Chapter 11

States of Matter; Liquids and Solids

Sections: 11.1 – 11.5

• Comparison of Gases, Liquids, and Solids

مقارنة الغازات والسوائل والمواد الصلبة:

- الغازات هي موائع (يحدث فيها جريان) قابلة للضغط.
- السوائل هي موائع غير قابلة للضغط نسبيًا.
- المواد الصلبة غير قابلة للضغط تقريبًا ومتماسكة.

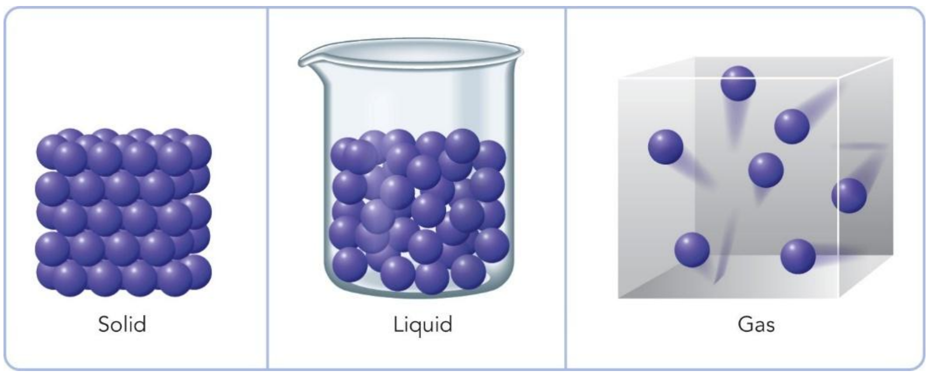


Table 12.1 Characteristic Properties of Gases, Liquids, and Solids

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 ⟶ Liquid

صلب سائل

(Melting, Fusion)


(ذوبان، انصهار)

2. Liquid ⟶ Solid

سائل صلب

(Freezing)


(التجمد)

3. Liquid ⟶ Gas

سائل غاز

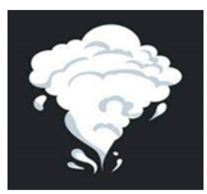
(Evaporation, Vaporization)


(التبخر)

4. Gas ⟶ Liquid

غاز سائل

(Condensation)

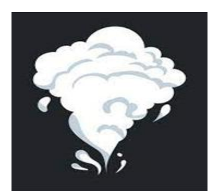



(التكاثف)

5. Solid ⟶ Gas

صلب غاز

(Sublimation)

(التسامي)

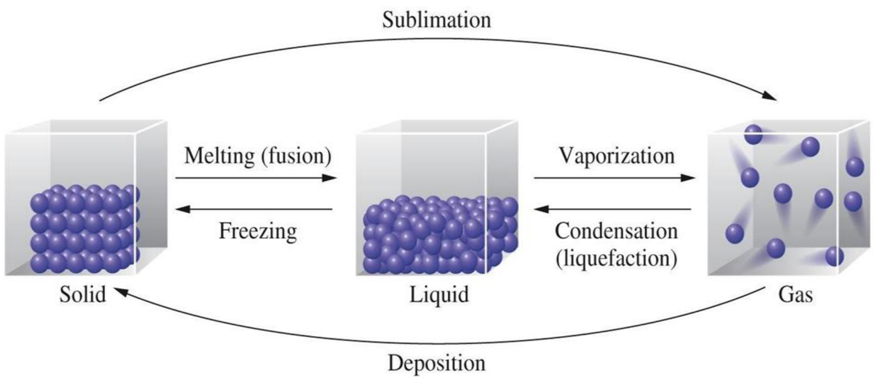
6. Gas ⟶ Solid

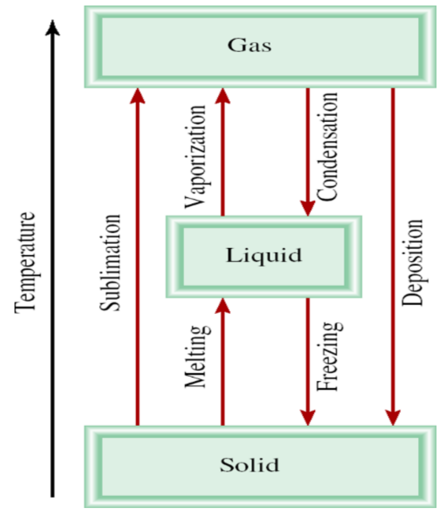
غاز صلب

(Deposition)


(الترسيب)

• Phase Transitions





Example 1:

What is the name for the following phase change?

$$I_{2\,(l)} \rightarrow I_{2\,(g)}$$

1. Condensation
2. <u>Vaporization</u>
3. Melting
4. Sublimation
5. Freezing

Example 2:

What is the name for the following phase change?

$$H_2O_{(s)} \rightarrow H_2O_{(g)}$$

1. Condensation
2. Vaporization
3. Melting
4. <u>Sublimation</u>
5. Freezing

• Intermolecular Forces: Explaining Liquid Properties

Intermolecular Forces

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

(Intramolecular 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

(Items 2–3: Van der Waals forces)

1. Hydrogen bonding (الرابطة الهيدروجينية)

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

Example:

H_2O , NH_3 , HF, CH_3OH , CH_3CO_2H

2. Dipole-dipole forces:

- قوى الجذب بين الجزيئات القطبية (polar) فقط

Example:

H_2S , PH_3 , CH_3OCH_3 , NCl_3

3. London (dispersion) forces:

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

Example:

C_2F_4 , C_4H_8 , CO_2 , CCl_4 , CH_3 , BCl_3 , O_2 , F

4. Ion-dipole:

- قوة تنتج عن ارتباط أيون بجزيء قطبي

Example:

$AlCl_3.6H_2O$, $Na^+ - H_2O$

5. Ionic:

- قوة تنتج عن ارتباط أيونين من فلز ولا فلز

Example:

$\boldsymbol{NaCl}$, $\boldsymbol{KI}$

ملاحظات مهمة بخصوص مقارنة القوى:

- ترتيب القوى من الأقوى إلى الأضعف:

Ionic > Ion-dipole > Hydrogen bonding > Dipole-dipole > London (dispersion)

1. المقارنة حسب قوة الترابط الرئيسية (**Intermoluclaer forces**)

Example:

$$CH_3CH_2CH_2OH > CH_3OCH_3 > CO_2$$

H-bonding **Dipole-dipole** **London**

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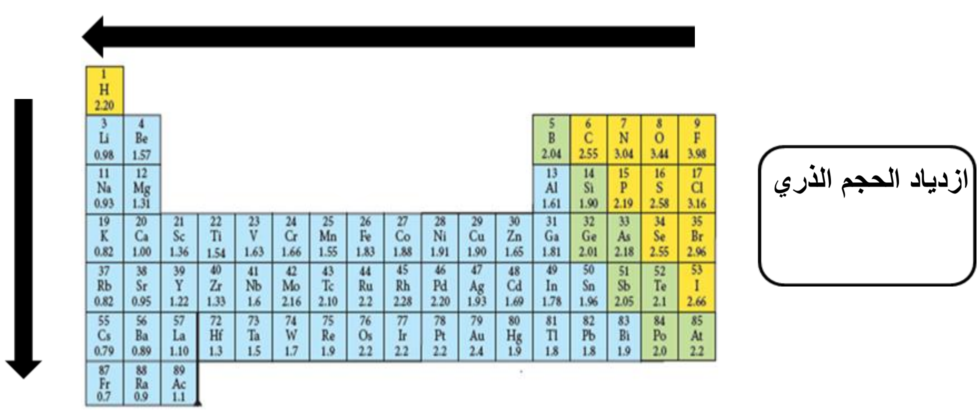
2. المقارنة في حال تشابهت القوى الرئيسية، تتم المقارنة عن طريق **الحجم الذري والكتلة المولية** (Mw):

Example:

$$GeH_4 > SiH_4 > CH_4$$



في المركبات العضوية يتم التعبير عن الكتلة المولية بعدد ذرات الكربون

Example:

$$CH_3CH_2CH_2CH_3OH > C_3H_8OH > CH_3CH_2OH$$

H-bonding **H-bonding** **H-bonding**

(4 C) **(3 C)** **(2 C)**

Example:

$$C_6H_{14} > C_5H_{12} > CH_3CH_2CH_2CH_3$$

London **London** **London**

(6 C) **(5 C)** **(4 C)**

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

Example:

$$Branching \uparrow \quad \rightarrow \quad Intermoluclar\ force \downarrow$$

$$CH_3CH_2CH_2CH_2Cl \; > CH_3 - CH - CH_2Cl \; > CH_3 - C - CH_3$$

Dipole-dipole **Dipole-dipole** **Dipole-dipole**

(4 C) **(4 C)** **(4 C)**

Example 3:

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

1. $\underline{CH_4}$
2. HF
3. H_2S
4. H_2O

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

ولكن كيف يمكننا التمييز ما إذا كان

المركب **قطبي** أم **غير قطبي**؟

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

Example:

CH_3Br , CH_3Cl , CH_3OCH_3

❖ إذا كانت جميع الذرات المحيطة بالذرة المركزية متشابهة:

- إذا كانت الذرة المركزية تمتلك أزواج منفردة من الإلكترونات يكون المركب قطبي (**polar**)

Example:

H_2S , NCl_3 , H_2O

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

Example:

CO_2 , BCl_3 , CH_3

❖ كيفية تحديد الذرة المركزية:

- الذرة التي تمتلك أقل عدد مولات تعتبر هي الذرة المركزية.

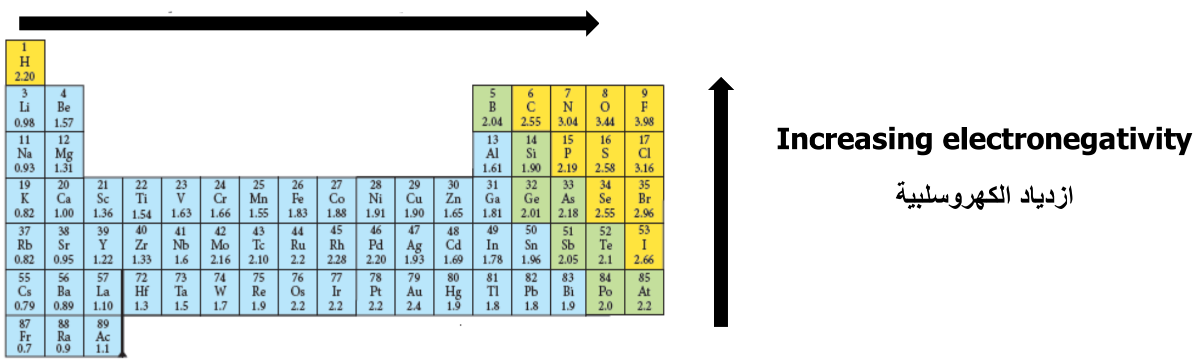
Example:

$H_2\mathbf{S}$, $\mathbf{N}Cl_3$, $H_2\mathbf{O}$, $\mathbf{C}O_2$

- الذرة الأقل كهر وسلبية تعتبر الذرة المركزية.

Example:

$\mathbf{C}H_3Br$, $\mathbf{C}H_3Cl$



- إذا كان المركب يتكون من كربون ونوع واحد فقط من الذرات (المركبات العضوية) يكون المركب غير قطبي **(nonpolar)**

Example:

CH_3 , CCl_4 , C_2H_6 , C_2F_4

- إذا كان المركب يتكون من كربون وأكثر من نوع من الذرات يكون المركب قطبي **(polar)**

Example:

CH_3Br , CH_3OCH_3

Example 4:

In the liquid state, which species has the **strongest** intermolecular forces, CH_4, Cl_2, O_2 or HF?

A. Cl_2
B. O_2
C. <u>HF</u>
D. A and D
E. CH_4

Example 5:

What is the **strongest** type of intermolecular force in $CHCl_3$?

A. Ion-dipole
B. <u>dipole-dipole</u>
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 $CHCl_3$
c. Butanol $CH_3CH_2CH_2CH_2OH$

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

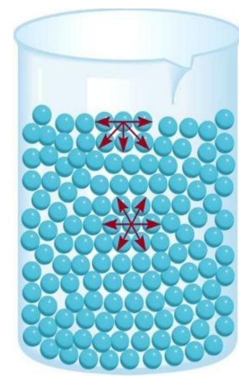
E. <u>i, ii, and iii</u>

Properties of liquids:

Surface tension: is the energy required to increase the surface area of a liquid by a unit amount. The values are given in J/m^2.

- الجزيء الموجود على السطح تكون عليه قوة على جميع الاتجاهات ما عدا للأعلى.
- الجزيء الموجود في الداخل عليه قوة من جميع الاتجاهات.

Strong intermolecular forces → High surface tension



Example 8:

What is the term for the force per unit area required to increase the surface area of a liquid by a unit amount?

A) Vapor pressure

B) Surface tension

C) Viscosity

D) Capillarity

Example 9:

Which of the following substances is most likely to have the **highest surface tension**?

A) C_8H_{18}

B) HF

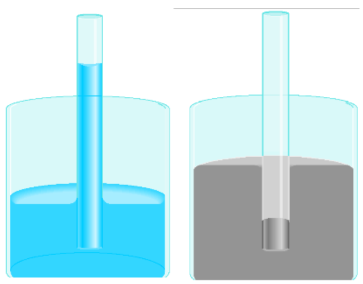
C) $CH_3CH_2CH_2CH_2CH_2CH_2CH_3$

D) CH_3CH_2Cl

E) CH_3OCH_3

- **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:

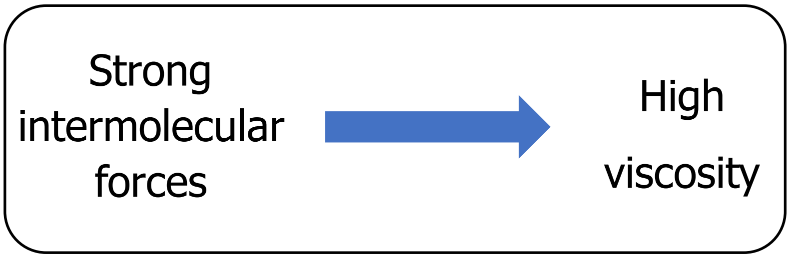
Which is the best reason for why water in a glass capillary has a concave meniscus, while mercury in a glass capillary has a convex meniscus?

A. Mercury has a greater dispersion force than water.
B. <u>The water is attracted more strongly to the glass than the mercury is attracted to the glass.</u>
C. The mercury is attracted more strongly to the glass than the water is attracted to the glass.
D. Water is a molecular compound while mercury is a metallic element.
E. Water has a greater dispersion force than mercury.

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

- viscosity **decreases** when temperature increases.

- تنخفض اللزوجة عندما ترتفع درجة الحرارة.



Kinetic energy (KE)

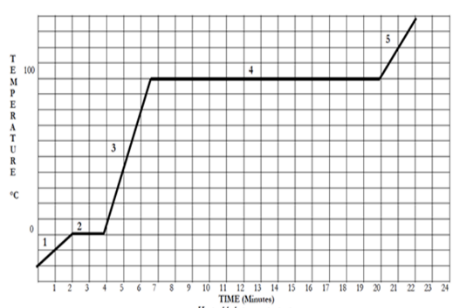
- As temperature increases, kinetic energy increase

- الجزيئات الموجودة في السائل وتمتلك طاقة حركية عالية تغادر سطح السائل وتتبخر

Example 13:

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. <u>1, 3, and 5</u>
E. 0



Example 11:

Which factor affects the viscosity of a liquid?

A) Temperature

B) Pressure

C) Molecular weight

D) Surface tension

Example 12:

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

A) C_2H_5Cl

B) CH_3OH

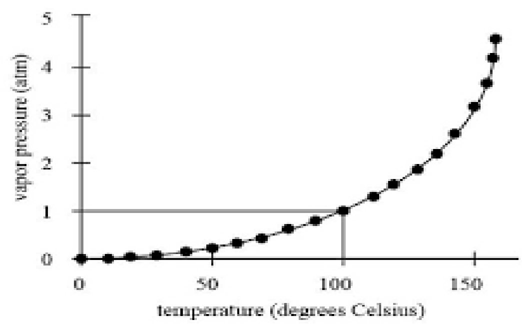
C) C_6H_{14}

D) $CH_3CH_2CH_2CH_3$

Vapor pressure (P)

- Transfer liquid to gas at current temperature.

Strong intermolecular forces → Lower vapor pressure



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

Example 14:

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

A) Decreases

B) Remains constant

C) Increases

D) Becomes zero

Example 15:

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 16:

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

A) CH3CH2OH

B) CH3CH2CH2OH

C) CH3CH2CH2CH2OH

D) CH3CH2CH2CH2CH2OH

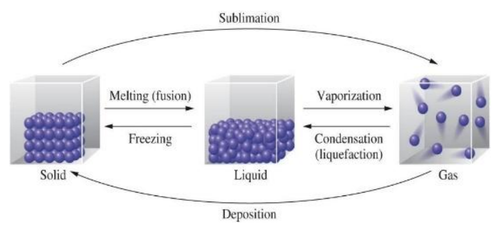
Transformations from one phase to another occur when energy is added or removed from a substance.

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

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

  - ΔH_{fus}: الطاقة اللازمة لإذابة مادة صلبة
  - ΔH_{vap}: الطاقة اللازمة لتبخير السائل

Strong intermolecular forces → High ΔH_{fus}, ΔH_{vap}



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

(Hess's Law)

Example 17:

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

The heat of phase transition

phase changes involve heat transfer:

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

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

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

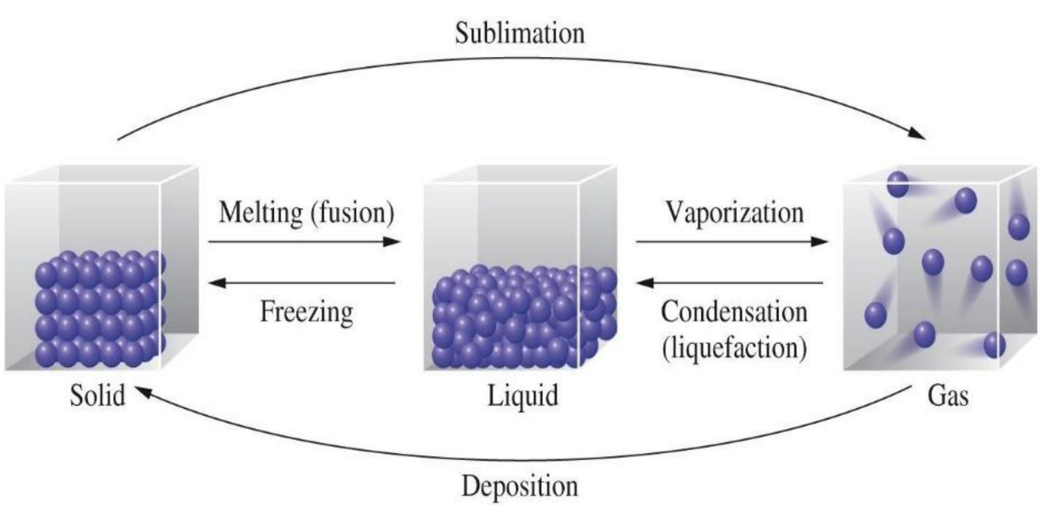
$$\Delta H = m.s.\Delta T$$

n = number of moles (mol)

m = mass (g or Kg)

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

ΔT = difference of temperature (°C)



Example 18:

The enthalpy of fusion of aluminum is $10.7\ KJ/mol$ ($Molar\ mass = 27\ g/mol$). How many grams of aluminum can be melted by adding $77.3\ KJ$ of energy to the metal at its melting point?

A. $313\ g$
B. $205\ g$
C. $439\ g$
D. $153\ g$
E. <u>$195\ g$</u>

Solution:

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

$$n = \frac{\Delta H}{\Delta H_{fus}} = \frac{77.3}{10.7} = 7.22\ mol$$

$$n = \frac{m}{Mw} \quad \longrightarrow \quad m = n \times Mw = 7.22 \times 27 = \mathbf{194.9\ mol}$$

Example 19:

Liquid butane, C_4H_{10} ($Molar\ mass = 58\ g/mol$), is stored in cylinders to be used as a fuel. Suppose 35.5 g of butane gas is removed from a cylinder. How much heat must be provided to vaporize this much gas? The heat of vaporization of butane is $21.3\ KJ/mol$.

A. $11\ KJ$
B. <u>$12.9\ KJ$</u>
C. $13\ KJ/mol$
D. $120\ J$
E. $21.3\ KJ/mol$

Solution:

$$n = \frac{m}{Mw} = \frac{35.5}{58} = 0.61\ mol$$

$\Delta\text{H} = \text{n} \times \Delta H_{vap} = 0.61 \times 21.3 = \mathbf{13\ KJ}$

Example 20:

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 $335\ J/mo$l, and the molar mass of water is $18\ g/mol$.

A. $4.18 * 10^3 J$

B. $7.44 * 10^3 J$

C. $\underline{6.05 * 10^3 J}$

D. 0

E. $1.86 * 10^3 J$

Solution:

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

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

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

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

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

Example 21:

Calculate the enthalpy change upon converting $1.00\ mol$ of ice at $-25.0\ °C$ to water at $30.0\ °C$ under a constant pressure of $1\ atm$. The specific heats of ice and liquid water are 3.07, and $4.18\ J/(g \cdot K)$, respectively. For H_2O, $\Delta H_{fus} =\ 6.86\ kJ/mol$.

Solution:

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

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

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

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

$$\Delta H_1 = m.s_{liquid}.\Delta T = 18 \times 4.18 \times (\mathbf{30 - 0}) = 2257.2J$$

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

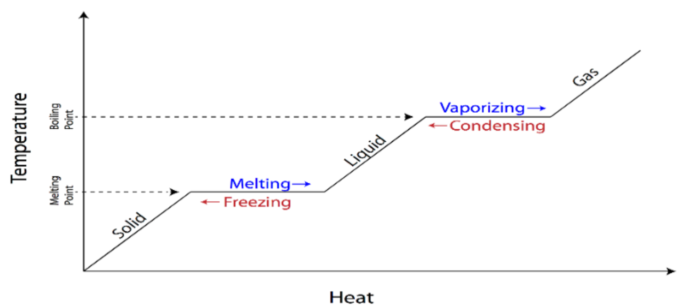
Boling point (درجة الغليان): the temperature at which the (equilibrium) vapor pressure of a liquid is equal to the external pressure.

When vapor pressure = external pressure

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

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

Strong intermolecular forces → High Boiling point



حفظ

❖ Normal boiling point pressure always at 1 atm
❖ 1 atm = 760 mmHg
❖ Boling point for water = 100 ℃

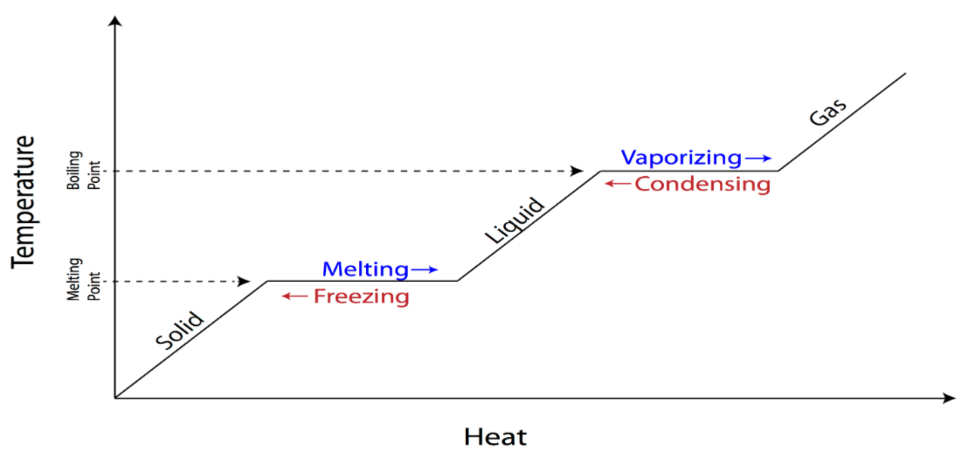
- **Freezing point:** the temperature at which a pure liquid change to a crystalline solid (or freezes).

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 تتبخر)



Example 22:

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 23:

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 24:

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 25:

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 Diagrams

- **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.

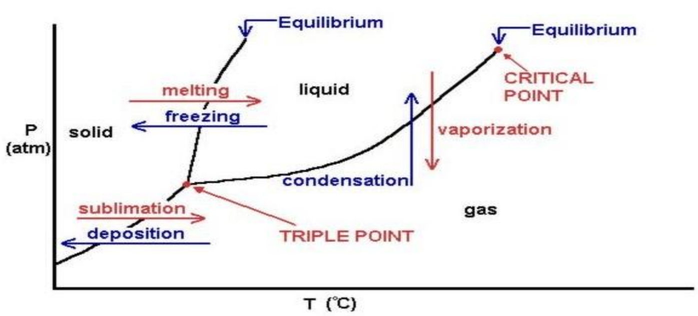
(P)الضغط الحرج: الضغط عند درجة الحرارة الحرجة.

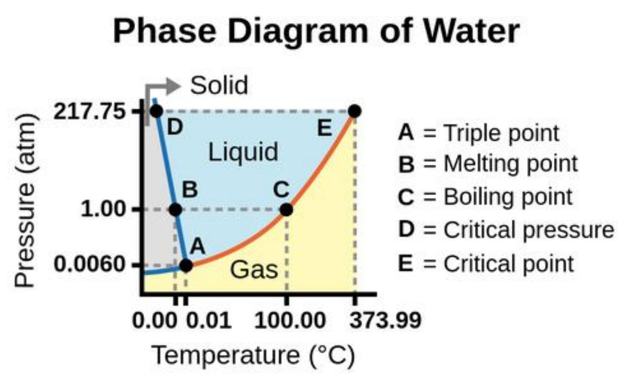
- **Critical point:**

النقطة المكونة من (P_c ,T_c)

- **Triple point:**

النقطة التي تجتمع فيها الحالات الثلاث (السائل، الغاز، الصلب) في حالة توازن.



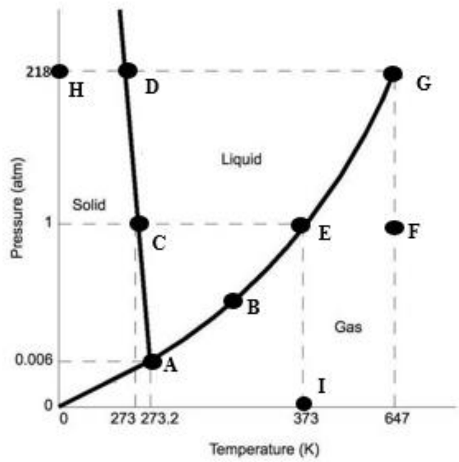


Strong intermolecular forces → **High (T_c)**

Example 26:

Consider the shown phase diagram for water. At which of the following points representing melting point, triple point, critical pressure, and boiling temperature **in order**?

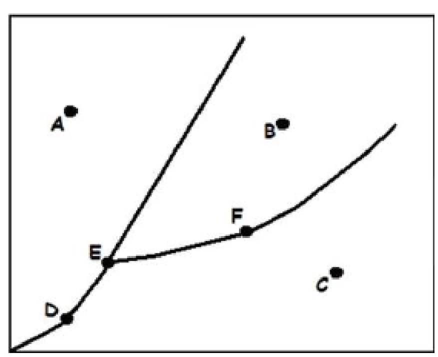
a) A, B, D and G
b) C, A, G and F
c) E, A, C, and I
d) C, A, H, and I
e) G, A, F and H



Example 27:

Consider the shown phase diagram. At which of the following points representing pressure and temperature, gas state can be seen at?

a) A, B, C and F
b) B, F, D and C
c) B, C, D and E
d) C, A, B and F
e) C, D, E and F



مهم جداً

As intermolecular forces (IMF) ↑

1. Surface tension ↑
2. Viscosity ↑
3. Vapor pressure ↓
4. Boiling point ↑
5. ΔH vaporization ↑
6. Critical temperature ↑
7. Mealting point ↑

According to the Clausius–Clapeyron equation:

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

مهم جداً

ΔH_{Vap} = Molar heat of vaporization (J/mol)

P = (equilibrium) vapor pressure

T = temperature (K)

R = gas constant ($8.314\ J/K \bullet mol$)

- 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) $℃$**

- للتحويل من ℃ إلى K نجمع ب 273

Example:

$$33℃ \rightarrow 33 + 273 = 306\ K$$

Example 28:

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

Calculate its temperature at a vapor pressure of $656\ mmHg$.

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

a) 32 °C
b) 305 °C
c) 350 K
d) 25 °C

Solution:

$P_1 = 401$ mmHg $\quad P_2 = 656$ mmHg

$T_1 = 18°C = 291$ K $\quad T_2 = ?$

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

$$R = 8.314\ J/mol \cdot K$$

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

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

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

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

$$\boldsymbol{T_2 = 304.96\ K = 31.96}°\text{C}$$

Example 29:

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. <u>613 mmHg</u>
D. 941 mmHg
E. 329 mmHg

Solution:

$P_1 = ?$ $\qquad P_2 = 760\text{ mmHg}$

$T_1 = 94°C = 367K \qquad T_2 = 100°C = 373\text{ K}$

$\Delta H_{vap} = 40.7\,\frac{KJ}{mol} = 40700\,\frac{J}{mol}$

$R = 8.314\ J/mol \cdot K$

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

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

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

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

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

Problems:

1) A $35.8\ g$ sample of cadmium metal ($Mw = 112.41\ g/mol$) was melted by an electric heater providing $4.66\ J/s$ of heat. If it took $6.92\ \text{min}$ from the time the metal began to melt until it was completely melted, what is the heat of fusion per mole of cadmium?

a) $620\ KJ/mol$
b) $6.2\ KJ/mol$
c) $1.9\ KJ/mol$
d) $19\ KJ$
e) $66.2\ KJ/mol$

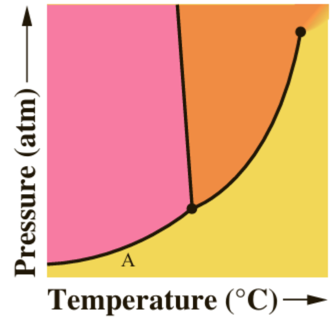
2) A quantity of ice at $0°\text{C}$ is added to $64.3\ g$ of water in a glass at $55\ ℃$. After the ice melted, the temperature of the water in the glass was $15\ ℃$. How much ice was added? The heat of fusion of water and ice are $6.01\ kJ/mol$ and the specific heat is $4.18\ J/(g\ \cdot °C)$.

a) $27.2\ g$
b) $1.8\ g$
c) $18\ g$
d) $29.8\ g$
e) $65\ g$

3) Methanol, CH_3OH, a colorless, volatile liquid, was formerly known as wood alcohol. It boils at $65.0°\text{C}$ and has a heat of vaporization of $37.4\ \text{kJ/mol}$. What is its vapor pressure at $22.0°\text{C}$?

a) $4\ atm$
b) $14.4\ atm$
c) $780\ mmHg$
d) $0.144\ atm$
e) $109.2\ atm$

4) Shown here is the phase diagram for compound Z. The triple point of Z is $-5.1\,℃$ at $3.3\ atm$ and the critical point is $51\,℃$ and $99.1\ atm$.



a) What is the state of Z at position A?

b) If we increase the temperature of the compound at position A to 60°C while holding the pressure constant, what is the state of Z?

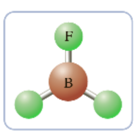
c) If we take the compound starting under the conditions of part b and reduce the temperature to 20°C and increase the pressure to 65 atm, what is the state of Z?

5) The triple point of a solid is at $5.2\ atm$ and $-57\,℃$. Under typical laboratory conditions of $P = 0.98\ atm$ and $T = 23\,℃$, this solid will:

a) remain solid indefinitely
b) Melt
c) Condense
d) Boil
e) Sublime

6) For each of the following substances, list the kinds of intermolecular forces expected.

a) BF_3



b) isopropyl alcohol, $CH_3CHOHCH_3$
c) hydrogen iodide, HI
d) krypton, Kr

7) Arrange the following substances in order of increasing magnitude of the London forces:

$CH_4, CH_3CH_2CH_2CH_3,\ C_2H_6,\ C_8H_{18}$

a) $CH_4 < CH_3CH_2CH_2CH_3, < C_2H_6, < C_8H_{18}$
b) $CH_4 < CH_3CH_2CH_2CH_3, < C_8H_{18}, < C_2H_6$
c) $CH_4 < C_2H_6, < CH_3CH_2CH_2CH_3, < C_8H_{18}$
d) $CH_3CH_2CH_2CH_3 < CH_4, < C_8H_{18}, < C_2H_6$
e) $CH_4 < C_2H_6, < C_8H_{18}, < CH_3CH_2CH_2CH_3$

8) Predict the order of increasing vapor pressure at a given temperature for the following compounds: $CH_3CH_2CH_2CH_2OH,\ CH_3CH_2OCH_2CH_3,\ HOCH_2CH_2CH_2OH$

a) $HOCH_2CH_2CH_2OH < CH_3CH_2CH_2CH_2OH < CH_3CH_2OCH_2CH_3$
b) $CH_3CH_2CH_2CH_2OH < HOCH_2CH_2CH_2OH < CH_3CH_2OCH_2CH_3$
c) $CH_3CH_2OCH_2CH_3 < CH_3CH_2CH_2CH_2OH < HOCH_2CH_2CH_2OH$
d) $b + c$
e) None of these

Answers:

1) b $(6.2\, KJ/mol)$

2) a $(27.2\, g)$

3) d $(0.144\, atm)$

4)

   a) Gas

   b) Gas

   c) Liquid

5) e (sublime)

6)

   a) London forces, dipole-dipole forces

   b) London forces, dipole-dipole forces, hydrogen bonding

   c) London forces, dipole-dipole forces

   d) London forces

7) c $(CH_4 < C_2H_6, < CH_3CH_2CH_2CH_3, < C_8H_{18})$

8) a $(HOCH_2CH_2CH_2OH < CH_3CH_2CH_2CH_2OH < CH_3CH_2OCH_2CH_3)$