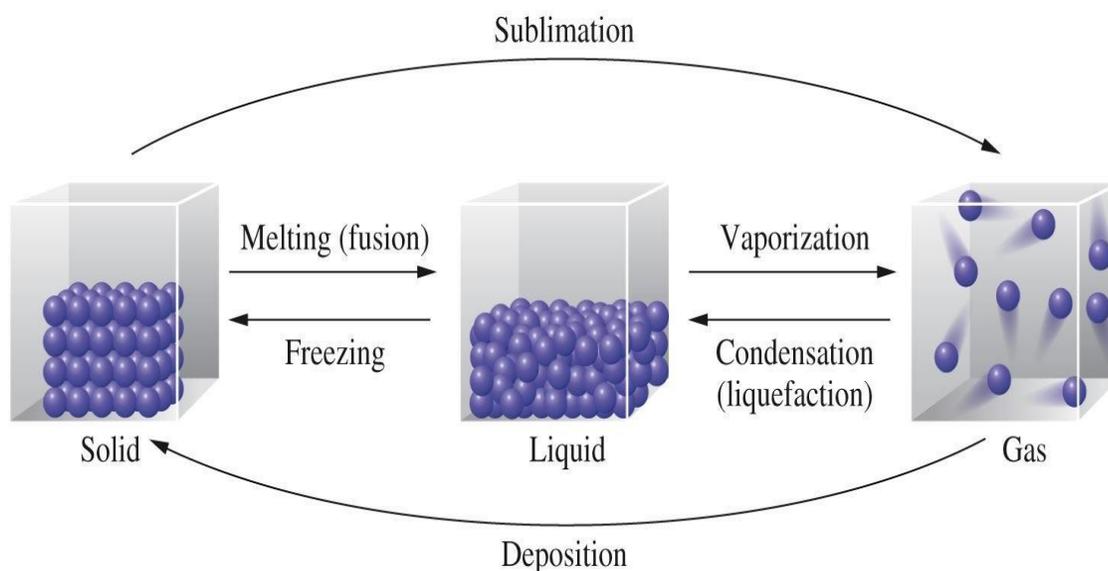
$s$  = specific heat capacity (J/g. K)

$\Delta T$  = difference of temperature ( $^{\circ}\text{C}$ )

$$\Delta H = n \times \Delta H_{vap}$$

$$\Delta H = n \times \Delta H_{fus}$$

$$\Delta H = m \cdot s \cdot \Delta T$$



**Example :**

How much heat must be added to raise a sample of 100g of water at 270K to 280K?

The specific heat capacity of water is 4.180J/g\*K, water's heat of fusion is 335 J/mol, and the molar mass of water is 18 g/mol

A.  $4.18 \times 10^3 J$

B.  $7.44 \times 10^3 J$

C.  $6.05 \times 10^3 J$

D. 0

E.  $1.86 \times 10^3 J$

**Solution:**

$$\Delta H = \Delta H_1 + \Delta H_2$$

$$\Delta H_1 = m \cdot s \cdot \Delta T = 100 \times 4.18 \times (280 - 270) = 4180 J$$

$$n = \frac{\text{mass}}{\text{molar mass}} = \frac{100}{18} = 5.55 \text{ mol}$$

$$\Delta H_2 = n \times \Delta H_{fus} = 5.55 \times 335 = 1861.1 J$$

$$\Delta H = \Delta H_1 + \Delta H_2 = 4180 + 1861.1 = 6041.1 J$$

**Example:**

Calculate the enthalpy change upon converting 1.00 mol of ice at  $-25.0^\circ\text{C}$  to water at  $30.0^\circ\text{C}$  under a constant pressure of 1 atm. The specific heats of ice and liquid water are 3.07, and 4.18 J/(g\*K), respectively. For H<sub>2</sub>O,  $\Delta H_{fus} = 6.86$  kJ/mol.

**Solution:**

$$\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3$$

$$\text{mass} = \text{molar mass} \times n = 18 \times 1 = 18 \text{ g}$$

$$\Delta H_1 = m \cdot s_{ice} \cdot \Delta T = 18 \times 3.07 \times (0 - -25) = 1381.5 J$$

$$\Delta H_2 = n \times \Delta H_{fus} = 1 \times 6.86 \times 1000 = 6860 J$$

$$\Delta H_3 = m \cdot s_{liquid} \cdot \Delta T = 18 \times 4.18 \times (30 - 0) = 2257.2 J$$

$$\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3 = 1381.5 + 6860 + 2257.2 = \mathbf{6041.1 J} = \mathbf{6.041 KJ}$$

# Phase change

**Boiling point (درجة الغليان) :** the temperature at which the (equilibrium) vapor pressure of a liquid is equal to the external pressure.

When vapor pressure = external pressure

- The **normal boiling point** is the temperature at which a liquid boils when the **external pressure is 1 atm**.

❖ Normal boiling point pressure always at 1 atm

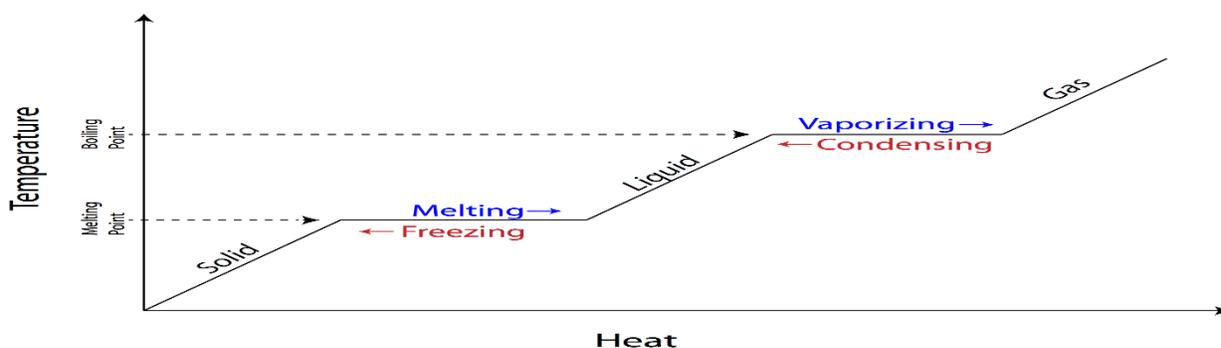
❖ 1 atm = 760 mmHg

دفع

❖ Boiling point for water = 100 °C

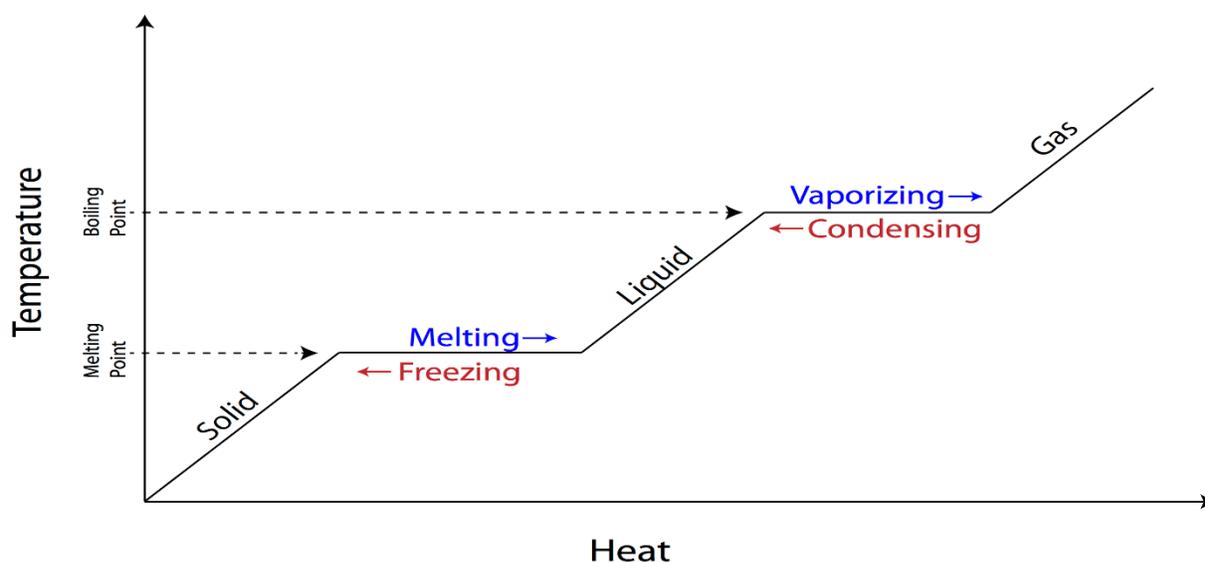
- **Pressure** ↑ → **Boiling point** ↑

**Strong intermolecular forces** → **High Boiling point**



# Phase change

- **Freezing point: the temperature at which a pure liquid changes to a crystalline solid (or freezes).**  
درجة الحرارة التي يتحول عندها السائل النقي إلى مادة صلبة بلورية (أو يتجمد).
- **Melting point: the temperature at which a crystalline solid changes to a liquid (or melts).**  
درجة الحرارة التي تتحول عندها المادة الصلبة البلورية إلى سائل (أو تذوب).
- **Boiling point** : درجة الحرارة التي تتحول عندها المادة السائلة إلى غازية (أو تتبخ).



**Example 17 :**

What is the name given to the temperature at which a liquid's vapor pressure equals the external pressure ?

- A) Boiling point
  - B) Freezing point
  - C) Sublimation point
  - D) Melting point
- 

**Example 18:**

Which substance is most likely to have the **lowest boiling point** ?

- A)  $H_2O$
  - B)  $H_2S$
  - C)  $CO_2$
  - D)  $CH_3CH_2OH$
- 

**Example 19:**

What is the term for the point at which a substance transition from the liquid phase to the solid phase?

- A) Freezing point
  - B) Melting point
  - C) Boiling point
  - D) Sublimation point
- 

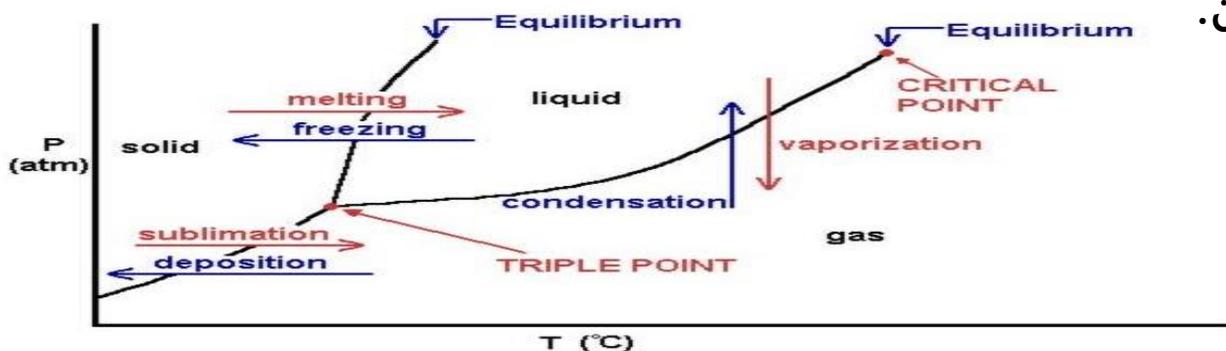
**Example 20:**

What is the term for the point at which a substance transitions from the solid phase to the liquid phase?

- A) Freezing point
- B) Melting point
- C) Boiling point
- D) Sublimation point

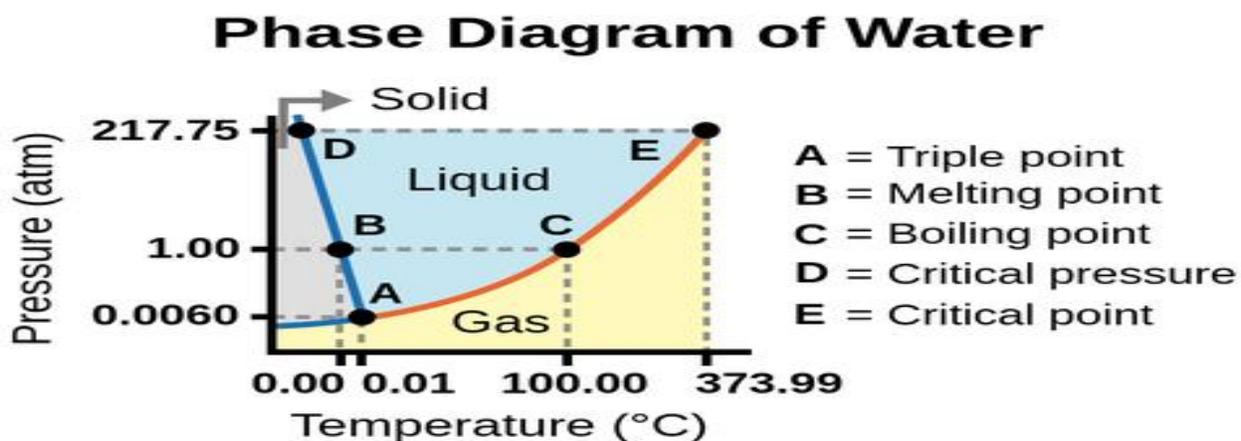
# Phase Diagram

- **Critical temperature ( $T_c$ )** : the temperature above which the gas cannot be made to liquefy, no matter how great the applied pressure.  
( $T_c$ ) درجة الحرارة الحرجة: درجة الحرارة التي بعدها لا يمكن تحويل الغاز إلى سائل تحت أي ضغط كان.
- **Critical pressure ( $P_c$ )** : the minimum pressure that must be applied to bring about liquefaction at the critical temperature.  
( $P_c$ ) الضغط الحرج: الضغط عند درجة الحرارة الحرجة.
- **Critical point:**  
النقطة المكونة من ( $P_c, T_c$ )
- **Triple point:**  
النقطة التي تجتمع فيها الحالات الثلاث (السائل، الغاز، الصلب) في حالة توازن.



Strong intermolecular forces → High ( $T_c$ )

## Phase Diagram of Water



## Intermolecular force

مهم جداً

**As intermolecular forces (IMF) ↑**

1. Surface tension ↑
2. Viscosity ↑
3. Vapor pressure ↓
4. Boiling point ↑
5.  $\Delta H$  vaporization ↑
6. Critical temperature ↑

## Phase change

➤ According to the Clausius–Clapeyron equation:

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta H_{\text{vap}}}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$\Delta H_{\text{vap}}$  = Molar heat of vaporization (J/mol)

$P$  = (equilibrium) vapor pressure

$T$  = temperature (K)

$R$  = gas constant (8.314 J/K•mol)

- This equation can be used to find the vapor pressure, the heat of vaporization, or the temperature.

❖ يجب أن تكون (T) بوحدة القياس (كلفن) K وليس (سيليسيوس) °C

▪ للتحويل من °C إلى K نجمع ب 273

**Example:**

$$33^{\circ}\text{C} \rightarrow 33 + 273 = 306 \text{ K}$$

**Example 21:**

The vapor pressure of diethyl ether is 401 mmHg at 18°C.

Calculate its temperature at a vapor pressure of 656 mmHg.

$$\Delta H_{\text{vap}} = 26.0 \text{ kJ/mol.}$$

- a) 32 °C
- b) 305 °C
- c) 350 K
- d) 25 °C

**Solution:**

$$P_1 = 401 \text{ mmHg} \quad P_2 = 656 \text{ mmHg}$$

$$T_1 = 18^\circ\text{C} = 291 \text{ K} \quad T_2 = ?$$

$$\Delta H_{\text{vap}} = 26 \frac{\text{KJ}}{\text{mol}} = 26000 \frac{\text{J}}{\text{mol}}$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta H_{\text{vap}}}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{401 \text{ mmHg}}{656 \text{ mmHg}}\right) = \frac{26000 \text{ J/mol}}{8.314 \text{ J/mol} \cdot \text{K}} \left(\frac{1}{T_2} - \frac{1}{291 \text{ K}}\right)$$

$$-0.492 = 3127.26 \left(\frac{1}{T_2} - \frac{1}{291 \text{ K}}\right)$$

$$\frac{1}{T_2} = \frac{-0.492}{3127.26} + \frac{1}{291 \text{ K}} = 0.003279$$

$$T_2 = 304.96 \text{ K} = 31.96^\circ\text{C}$$

**Example 22:**

In a certain mountain range, water boils at 94°C. What is the atmospheric pressure under these conditions? The enthalpy of vaporization of water at 100°C is 40.7 kJ/mol. The normal boiling of water is 100°C

- A. 1750 mmHg
- B. 324 mmHg
- C. 613 mmHg
- D. 941 mmHg
- E. 329 mmHg

**Solution:**

$$\begin{aligned}
 P_1 &= ? & P_2 &= 760 \text{ mmHg} \\
 T_1 &= 94^\circ\text{C} = 367\text{K} & T_2 &= 100^\circ\text{C} = 373\text{K} \\
 \Delta H_{\text{vap}} &= 40.7 \frac{\text{kJ}}{\text{mol}} = 40700 \frac{\text{J}}{\text{mol}} \\
 R &= 8.314 \text{ J/mol} \cdot \text{K}
 \end{aligned}$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta H_{\text{vap}}}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{P_1}{760 \text{ mmHg}}\right) = \frac{40700 \text{ J/mol}}{8.314 \text{ J/mol} \cdot \text{K}} \left(\frac{1}{373 \text{ K}} - \frac{1}{367 \text{ K}}\right)$$

$$\ln\left(\frac{P_2}{760 \text{ mmHg}}\right) = -0.21457$$

$$\frac{P_2}{760 \text{ mmHg}} = e^{-0.21457} = 0.8069$$

$$\mathbf{P_2 = 613.235 \text{ mmHg}}$$